



**TOWARDS INTERNATIONALLY
COMPETITIVE SCIENCE AND RESEARCH**

**Proceedings of the IGU Commission on
African Studies Annual Conference,
17-19 June 2019, University of
Zululand, South Africa.**

Inocent Moyo and Christopher Changwe Nshimbi (Editors)

Copyright © 2020 the editors for the entire porceedings and the authors for their particular contributions. All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, electrical, chemical, mechanical, optical, photocopying, recording or otherwise, without prior written permission of the copyright holders.

ISBN 978-0-620-82855-0

Acknowledgements

This publication is a direct product of the Second Annual Conference of the International Geographical Union Commission on African Studies, which was held at the University of Zululand from 16 -19 June 2019.

We want to thank all the delegates sincerely whose attendance made the conference a roaring success, of which this volume provides ample evidence. The publication would not have been possible without the help of many organisations and individuals. First, our thanks to the National Research Foundation (NRF), Republic of South Africa, for the generous funding allocated to this event. Second, we wish to extend our gratitude to the Durban KwaZulu-Natal Convention Bureau and the KwaZulu-Natal Provincial government for supporting this event. We want to thank Sonto Mayise particularly in this regard. Likewise, we are thankful to the Mayor of the City of uMhlatuze, the Honourable Councillor M. Mhlongo, for partnering with the IGU Commission on African Studies in hosting the conference. Third, there are many reviewers who were called upon and gladly agreed to review the many papers in this volume. Their contribution to this volume is acknowledged. Similarly, the Local Organising Committee of the IGU Commission on African Studies Second Annual Conference played an instrumental role in this regard. These members include: Dr. I. Nojiyeza, Department of Anthropology and Development Studies, University of Zululand; Dr. S.S. Nhlabathi, Department of Anthropology and Development Studies, University of Zululand; Dr M. Mdoka, Department of Geography and Environmental Studies, University of Zululand; Dr. M. Sibanda, Department of Agriculture, University of Zululand; Mrs. N.P. Ndimande, Department of Geography and Environmental Studies, University of Zululand; Mrs. D. Khumalo, Secretary, Department of Geography and Environmental Studies, University of Zululand; and Mr. A.T. Mthembu, Department of Geography and Environmental Studies, University of Zululand.

Inocent Moyo (PhD) and Christopher Changwe Nshimbi (PhD)

KwaDlangezwa, January 2020

Table of Contents

List of figures	8
List of tables	12
Chapter 1: Introduction – Africa in the global imaginary: Towards internationally competitive science and research Inocent Moyo and Christopher Changwe Nshimbi	16
Section A: Climate change issues in Africa	
Chapter 2: Modelling the relationship between climatic variables and NDVI with Markov-switching model Solomon G. Tesfamichael, Thendo Mugwena, Tatenda Turukai Chibi and Yegnanew A. Shiferaw	19
Chapter 3: Using the Cropwat model to estimate the effects of climate change and shifting planting dates on <i>Jatropha</i> water requirements in semi-arid conditions of Botswana Moseki O, Murray-Hudson M, Kashe K, Moses O, Kgathi D.L, Moroke T.S. and Moseki B, Mmopelwa G	29
Chapter 4: Regards historiques et recents sur le contexte climatique de la region de Fatick au Senegal Ibrahima Mbaye	50
Section B: Environmental problems in Africa	
Chapter 5: Influence of human management strategies on soil erosion in Nzhelele Valley, Limpopo Province, South Africa Blessing Mavhuru, Nthaduleni Nethengwe, Hector Chikoore and Onyango Beneah Daniel Odhiambo	61
Chapter 6: A time series analysis of land cover change – A case study of Bewaarkloof Nature Reserve, Limpopo, South Africa Nesisa Analisa Nyathi and Thendo Mugwena	75
Chapter 7: A spatial analysis of the influence of infrastructural planning on solid waste management: lessons from Peleng Township in Lobatse, Botswana Nametso D. Phonchi-Tshekiso, Patricia K. Mogomotsi, Goemeone E.J. Mogomotsi and Reniko Gondo	95
Chapter 8: Exploitation et gestion durable des ressources halieutiques en Lagune Aby (Côte d’Ivoire) Koulai-Djedje Edith	105

Chapter 9: Modelisation prospective de l'occupation du sol d'une zone a forte pression anthropique: Cas du site Ramsar de Grand-Bassam (Sud-Est de la Cote d'Ivoire)	
Akadjé Léocadie Marie-Claude, Kangah Armand, Boussougou Boussougou Guy, Hauhouot Asseyo Célestin, Brou Yao Téléphore	116

Section C: Environmental conservation, natural resource use and governance

Chapter 10: Community opinions on land use practices and activities in relation to natural resource conservation at the Amboseli ecosystem, Kenya	
Tom W. Okello	132

Chapter 11: Natural resource governance and protected areas: On the co-management of the Okhahlamba-Drakensberg National Park, KwaZulu-Natal, South Africa	
Hlengiwe M.S. Cele and Inocent Moyo	146

Chapter 12: The influence of donor funded community development on population growth in selected communities bordering the Phinda Private Game Reserve (South Africa)	
Claire Louisa Fordred and Kevin Mearns	154

Chapter 13: Indigenous communities, hegemonic subjugation and environmental conservation: On protected areas in KwaZulu-Natal, South Africa	
Hlengiwe Cele and Inocent Moyo	167

Section D: Globalisation and regional economic integration in Africa

Chapter 14: Africa inaction in globalisation - contests and prospects	
Phemelo Olifile Marumo	175

Chapter 15: L'intégration économique et politique africaine à l'ère du numérique	
Loukou Alain François	183

Section E: Rural development

Chapter 16: Nutritional composition and sensory acceptability of cowpea wheat biscuits by rural youth in KwaZulu-Natal	
--	--

Section F: Water resources in Africa

Chapter 17: Assessment of water quality indicators within a mining environment using Landsat reflectance data– the case study of Mooi River near Carletonville, South Africa Modiegi O. Monaledi, Isaac T. Rampedi and Solomon G. Tesfamichael	211
Chapter 18: Assessing chlorophyll-a and turbidity in the Hartbeespoort Dam (South Africa) using Landsat imagery Craig Mahlasi, Richard Greenfield, Modiegi O. Monaledi and Solomon G. Tesfamichael	222
Chapter 19: Assessing seasonal changes in waterbodies within wetlands using Landsat imagery: The case of southern Johannesburg Lutendo Zwedzi and Solomon G. Tesfamichael	234
Chapter 20: Hydrological modelling through regionalisation of parameters: A case of Mazowe Dam Catchment Ellen Nhedzi Gozo	243
Chapter 21: Water management in the wildlife lodge industry: A southern African perspective. Jacobus Grobler and Kevin Mearns	257
Chapter 22: Household water demand management strategies for sustainable use in Maun, Botswana Manga Motho, Oluwatoyin D. Kolawole, Moseki R. Motsholapheko, Patricia K. Mogomotsi	271
Chapter 23: An analysis of sector-based water supply and demand: Mapping the possible water development and management ways for Sanyati catchment, Zimbabwe Kusena Winmore, Nojiyeza Innocent Simphiwe and Debwe Thomas	288

Editors' biographies

1. Dr. Inocent Moyo is a Senior Lecturer in the Department of Geography and Environmental Science at the University of Zululand, South Africa. Inocent is a Human Geographer with a deep interest in the interface between people and the environment, particularly within the broader fields of Political Geography, Political Economy, Political Ecology, Migration, Regional Development, Globalisation and Transnationalism, Borders and Borderlands, Cross Border Informality and Alternative Regionalism in Africa, Urban Informality and Governance. He has published and delivered international presentations on these themes. Inocent is committed to emancipatory research and the deployment of critical social theory in an attempt to understand the problems that affect humankind today, and will do so in the future, and strive to contribute to solutions. Inocent is the founding Chair of the IGU Commission on African Studies (IGU CAS).

2. Dr. Christopher Nshimbi is Director and Head of the Department of Science and Technology-National Research Foundation (DST-NRF), Research Fellow in the Centre for the Study of Governance Innovation (GovInn), Department of Political Sciences, University of Pretoria. He researches regional and sub-regional integration (especially in East and Southern Africa and Southeast Asia), borders and borderlands, informal cross-border trade, grassroots non-state actors, social cohesion and water resources management. He teaches Regional Integration; African Politics and Regions; and Political Dynamics in the Department of Political Sciences. Dr. Nshimbi has participated in and sits on regional and international technical working groups on labour and migration, the integrated water sector, social protection and well-being.

List of figures

Chapter 1: No figures

Chapter 2:

Figure 2.1: Map of study areas showing a 10 km radius zone of a weather station, and sampling units of grassland, shrubland and forest, each measuring 60 m radius within the 10 km radius zone of a station. Images representing land covers were extracted from Google Earth™

Figure 2.2: Observed and estimated climate data using the MS approach for the three land cover examples in Nelspruit

Chapter 3:

Figure 3.1: Change in reference evapotranspiration under the current and the future climatic conditions in Botswana. Baseline = ETo at the current state of temperature and rainfall; S3 = ETo at the projected temperature and rainfall patterns in 2020-2039

Figure 3.2: Change in effective rainfall under varying climatic scenarios in Botswana. Baseline = CWR at the current state of temperature and rainfall; S3 = CWR at the projected temperature and rainfall patterns in 2020-2039

Figure 3.3: Jatropha water requirements for different developmental stages under varying climatic scenarios (Baseline to S3) modelled for Botswana conditions. Baseline = CWR at the current state of temperature and rainfall; S1 = CWR at the projected temperature and the current rainfall state; S2 = CWR at projected rainfall of 2020-2039 and current state of temperature; S3 = CWR at both the projected temperature and rainfall patterns in 2020-2039.

Figure 3.4: Jatropha total water requirements under varying climatic scenarios (Baseline-S3) modelled outputs for Botswana conditions. Baseline = CWR at the current state of temperature and rainfall; S1 = CWR at the projected temperature from 2020-2039 and current state of rainfall; S2 = CWR at the projected rainfall of 2020-2039 and current state of temperature; S3 = CWR at the projected temperature and rainfall patterns in 2020-2039

Figure 3.5: Sensitivity analysis of CWR to varying planting dates under changing air temperature and rainfall

Figure 3.6: Effect of temperature variation on Jatropha water requirements in different developmental stages

Figure 3.7a: Jatropha ETc as projected by different climate change models from the CMIP 5 project

Figure 3.7b: Jatropha ETc in different developmental stages as projected by climate change models (bcc_csm1_1_m is used in this study)

Chapter 4

Figure 4.1: Carte administrative de la région de Fatick

Figure 4.2: Localisation des domaines climatiques du Sénégal et des stations de l'étude

Figure 4.3: Variabilité interannuelle de la pluviométrie à Fatick de 1991 à 2014

Figure 4.4: Variabilité interannuelle de la pluviométrie à Foundiougne de 1970 à 2011

Figure 4.5: Variabilité interannuelle de la pluviométrie standardisée à Fatick de 1991 à 2014

Figure 4.6: Variabilité interannuelle de la pluviométrie à Gossas de 1950 à 2008

Figure 4.7: Variabilité interannuelle de la température moyenne de l'air à Fatick de 1991 à 2014

Figure 4.8: Variabilité interannuelle de la température moyenne de l'air à Fatick

(1991-2002; 2003-2014)

Chapter 5

Figure 5.1: Map of South Africa showing study area Nzhelele Valley

Chapter 6

Figure 6.1: An illustration of the random points that were used to classify the Landsat image

Figure 6.2:

Figure 6.3: An illustration of natural and false colour composites. (a) Classified (b) natural colour and (c) false colour showing an area dominated by built-up areas. (d) Classified (e) natural colour and (f) false colour showing areas that are dominated by vegetation

Figure 6.4: Map showing the different land cover types for the stipulated years⁴

Figure 6.4: Map showing the different land cover types for the stipulated years

Figure 6.5: A graph showing different percentage changes according to class types and years

Figure 6.5: A graph showing different percentage changes according to class types and years

Figure 6.6: Accuracy assessment of the classified image

Figure 6.7: NDVI maps of study area showing the different NDVI values on the stipulated dates (1999, 2004, 2009, 2016 and 2018)

Chapter 7

Figure 7.1: Map showing household and road infrastructure of Peleng township

Figure 7.2: Selected households at 10m, 15m & 20m

Figure 7.3: Selected households at 10m, 15m & 20m

Chapter 8

Figure 8.1: Le système lagunaire Aby-Tendo-Ehy

Figure 8.2: Des espèces de petites tailles

Figure 8.3: Une espèce en état de ponte

Figure 8.4: Localisation des baies

Figure 8.5: Siège de la coopérative des pêcheurs collectifs d'Eplemlan (Adiaké)

Chapter 9

Figure 9.1: Localisation de la zone RAMSAR de Grand-Bassam et ses environs

Figure 9.2: Coefficient de Cramer pour chaque variable

Figure 9.3: Représentation des relations entre les changements d'occupation du sol et les variables explicatives en mètre par hectare

Figure 9.4: Carte de vulnérabilité des types d'occupation du sol simulé en 2013

Figure 9.5b: Comparaison de l'occupation du sol (réelle et simulée) en 2013

Figure 9.6: Simulation de l'occupation du sol en 2030

Chapter 10

Figure 10.1: The group ranches between Amboseli National Park and Tsavo / Chyulu Parks in southern Kenya. Inset is the map of Kenya with region demarcations

Chapter 11:

Figure 11.1: Ezemvelo KZN and stakeholders involved in the co-management plan

Figure 11.2: Illustration of the flow of information between parties

Chapter 12:

Figure 12.1: A map representing the location of &Beyond Phinda Private Game Reserve's location in South Africa and the surrounding communities where Africa Foundation is implementing programmes

Chapter 13: No figures

Chapter 14: No figures

Chapter 15

Figure 15.1 : Carte des Communautés Économiques Régionales (CER) d'Afrique

Figure 15.2 : Interaction dynamique « TIC- Intégration régionale

Chapter 16

Figure 16.1: Cowpea (*Vigna species*) local grain varieties cultivated in Northern Zululand

Figure 16.2: Proximate composition of flours and biscuits from the two cowpea varieties

Figure 16.3: Consumer acceptability of cowpea biscuits from two cowpea varieties

Chapter 17

Figure 17.1: Study area in the south-western part of Gauteng, South Africa

Figure 17.2: Comparison of observed and predicted values using the reflectance of Landsat OLI bands.

Chapter 18

Figure 18.1: Location of the Hartbeespoort Dam and distribution of sampling locations. Note that the sampling locations are given as 45 m buffers symbolized by red colour

Figure 18.2: Best performing In (chlorophyll) models using band 5, band 6, band 7, NDVI and NDWI

Figure 18.3: Best performing turbidity models using band 5, band 6, band 7, NDVI and NDWI

Figure 18.4: Spatial distribution of chlorophyll-a in the Hartbeespoort Dam

Figure 18.5: Spatial distribution of turbidity in the Hartbeespoort Dam

Chapter 19

Figure 19.1: Study area showing waterbodies and wetlands, south of Johannesburg

Figure 19.2: Waterbodies identified using maximum likelihood classification in January, May, July and November 2015

Chapter 20

Figure. 20.1: Map showing the Mazowe Dam Catchment

Figure 20.2: A map showing the four created sub-basins of the Mazowe Damcatchment

Figure 20.3: L Relationship between Observed and Simulated Runoff for Dassura Sub-basin during the calibration period (1988-1998)

Figure 20.4. : Relationship between Observed and Simulated Runoff for Dassura Sub-basin during the validation period (1999-2005)

Figure. 20.5: Relationship between Observed and Simulated Runoff for Upper Mazowe Sub-basin during the calibration period (1988-1998)

Figure 20.6: Relationship between Observed and Simulated Runoff for Upper Mazowe Sub-basin during the validation period (1999-2005)

Figure 20.7: Observed and simulated runoff for Dassura sub-basin in the years 2000 – 2003

Figure 20.8: Observed and simulated runoff for Upper Mazowe sub-basin in the years 2000 – 2003

Figure 20.9: Relationship between observed runoff and simulated runoff by calibration parameters for Dassura sub-basin (1989-2005)

Figure 20.10: Relationship between observed runoff and simulated runoff by regionalization for Dassura sub-basin (1989-2005)

Chapter 21

Figure 21.1: Average litre per guest night for all the lodges included in the study within South Africa, Namibia and Botswana

Figure 21.2: Average litre per bed night from all the lodges

Figure 21.3: Average litre per guest per night from the eight lodges in South Africa

Figure 21.4: Average litre per bed night from the eight lodges in South Africa

Figure 21.5: Average litre per guest per night from the eight lodges in Namibia

Figure 21.6: Average litre per bed night from the eight lodges in Namibia

Figure 21.7: Average litre per guest night from the 15 lodges in Botswana

Figure 21.8: Average litre per bed night from the 15 lodges in Botswana

Chapter 22

Figure 22.1: Map showing the location of Maun (Source: Okavango Research Institute-GIS, 2018)

Figure 22.2: Responses on the effectiveness of household WDM strategies. Source: Field survey, April 2019

Chapter 23

Figure 23.1: Map Showing the study area

Figure 23.2: Possible IBTS routes

List of tables

Chapter 1: No tables:

Chapter 2

Table 2.1: Model criteria of non-switching and MS approaches for data set of Nelspruit and Skukuza locations. Predictor variable was NDVI

Chapter 3

Table 3.1: Monthly mean values of the current climatic conditions (1986-2017) for Sir Seretse Khama International Airport weather station

Table 3.2: Projected monthly mean maximum and minimum temperature and rainfall for 2020-2039; the assumption is that humidity, windspeed and sunshine hours remain the same as for the 1986-2017 period

Table 3.3: List of climate models used in the CMIP5 project. The model printed in bold is the selected driving model for the CROPWAT model (table adapted from The World Bank (2018))

Chapter 4: No tables

Chapter 5

Table C2: Spearman rank correlation coefficient on land use management strategies

Chapter 6

Table 6.1: Land cover classes defined in the field

Table 6.2: coverage of the land cover types for the five years considered in the study

Table 6.3: NDVI values of the different years within the same study area. Range represents the NDVI values of each land cover types

Chapter 7: No tables

Chapter 8: No tables

Chapter 9

Tableau 9.1: Transitions et sous-modèles de changement

Tableau 9.2: Matrice de Markov

Tableau 9.3 : Superficies des types d'occupation du sol simulés en 2013 et 2030

Chapter 10

Table 10.1: Demographics of respondents

Table 10.2: Community opinions on the status of the environment

Table 10.3: Community opinions of land ownership, economic loss and compensation

Table 10.4: Attitudes towards environmental conservation

Chapter 11: No tables

Chapter 12: No tables

Chapter 13: No tables

Chapter 14: No tables

Chapter 15: No tables

Chapter 16

Table 16.1: Formulations of flour blends for biscuit preparation

Table 16.2: Weight of ingredients used in biscuit samples

Table 16.3: Physical properties of biscuits

Table 16.4: Mean values of colour measurements with varying levels of wheat and cowpea flours

Table 16.5: Hardness and fracturability of biscuits samples for a bending test

Chapter 17

Table 17.1: A summary of water quality parameters used in the study

Table 17.2: Landsat OLI bands that generated the best models to estimate field observed water quality parameters based on AIC, adjusted R^2 and RMSE

Chapter 18:

Table 18.1: Summary statistics of chlorophyll-a (ug/L) and turbidity (NTU) acquired after the field survey and laboratory analysis

Table 18.2: Statistical results of correlation analysis of ln(chlorophyll-a) and turbidity for the best performing Landsat 8 products. p at a confidence level of 95%

Chapter 19

Table 19.1: Landsat OLI bands used to create multispectral image per season in this study

Table 19.2: Classification accuracies of water and non-water categories obtained in the study

Table 19.3: Number of waterbodies and area identified by the maximum likelihood classification in the study

Chapter 20

Table 20.1: Optimum parameter values for Dassura and Upper Mazowe sub-basins

Table 20.2: Error analysis values for the optimum parameters obtained during calibration

Table 20.3: Error analysis values obtained during model validation

Table 20.4: Parameter transfer to ungauged sub-basins

Table 20.5: Model parameters transferred from Dassura and Upper Mazowe sub-basins to Thetford and Lower Mazowe sub-basins

Chapter 21

Table 21.1: Baseline water consumption for tourism ventures by country / region

Table 21.2: Water consumption summary

Chapter 22

Table 22.1: The four Dublin principles

Table 22.2: Characteristics of respondents of the survey

Table 22.3: Household WDM strategies (n = 31)

Table 22.4: Benefits of application of household WDM strategies

Table 22.5: Perceptions of household heads on WDM (n = 40)

Chapter 23

Table 23.1: Rainfall per region

Table 23.2: Major rivers in Sanyati catchment

Table 23.3: Major dams in the Sanyati catchment

Table 23.4: Updated raw water clients by category for 2018-2019 water year

Table 23: The different water use levels per activity in the Sanyati catchment

Chapter 1: Introduction – Africa in the global imaginary: Towards internationally competitive science and research

Inocent Moyo¹ and Christopher Changwe Nshimbi²

¹*Department of Geography and Environmental Studies
University of Zululand, South Africa
moyol@unizulu.ac.za*

²*Centre for the Study of Governance Innovation (GovInn), Department of Political
Sciences, University of Pretoria, South Africa*

Abstract

The International Geographical Commission (IGU) Commission on African Studies (CAS) held its second annual conference at the University of Zululand in June 2019. One of the direct products of the conference is the publication of these conference proceedings, whose authors are drawn from different parts of Africa, and include post-graduate students. The papers in this volume engage with various aspects of the conference theme, which is Africa in the global imaginary: Towards internationally competitive science and research. The authors represent different disciplinary backgrounds in the natural and social sciences and humanities. The chapters in the publication are organised under the following themes and sections: climate change issues in Africa, environmental problems in Africa, environmental conservation, natural resource use and governance, globalisation and regional economic integration in Africa, rural development and water resources. The contributions illustrate various research projects in Africa as well as different debates on natural and social reality on the continent. Some of the contributions also reveal innovative approaches to the study and/or analysis of natural and/or social reality, the results and conclusions of which are thought-provoking.

Introduction

The International Geographical Commission (IGU) Commission on African Studies (CAS) was formed in May 2017. It is headquartered in the Department of Geography and Environmental Studies, University of Zululand, South Africa, with members, associates and affiliates located in major centres and institutions of research and learning across Africa and in other parts of the world. Members of the Steering Committee of the Commission are, for instance, currently drawn from Benin, Ivory Coast, Namibia, New Zealand, Senegal, South Africa, Uganda and the United Kingdom (UK). The Commission is a research and scientific body composed of and dedicated to African and Africanist scholars researching issues around and in Africa, ranging from social sciences to natural sciences, but informed in the main by geographical, multi- and interdisciplinary perspectives. The CAS operates under the auspices of the International Geographical Union (IGU).

Pursuant to the inaugural CAS annual conference, which was successfully held at the University of Namibia from 17-18 May 2018, the second annual conference was held at the University of Zululand from 17-19 June 2019, with the comprehensive theme: *Africa in the global imaginary: Towards internationally competitive science and research*. The aim of the conference was to bring together geographical and interdisciplinary scientific research and thought on, about and in Africa. By these means, the conference has responded to the need for globally competitive research and scientific innovation which it seeks to convey to the international academic community through the CAS.

The objectives of the conference were to improve and/or increase participation in IGU scientific activities by South African and Africa-based scholars and researchers; to grow, nurture and expand IGU scientific and other activities in South Africa and the rest of Africa; to initiate and expand the participation of post-graduate, young and emerging researchers in the scientific and research activities of the Commission specifically and the IGU in general; and to strengthen the connection and networking of geographers within and between South Africa and other African countries and regions of the world. It is anticipated that some of the findings and arguments presented in the contributions will encourage and initiate debate and foster similar research, which should sustain globally competitive science and research on the African continent well into the future.

All contributions to this volume were subjected to a blind peer review process. There were two stages in this process. The first stage was the peer review of abstracts by specialists in the relevant disciplines. Consequently, all the abstracts and papers which were accepted and presented at the conference were peer reviewed. After the conference, the full papers were similarly subjected to blind peer review.

Section A: Climate change issues in Africa

Chapter 2: Modelling the relationship between climatic variables and NDVI with the Markov-switching model

Solomon G. Tesfamichael^{1*}, Thendo Mugwena¹, Tatenda Turukai Chibi¹ and Yegnanew A. Shiferaw²

¹Department of Geography, Environmental Management and Energy Studies
University of Johannesburg, Auckland Park Kingsway Campus
PO Box 524, Johannesburg 2006, South Africa

²Department of Statistics, University of Johannesburg.

*Corresponding author: sgtesfamichael@uj.ac.za

Abstract

Knowledge of the relationships between climate and vegetation helps to assess one based on the other, particularly when there is a scarcity of information on one of them. These relationships usually display non-linear properties through time, making linear assumptions inappropriate for describing the relationships. This paper introduces the Markov-switching (MS) model to study the non-linear relationship between vegetation dynamics and selected climatic variables such as temperature, rainfall and humidity. The paper applied the MS model on three land cover types to quantify climatic variables from the Normalized Difference Vegetation Index (NDVI), and compared its performance with the non-switching model that assumes linear relationships between response and explanatory variables. The results showed that the relationships were not linear, and thus the fitted MS models that captured the non-linear relationships were justified. Mixed results were obtained regarding the relationship between the models and land cover types. These, however, strengthen the justification as to why regime-switching regressions are appropriate, since they follow the given data properties rather than generic land cover based assumptions. This study, therefore, encourages investigations and fine-tuning of the MS approach to capture the complexity and asymmetry observed in most climate and remote sensing data in order to improve the reliability and robustness of estimations.

Keywords: Remote sensing, Markov switching model, temperature, rainfall, humidity

1. Introduction

Understanding patterns in the vegetation dynamics, climate variability and in the relationships between the two provides vital inputs not only to the prediction of future scenarios but also in informing decision-making processes that seek to implement sustainable resource management efforts. Accurate, cost-effective and efficient assessment to characterise the relationship between vegetation and climate can be aided by utilising remote sensing techniques. A common approach used to assess the relationship is by using separate trend analyses of temporally coincident climate and vegetation index derived from remotely sensed spectral data such as the Normalized Difference Vegetation Index (NDVI) (e.g. Julien *et al.* 2006; Boschetti *et al.* 2013; Li *et al.* 2013; Eckert *et al.* 2015; Tan and Li, 2015; Barbosa and Lakshmi Kumar, 2016; Li *et al.* 2017; Pang *et al.* 2017; Zewdie *et al.* 2017). Zewdie *et al.* (2017), for example, investigated long-term dryland vegetation dynamics by looking at the trends of NDVI derived

from Moderate-resolution Imaging Spectroradiometer (MODIS), precipitation and temperature data. The trends were assessed using Breaks for Additive Seasonal and Trend (BFAST) which was proposed by Verbesselt *et al.* (2010, 2012) and quantifies the magnitude and direction of changes in a time-series data, and Mann Kendall test statistic. Pang *et al.* (2017) utilised three trend analysis methods to assess the relationship between NDVI derived from an Advanced Very High Resolution Radiometer (AVHRR) sensor aboard the National Oceanic and Atmospheric Administration (NOAA), and temperature and precipitation data along a vegetation gradient in the Tibetan Plateau. All three methods included least squares linear trend models, Pearson's correlation coefficient and Ensemble Empirical Mode Decomposition (EEMD), which is suited to short-time interval analysis of non-linear and non-stationary data. Fairly strong positive relationships were observed between NDVI-inferred vegetation cover and temperature, while a weaker correlation was observed with precipitation for both the inter-annual and seasonal time-series analysis.

Relationships explained through trend analysis can be extended to build prediction models in which mostly vegetation characteristics are inferred from climate data (e.g. Balaghi *et al.* 2008; Omuto *et al.* 2010; Quiroz *et al.* 2011; Xu *et al.* 2011; Li *et al.* 2013; Birtwistle *et al.* 2016; Georganos *et al.* 2017). Li *et al.* (2013), for example, applied Ordinary Linear Squares regression to model the relationship between NDVI derived from MODIS and rainfall in community grassland pastures in Canada, and reported a very high accuracy ($R^2=0.97$); the correlation was however assessed on spatially aggregated community pastures indicating a generic relationship that ignores temporal variations at each location. As part of an investigation to evaluate the success of the Green Great Wall conservation programme in reducing dust storm intensity in China, Tan and Li (2015) showed the effect of precipitation on NDVI using descriptive statistics (mean and standard deviation) of time-series data of both variables. The time-series analysis used in the study also found a good relationship ($R^2=0.5$) between NDVI and dust storm intensities that were categorised according to ease of visibility. Formica *et al.* (2017) related MODIS NDVI and precipitation spatially using the General Linear Model (GLM) and temporally using a Generalized Linear Mixed effects Model (GLMM) in a large spatial area dominated by arid and semi-arid environments. The findings showed the sensitivity of NDVI to precipitation, and the dependence of the sensitivity on ecoregions. Georganos *et al.* (2017) related AVHRR NDVI and rainfall in the Sahel region. The study reported generally good correlations between NDVI and precipitation in certain areas ($R^2 > 0.5$) while it found the correlations to be location-dependent, indicating the gap for improved modelling approaches if NDVI is to be exploited reliably. This approach is however ideal for data (variables) that are distributed in space.

Two gaps are identified and addressed in this study. Firstly, limited work has been documented on the estimation of climate variables from vegetation. Quiroz *et al.* (2011) demonstrated the potential of NDVI as well as Fourier Transform and Wavelet Transform analyses to estimate precipitation at a high temporal resolution. Although the work proved successful by attaining acceptable accuracy levels, it focused mainly on integrating NDVI and data collected from sparsely distributed rain gauges. The ability to infer climate information from remotely-sensed data has a significant importance particularly to areas where there is a scarcity of weather stations. In this regard, there is a need for increased emphasis by the remote sensing community to derive climate data by using easily available physical data such as vegetation amount. Secondly, the approaches to relate NDVI and climate data in the aforementioned and similar studies assume single-regime relationships between the two variables. Although stratifications (e.g. per season) can be used to fine-tune the relationships

(e.g. Scanlon *et al.* 2002; Tan and Li, 2015; Georganos *et al.* 2017), they basically remain static models that assume single relationships per season. Such an approach may fail to capture the intra-season non-stationary relationships. This is particularly a valid concern for NDVI–climate relationships, which tend to saturate at certain NDVI values above which NDVI generally remains unchanged for corresponding increases in climatic variables (e.g. precipitation) (Huete *et al.* 1997; Martiny *et al.* 2006). In addition, there is no guarantee that rainfall patterns honour seasonal calendars at all times; that is, rain may start or end earlier or later than the expected times. There is therefore a need to investigate modelling approaches that adapt to data dynamics.

This study therefore introduces a modelling approach that adapts to data characteristics in order to estimate selected climate data (temperature, precipitation and humidity) by using NDVI as an explanatory variable. It specifically addresses three objectives. The first objective investigates the applicability of Markov-Switching (MS) and Autoregressive Markov-switching dynamic (MSD-AR) time series models to build the relationship between NDVI and climate data. Markov-switching modelling was proposed by Hamilton (1989) to estimate the probability of a recession in the U.S. economy and has since been applied in diverse fields such as economics (Hamilton, 1990; Filardo, 1994; Bansal and Zhou, 2002), epidemiology (Shumway and Stoffer, 1991) and prediction of wind power fluctuations (Pinson *et al.* 2009). The selling point in these models is their flexibility and richness in capturing non-linear relationships. We believe that this approach is ideal to characterise the complex relationship between NDVI and climate data. The second objective is to compare the performances of MS and MSD-AR time series models against non-switching regression models through applying these modeling techniques in investigating the dynamics of NDVI and climate data. In principle, MSD-AR has relevance to NDVI–climate data relationships since there is a temporal lag between occurrence of climate data and the response of vegetation (Farrar *et al.* 1994; Udelhoven *et al.* 2009). The third objective investigates the performances of MS and MSR and ADL in different vegetation forms (grassland, shrub and forest). This objective is specifically intended to determine the level of complexity in the NDVI–climate relationships for different vegetation types. Furthermore, it is expected to provide an indication on the time delay (lag) between climatic variables and the effect on vegetation growth.

2. Methodology

2.1 Study areas and sampling protocol

Weather stations were the determinant factor in selecting the study areas, since the study focused solely on correlation analyses of time-series data at pointed locations. Two weather stations, one in Skukuza and another in Nelspruit in Mpumalanga Province of South Africa, (Figure 2.1) were therefore selected as the basis of sampling. A zone of 10 km radius around each station was considered to be climatically homogeneous, and was delineated to restrict sampling. Three samples representing grassland, shrubland and forest land cover types were plotted within the zone. Identification of these land cover types was informed by the national land cover map of South Africa produced from Landsat imagery acquired during 2013 to March (DEA, 2015) as well as Google Earth™ image, which was also used for verification of the land cover map. Google Earth™ served as the main source of sampling framework for two reasons. Firstly, it uses high spatial resolution images that allow feature discrimination fairly well. Secondly, it provides time-series data from which temporal dynamics of land use and land cover can be tracked. This was particularly important in identifying natural land cover types that did not change over the years. Selection of natural areas with limited-to-nil intervention

was necessary to eliminate other factors such as irrigation that may explain the variation in NDVI.

The distance between sample points was kept to a minimum, as much as possible, to avoid spatial correlation and thereby ensure independence of the sample locations. Accordingly, the minimum distance between two samples in a weather station zone was 2.6 km. A 60 metre buffer was created around each sample point; this buffer size supported a number of pixels of Landsat imagery. Inclusion of multiple pixels to represent a land cover type was an effort to minimise the uncertainty associated with reliance on a single pixel that could be misplaced due to atmospheric interference on path radiance or limitations related to the spatial resolution. Having multiple pixels as a sampling unit was also deemed appropriate since it enhanced the reliability of representing the dominant land cover features in a sampling buffer that also contained other land cover types in small amounts.

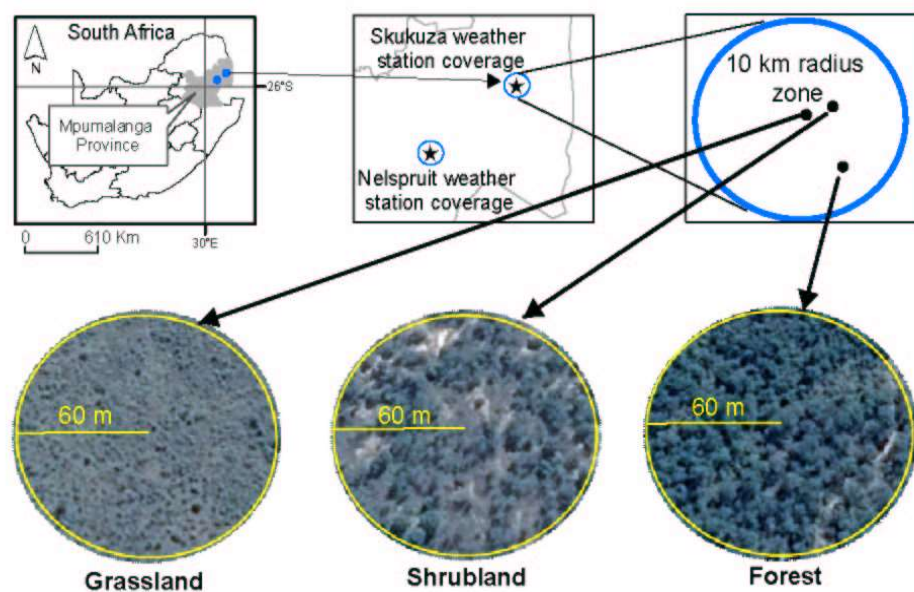


Figure 2.2: Map of study areas showing a 10 km radius zone of a weather station, and sampling units of grassland, shrubland and forest, each measuring 60 m radius within the 10 km radius zone of a station. Images representing land covers were extracted from Google Earth™

2.2 Climate data

Climate data used in the study included precipitation, temperature and humidity. In total, 78 monthly total precipitation and mean temperature records were used between 2010 and 2016. Percent humidity records were measured daily at 8:00 am, 2:00 pm and 8:00 pm local time; these records were averaged for each day. Monthly mean humidity was subsequently quantified from daily means.

2.3 NDVI

Landsat imagery was used to derive NDVI used in this study. The imagery was chosen due to its rich historical record that started in the early 1970s, making it suitable for long-term time-series analysis. Moreover, the relatively high spatial resolution (30 or 60 m) of the image is suitable to capture the land cover variations within short spatial extents that were enforced by proximity to a weather station. Although Landsat has a high temporal resolution of 16 days, utilising it at such a resolution is hampered mainly by atmospheric interferences such as clouds that degrade the quality of reflectance in the visible and infrared regions of the electromagnetic radiation. Therefore, only images that had zero cloud cover (based on visual assessment) within the 60 m buffer zones were selected for the study. In addition, the selection was limited to dates that fell within the months of climate data acquisition. Accordingly, Landsat images matching the months with climate data were used. The NDVI, which estimates the amount or vigour of vegetation by exploiting the contrast in reflectance levels of red and near-infrared electromagnetic radiations from vegetation components, was computed using Equation 1 (Tucker, 1979). Mean NDVI per 60 m buffer was then calculated for each of the 68 times.

$$\text{NDVI} = (\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red}) \quad (1)$$

2.4 Markov-switching modelling

The Markov switching model has been demonstrated to model the non-linear dynamics usually witnessed in economic and financial time series data. In this paper, we apply this model to study the relationship between vegetation and climate variables including temperature, rainfall and humidity. The standard MS model (Hamilton, 1989) is defined as,

$$y_t = \mu_{S_t} + \mathbf{x}'_t \boldsymbol{\beta}_{S_t} + \epsilon_t, \quad t = 1, 2, \dots, T \quad (2)$$

where S_t is the latent variable whose value determines the regime at time t ; μ_{S_t} is intercept while in state S_t ; $\boldsymbol{\beta}_{S_t}$ is regression coefficient of explanatory variables (NDVI) while in state S_t and $\epsilon_t \sim iidN(0, \sigma_{S_t}^2)$. In this study, we specified a two-regime modelling computed as follows (Equation 3).

$$y_t = \begin{cases} \mu_1 + \boldsymbol{\beta}_1 \mathbf{x}_t + \epsilon_{t,1}, & \epsilon_{t,1} \sim N(0, \sigma_1^2) \text{ for Regime 1,} \\ \mu_2 + \boldsymbol{\beta}_2 \mathbf{x}_t + \epsilon_{t,2}, & \epsilon_{t,2} \sim N(0, \sigma_2^2) \text{ for Regime 2} \end{cases} \quad (3)$$

where σ_1^2 and σ_2^2 denote variances under the two regimes. The switching between the two regimes is determined by a transition probability matrix given as:

$$P = \begin{bmatrix} P(S_t = 1 | S_{t-1} = 1) & P(S_t = 2 | S_{t-1} = 1) \\ P(S_t = 1 | S_{t-1} = 2) & P(S_t = 2 | S_{t-1} = 2) \end{bmatrix} = \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix} \quad (4)$$

where P_{ij} denotes the probability of switching from Regime i (starting regime) at time $t-1$ to Regime j (landing regime) at time t . For example, p_{12} denotes the probability of a switch from Regime 1 to Regime 2, while p_{11} represents the probability of staying in Regime 1. Model qualities were evaluated using the coefficient of determination (R^2), Akaike information criterion (AIC; Akaike, 1973) and log-likelihood function.

3. Results

Estimation models for the three climate variables using the traditional non-switching (single

model) and MS approaches for Nelspruit and Skukuza are presented in Table 1. For Nelspruit, the best model to estimate temperature in grassland was obtained for data classified in regime 2 using MS model ($R^2 = 0.41$). Similarly, both regimes of the MS model were better predictors than the non-switching model for rainfall estimation in the same land cover types. Such observations were made for humidity estimation in grassland. In addition to R^2 , the AIC and log-likelihood criteria show the MS-based model to be better than the non-switching models for the estimation of the three climate variables. Temperature estimation in the forest showed the highest accuracy in Regime 1, while non-switching approach yielded a better estimation than the Regime 2 of MS approach. In the same way, rainfall in the forest and shrubland land cover types was estimated best by one of the regimes while the other regime was the least accurate. However the AIC and log-likelihood statistics show better overall fit for MS than for a non-switching approach. Such good performances for an MS-based approach were also observed for Skukuza location.

Table 2.1: Model criteria of non-switching and MS approaches for data set of Nelspruit and Skukuza locations. Predictor variable was NDVI

Land cover	Climate variable	Statistics	Nelspruit			Skukuza		
			Non-switching	MS		Non-switching	MS	
				Regime 1	Regime 2		Regime 1	Regime 2
Grassland	Temperature	R^2	0.17	0.31	0.41	0.28	0.44	0.27
		AIC	365	353		91	81	
		Loglik	-180	-173		-42	-36	
	Rainfall	R^2	0.31	0.40	0.73	0.11	0.7	0.8
		AIC	142	135		147	113	
		Loglik	-68	-63		-71	-52	
	Humidity	R^2	0.03	0.83	0.32	0.13	0.30	0.37
		AIC	650	567		459	447	
		Loglik	-322	-279		-227	-219	
Forest	Temperature	R^2	0.11	0.28	0.02	0.06	0.28	0.98
		AIC	364	347		374	360	
		Loglik	-179	-170		-184	-176	
	Rainfall	R^2	0.22	0.07	0.39	0.08	0.67	0.06
		AIC	404	383		147	118	
		Loglik	-199	-188		-70	-55	
	Humidity	R^2	0.06	0.28	0.48	0.09	0.33	0.09
		AIC	652	574		463	450	
		Loglik	-323	-283		-228	-221	
Shrubland	Temperature	R^2	0.10	0.56	0.16	0.06	0.28	0.98
		AIC	364	348		374	359	
		Loglik	-179	-170		-184	-156	
	Rainfall	R^2	0.30	0.41	0.16	0.07	0.03	0.45
		AIC	396	378		143	136	
		Loglik	-195	-185		-68	-64	
	Humidity	R^2	0.02	0.86	0.34	0.04	0.26	0.07
		AIC	651	559		466	459	
		Loglik	-322	-275		-230	-225	

Figure 2.2 illustrates the time-series process of observed and estimates using the MS approach for Nelspruit. High and low temperature values, respectively, are identified as Regime 2 and Regime 1 scenarios in grassland cover type. Therefore, a model that was developed for Regime 1 data is a better predictor of low temperature values, and vice versa. For rainfall data, Regime 1 and Regime 2 represent high and low values. In certain instances (forest land cover and shrubland), Regime 1 showed low dynamism compared to Regime 2. The low dynamism and mismatch between observed and fitted temperature in forest land cover type in Regime 1 agrees with the low R^2 values reported in Table 2.1. On the other hand, the high dynamics in other instances (Regime 1 or Regime 2) matching with the observed time-series process have relatively good R^2 values.

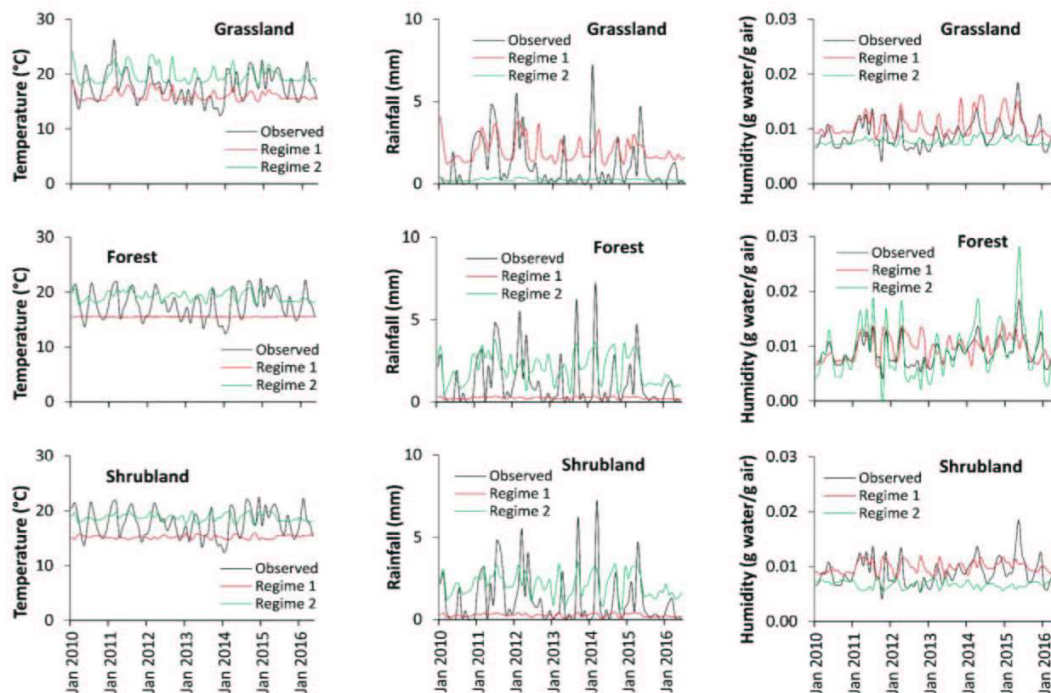


Figure 2.2: Observed and estimated climate data using the MS approach for the three land cover examples in Nelspruit

4. Discussions

Few studies have attempted to estimate climate data based on vegetation characteristics; instead, the predominant approach has been correlation analysis that explores trends in the relationship between the two variables. This study sought to contribute by therefore quantifying selected climate data using vegetation represented by NDVI as a predictor. In doing so, it proposed a Markov-Switching (MS) modelling approach that can capture the changing relationship between two sets of variables. The model characteristics showed the superiority of MS modelling, which pools data into a specified number of regimes, to single-regime modelling in estimating all three climatic data of interest and in both study locations (Table 2.1). Variations were observed in accuracy between the two regimes. Despite such variations, estimations under each of the two regimes were better than the single-regime models in most cases. In certain instances, a non-switching model was better than a switching model for one

of the regimes. However, this should not be viewed as a weakness of the regime switching approach; in fact, the approach is useful in that it highlights the difference in the degree of association between variables across the data range. On the other hand, the non-switching approach forces a single-regime model through data even if there might be inconsistent relationships in the data.

Modelling based on a regime switching approach showed a certain degree of pattern that can be attributed to land cover type. For example, comparison of temperature modelling between Regimes 1 and 2 were somewhat similar for grassland and shrubland, and less so for forest in the Nelspruit study location (Table 2.1). A similar comparison can be observed for rainfall and humidity estimations. This is not surprising, since the former two land cover types as represented (sampled) in this study appear to have a closer morphological similarity with each other than with a forest. In contrast, such a pattern was not discernible when a non-switching approach was used. These findings do not necessarily agree with the ones in the Skukuza location where similarities switched between land cover types. For example, there was a similarity between forest and shrubland with regard to Regime 1 vs. Regime 2 comparison in the estimations of temperature and humidity, while such similarity was observed more between grassland and shrubland for estimating rainfall. In conclusion, this research revealed that the MS models were superior to the non-switching regression model since the probabilities have changed noticeably throughout the period under analysis. This provides a clear insight into the non-linear relationship between climate variables and NDVI. Markov-switching regression is therefore the ideal approach that the remote sensing community should explore more to model the relationship.

Acknowledgements

This study was funded by the University of Johannesburg. We thank the South African Weather Service for the climate data used in the study.

References

- Balaghi, R., Tychon, B., Eerens, H. and Jlibene, M. 2008. Empirical regression models using NDVI, rainfall and temperature data for the early prediction of wheat grain yields in Morocco. *International Journal of Applied Earth Observation and Geoinformation*, 10, 438-452.
- Barbosa, H.A. and Lakshmi Kumar, T.V. 2016. Influence of rainfall variability on the vegetation dynamics over Northeastern Brazil. *Journal of Arid Environments*, 124, 377-387.
- Birtwistle, A.N., Laituri, M., Bledsoe, B. and Friedman, J.M. 2016. Using NDVI to measure precipitation in semi-arid landscapes. *Journal of Arid Environments*, 131, 15–24.
- Boschetti, M., Nutini, F., Brivio, P.A., Bartholomé, E., Stroppiana, D. and Hoscilo, A. 2013. Identification of environmental anomaly hot spots in West Africa from time series of NDVI and rainfall. *ISPRS Journal of Photogrammetry and Remote Sensing*, 78, 26–40.
- DEA. 2015. 2013 – 2014 South African National land cover dataset. Version 05 #2. Available from <https://www.geoterraimage.com/uploads/GTI%202013-14%20SA%20LANDCOVER%20REPORT%20-%20CONTENTS%20vs%2005%20DEA%20OPEN%20ACCESS%20vs2b.pdf>. Accessed on 24/11/2017.
- Eckert, S., Hüsler, F., Liniger, H. and Hodel, E. 2015. Trend analysis of MODIS NDVI time series for detecting land degradation and regeneration in Mongolia. *Journal of Arid*

- Environments*, 113, 16-28.
- Farrar, T.J., Nicholson, S.E., Lare, A.R. 1994. The influence of soil type on the relationships between NDVI, rainfall, and soil moisture in semi-arid Botswana. II. NDVI response to soil moisture. *Remote Sensing of Environment*, 50, 121–133.
- Formica, A.F., Burnside, R.J. and Dolman, P.M. 2017. Rainfall validates MODIS-derived NDVI as an index of spatio-temporal variation in green biomass across non-montane semi-arid and arid Central Asia. *Journal of Arid Environments*, 142, 11–21.
- Georganos, S., Abdi, A.M., Tenenbaum, D.E. and Kalogirou, S. 2017. Examining the NDVI–rainfall relationship in the semi-arid Sahel using geographically weighted regression. *Journal of Arid Environments*, 146, 64-74.
- Huete, A.R., Liu, H.-Q., Batchily, K. and Van-Leeuwen, W. 1997. A comparison of vegetation indices over a global set of TM images for EOS-MODIS. *Remote Sensing of Environment*, 59, 440–451.
- Julien, Y., Sobrino, J.A. and Verhoef, W. 2006. Changes in land surface temperatures and NDVI values over Europe between 1982 and 1999. *Remote Sensing of Environment*, 103, 43–55.
- Li, F., Song, G., Liujun, Z., Yanan, Z. and Di, L. 2017. Urban vegetation phenology analysis using high spatio-temporal NDVI time series. *Urban Forestry & Urban Greening*, 25, 43–57.
- Li, Z., Huffman, T., McConkey, B. and Townley-Smith, L. 2013. Monitoring and modeling spatial and temporal patterns of grassland dynamics using time-series MODIS NDVI with climate and stocking data. *Remote Sensing of Environment*, 138, 232–244.
- Martiny, N., Camberlin, P., Richard, Y. and Philippon, N. 2006. Compared regimes of NDVI and rainfall in semi-arid regions of Africa. *International Journal of Remote Sensing*, 27, 5201–5223.
- Omuto, C.T., Vargas, R.R., Alim, M.S. and Paron, P. 2010. Mixed-effects modelling of time series NDVI-rainfall relationship for detecting human-induced loss of vegetation cover in drylands. *Journal of Arid Environments*, 74, 1552–1563.
- Pang, G., Wang, X. and Yang, M. 2017. Using the NDVI to identify variations in, and responses of, vegetation to climate change on the Tibetan Plateau from 1982 to 2012. *Quaternary International*, 444, 87–96.
- Quiroz, R., Yarlequé, C., Posadas, A., Mares, V. and Immerzeel, W.W. 2011. Improving daily rainfall estimation from NDVI using a wavelet transform. *Environmental Modelling & Software*, 26, 201–209.
- Scanlon, T.M., Albertson, J.D., Caylor, K.K. and Williams, C.A. 2002. Determining land surface fractional cover from NDVI and rainfall time series for a savanna ecosystem. *Remote Sensing of Environment*, 82, 376–388.
- Tan, M. and Li, X. 2015. Does the Green Great Wall effectively decrease dust storm intensity in China? A study based on NOAA NDVI and weather station data. *Land Use Policy*, 43, 42-47.
- Tucker, C.J. 1979. Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment*, 8, 127–150.
- Udelhoven, T., Stellmes, M., del Barrio, G. and Hill, J. 2009. Assessment of rainfall and NDVI anomalies in Spain (1989–1999) using distributed lag models. *International Journal of Remote Sensing*, 30, 1961–1976.
- Verbesselt, J., Hyndman, R., Zeileis, A. and Culvenor, D. 2010. Phenological change detection while accounting for abrupt and gradual trends in satellite image time series.

- Remote Sensing of Environment*, 114, 2970–2980.
- Verbesselt, J., Zeileis, A., Herold, M., 2012. Near real-time disturbance detection using satellite image time series. *Remote Sensing of Environment*, 123, 98–108.
- Xu, W., Gud, S., Zhao, X., Xiao, J., Tang, Y., Fang, J., Zhang, J. and Jiang, S. 2011. High positive correlation between soil temperature and NDVI from 1982 to 2006 in alpine meadow of the Three-River Source Region on the Qinghai-Tibetan Plateau. *International Journal of Applied Earth Observation and Geoinformation*, 13, 528–535.
- Zewdie, W., Csaplovics, E. and Inostroza, L. 2017. Monitoring ecosystem dynamics in northwestern Ethiopia using NDVI and climate variables to assess long term trends in dryland vegetation variability. *Applied Geography*, 79, 167–178.
- Zhou, J. Jia, L. and Menenti, M. 2015. Reconstruction of global MODIS NDVI time series: Performance of Harmonic ANalysis of Time Series (HANTS). *Remote Sensing of Environment*, 163, 217–228.

Chapter 3: Using the Cropwat model to estimate the effects of climate change and shifting planting dates on *Jatropha* water requirements in semi-arid conditions of Botswana

Moseki, O.^{a*}, Murray-Hudson, M., Kashe, K., Moses, O., Kgathi, D.L.,
Moroke, T.S., Moseki, B. and Mmopelwa, G.

^aOkavango Research Institute, University of Botswana
Private Bag 285, Maun, Botswana

^bUniversity of Botswana, Private Bag 0022, Gaborone, Botswana

^cBotswana University of Agriculture and Natural Resources, Private Bag 0027, Gaborone

*Corresponding author: mosekio14@gmail.com

Abstract

*Changes in climate are likely to influence crop water requirements, due to temperature and precipitation variation projected. Although little can be done to prevent these changes in climate, adaptation and mitigation strategies can be employed to curb the impacts, especially with regard to limited water resources for crop production. This study was conducted to assess the possible effects of climate change and the shifting of planting dates on *Jatropha* water requirements in Botswana. The following four scenarios were simulated to estimate the impact of climate change on crop water and irrigation requirements under the prevailing local conditions: 1) crop water requirements (CWR) at the current state of temperature and rainfall (baseline scenario), 2) CWR at the projected temperature from 2020-2039 and current state of rainfall (S1), 3) CWR at projected rainfall of 2020-2039 and current state of temperature (S2), 4) CWR at projected temperature and rainfall patterns in 2020-2039 (S3). Current climatic conditions were obtained from the Department of Meteorological Services weather station located at Sir Seretse Khama International Airport, Gaborone, Botswana, while future climatic conditions were obtained from Global Climate Models (GCMs) projections following representative concentration pathway (RCP) 4.5. These climatic conditions were used as inputs into the CROPWAT model to estimate the reference evapotranspiration (ET_o), effective rainfall and crop water requirements (CWR). Reference evapotranspiration, effective rainfall, and *Jatropha curcas* L. water requirements varied with different climatic scenarios. Compared with the baseline (1986-2017), all scenarios showed an increase in *Jatropha* water requirements. S3 showed the highest crop water requirements (CWR) (12750m³/ha/year), followed by S1 (12110m³/ha/year), S2 (10937m³/ha/year) and lastly the baseline (10300m³/ha/year), respectively. S3 exhibited the most extreme effect and will require 2450m³/ha/year of irrigation water above the baseline. This might be ascribed to high temperatures coupled with low projected rainfall for this scenario. These act to increase the crop evapotranspiration (ET_c), which equals CWR. S1 and S2 require an incremental of 1810 m³/ha/yr and 637 m³/ha/yr above the baseline, respectively. When shifting the *Jatropha* planting dates forward, water requirements generally decreased. This strategy can be used as a water saving measure in semi-arid conditions. Clearly, the cultivation of *Jatropha* under future climates will require careful planning and strong justification against more water-conservative crops.*

Keywords: Climate change, crop water requirements, Jatropha, CROPWAT, water resource management, semi-arid

1.0 Introduction

Globally, agriculture accounts for 80-90% of all freshwater withdrawals from rivers, lakes, and aquifers used by humans, and most of that is used in irrigation for crop production (Shiklomanov and Rodda, 2004; Morison *et al.* 2008). In many parts of the world, this water has high competition from different water users and is often unsustainable due to poor quality and climate change impacts. Unsustainable water supplies affect agricultural production and productivity (Elgaali *et al.* 2006). In the U.S. total consumptive water use for irrigation accounted for 62% of the total water withdrawals and reclaimed wastewater in 2015 (Dieter, 2018). In Africa, water withdrawals are mostly directed towards agriculture, mainly because of the climatic conditions experienced in the continent. Rainfall in this continent is highly variable. About 86% of human water withdrawals in this continent are directed to agricultural production annually and this percentage may be higher in arid and semi-arid parts of the continent (Frenken, 2005). In 2014 - 2015 agriculture in Botswana accounted for 42% of the total water consumption of 166.8 million cubic meters (MCM). Compared to other sectors such as households and mining, which accounted for 25% and 23% of total water consumption respectively, the contribution of agriculture to total water consumption is relatively higher. Although agriculture accounted for 42% of the total water consumption in 2014/15, its contribution to GDP was less than 2% (Government of Botswana, 2016a). This small proportion is an indicator of the difficulties facing food production in this semi-arid region, rather than great efficiency in agricultural water use. Due to the difficulties facing food production, Botswana imports about 16.3 percent of foodstuffs from other countries (Statistics Botswana, 2018). In Botswana agricultural productivity is limited by environmental factors such as unreliable water supply, episodic rains, poor soils and the desert covering around 80% of the country (Darkoh, 1999; Moroke *et al.* 2010; Government of Botswana, 2016b). These environmental factors together with crop type and soil parameters consequently affect CWR, which to some extent is linked to agricultural productivity. CWR is the amount of water needed by plants to compensate for water lost to the atmosphere as a result of environmental demand (Allen *et al.* 1998) for optimum outputs required.

Environmental demand is driven by temperature, wind speed, humidity, precipitation, and solar radiation. These parameters may work singly or together to influence the amount of water lost to the atmosphere from both the soil and plants through the processes of evaporation and transpiration. The two processes are difficult to separate, hence they are collectively termed evapotranspiration (ET). ET is the amount of water lost to the atmosphere from a specific crop due to the aerodynamics and soil heat flux of a specific location (Jensen *et al.* 1990; Allen *et al.* 1998; Jensen and Allen, 2016). Understanding crop water relations by quantifying soil and crop evapotranspiration (ETc) is an essential part of agricultural water management, a concept which refers to strategies that aim to improve crop production, reduce unproductive water losses, and preserve natural resources degradation. The rate of ET is, however, anticipated to exacerbate at the land surface and from all the freshwater flows and discharges due to climate change (Shibuo *et al.* 2007; Connor, 2015).

Climate change is mainly driven by increasing greenhouse gas concentrations in the atmosphere. Greenhouse gases (GHGs) are naturally occurring, maintaining a habitable temperature for the planet, which is about 15°C (Mitchell, 1989; Hartmann, 2015; Kweku *et al.* 2017). These include carbon dioxide (CO₂), methane (CH₄), nitrous dioxide (N₂O),

chlorofluorocarbons (CFCs) and water vapour. However, their concentrations have been increasing steadily, which is attributed to different human activities such as fossil fuel burning, intensive agriculture and deforestation. GHGs contribute to the greenhouse effect by absorbing infrared radiation in the atmosphere, which results in raising global temperature. Increased global temperature will clearly affect both plant growth rates and transpiration demand for cooling and accelerated photosynthesis. While the certainty of elevated temperatures driven by global warming is high (Leggett, 1990; Pachauri and Reisinger, 2007; Parry *et al.* 2007), the same cannot be said about the potential effects on regional precipitation (Downing *et al.* 1997; Watson *et al.* 1998; Sato *et al.* 2007). In southern Africa, the uncertainty linked to projected precipitation is very high (Serdeczny *et al.* 2017). In summary, then, the cultivation of crop plants (whether for food or energy) in southern Africa in the future is likely to require more water than under previous conditions. As indicated above, increased temperatures will increase crop water requirements, which will require additional irrigation in low-rainfall areas.

It is, therefore, imperative to understand how various crops may respond to the various climatic and environmental factors, especially under climate change, to allocate water resources wisely. Studies have been conducted to determine the influence of climate change on the water requirements of different crops globally (Rao *et al.* 2011; Lalic *et al.* 2013; Parekh and Prajapati, 2013; Chowdhury *et al.* 2016; Huang *et al.* 2016). Using future climate scenarios to analyse the water requirements of different crops is important for making decisions on water allocation.

A simplified approach is presented in the IPCC Fifth Assessment report (Allen *et al.* 2014; Stocker, 2014) which includes four Representative Concentration Pathways (RCPs) scenarios, namely, RCP2.6, RCP4.5, RCP6.0, and RCP8.5. These scenarios represent different CO₂ concentrations in the biosphere, radiative forcing levels and their pattern of change up to 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m²), respectively. They do not include land use, dust, or nitrate aerosol forcing (Van Vuuren *et al.* 2011). They are used to give projections on how the future climate may change as a result of human activities such as fossil fuel burning and large-scale deforestation. Radiative forcing is the difference between sunlight absorbed by the earth and the energy radiated back to space (Shindell *et al.* 2013). The feedback can be either negative or positive. Positive radiative forcing means the earth receives more incoming energy from sunlight than it radiates to space, causing warming. Conversely, negative radiative forcing indicates greater energy losses from the earth to space than it receives from the sun, which causes cooling. RCP2.6 indicates a decreasing trend of positive radiative forcing in 2100, RCP4.5 and 6.0 represent an intermediate positive forced radiation by 2100 while RCP8.5 involves high greenhouse gas emissions with forced radiation increasing before 2100. CO₂ concentrations are projected to reach 421, 538, 670 and 936 ppm in 2100 for RCP2.6, 4.5, 6.0 and 8.5 scenarios, respectively (Van Vuuren *et al.* 2011; Jones *et al.* 2013). Several studies conducted globally indicated that climate change is likely to influence water requirements of various crops such as maize, wheat, and rice (Parekh and Prajapati, 2013; Lee and Huang, 2014; Mohan and Ramsundram, 2014; Manasa and Shivapur, 2016; Awal *et al.* 2018). There is a gap in knowledge concerning climate change impacts on *Jatropha* water requirements. This information is critical for the continued promotion of *Jatropha* as an alternative energy source in dry areas of Botswana. This paper, therefore, forms part of the co-research project between Botswana and Japan which aimed at creating a bioenergy (biofuel) production model based on biological resources available in Botswana. The paper contributes to the overall project by using the available past climate data and future projections from the GCMs to estimate future water requirements. It was hypothesised that climate change and

shifting planting dates of *Jatropha* will have an impact on ETo, effective rainfall and consequently, *Jatropha* water requirements. Thus, the objectives of the study were to determine the effects of temperature and rainfall pattern change on ETo, effective rainfall, CWR under different climate scenarios and the effect of shifting planting dates on *Jatropha* water requirements in semi-arid conditions of Botswana. This paper is entirely on modelling of secondary data.

2.0 Materials and methods

ETo, effective rainfall, and *Jatropha* water requirement simulations were done using the Food and Agriculture Organisation's (FAO) CROPWAT model (version 8.0) (Allen *et al.* 1998) under varying climate change scenarios. This model was selected based on its applicability in various environments and to various crops. The model has been used in different environmental conditions to estimate the rate of evapotranspiration, crop water and irrigation requirements (Rajaona *et al.* 2012; Rao *et al.* 2012; Song *et al.* 2015) and to estimate yield response to water at all spatial scales (field, farm, regional and national). The CROPWAT model uses the Penman-Monteith equations which are based on well-established theories and empirical environmental relationships to generate estimate ETo, ETc and effective rainfall from weather parameters. Four different scenarios were formulated to estimate CWR in semi-arid conditions of Botswana:

- CWR at the current state (1986-2017) of temperature and rainfall (baseline scenario)
- CWR at the projected temperature for 2020-2039 (future period) and current state of rainfall (S1 scenario)
- CWR at projected rainfall for 2020-2039 and at the current state of temperature (S2 scenario)
- CWR at projected temperature and rainfall for 2020-2039 (S3 future scenario)

To simulate *Jatropha* water requirements under the given four scenarios, values for humidity, windspeed and sunshine for 2020-2039 were assumed to be the same as those for the current state (1986-2017). Precipitation and temperature values were obtained from the downscaled outputs of the bcc_csm1_1_m model of the CMIP5 project (Table 3.2) under the RCP4.5 scenario. The bcc_csm1_1_m model was chosen because it responded to several very important criteria used by many researchers, including the following: the participation in one of the Coupled Model Inter-comparison Project 5 (CMIP5); it must be well documented in peer-reviewed journals and the model must be a coupled ocean-atmosphere (Parry, 2002; Barrow *et al.* 2004; Wu *et al.* 2014).

2.1 Datasets

2.1.1 Observational climate data

The CROPWAT model requires input data of maximum and minimum air temperature, humidity, windspeed, sunshine hours, and rainfall to calculate ETo, effective rainfall and CWR. In order to develop climate files for CROPWAT, the climatic data (Table 1) for the current state of climate (1986-2017) for Sir Seretse Khama International Airport (SSKIA) were collected from the Department of Meteorological Services, Gaborone, Botswana. SSKIA is located at latitude 24°42' S and Longitude 25°55' E, with an elevation of 975 m above sea level. The station was selected due to its proximity to the study area, Sebele. The data was from 1986-2017, which was used as the baseline. From these parameters, daily estimates of Penman-Monteith reference evapotranspiration (Allen *et al.* 1998) were derived from the CROPWAT

model.

Table 3.1: Monthly mean values of the current climatic conditions (1986-2017) for Sir Seretse Khama International Airport weather station							
Month	Min Temp (°C)	Max Temp (°C)	(%)	Windspeed (m/s)	Sun (hours)	Rainfall (mm)	
January	19.4	31.9	57	Humidity 3.4	8.6	85.8	
February	19.1	31.5	58	3.2	8.7	83.9	
March	17.4	30.2	60	2.8	8.3	60.5	
April	13.5	27.7	59	2.7	8.4	30.9	
May	8	25.3	54	2.4	9.3	12.5	
June	4.6	22.5	54	2.6	9.2	9	
July	4.1	22.4	50	2.6	9.5	1	
August	7.2	25.7	44	3.2	9.5	0.9	
September	12.1	29.5	39	3.7	9.3	6.8	
October	16.3	31.5	42	4.2	9	36.1	
November	17.8	31.6	47	4	8.7	64.2	
December	19	31.7	54	3.5	8.4	77	
Average /Sum	13.2	28.5	52	3.2	8.9	468.6	

2.1.2 Climate model data

In addition to the historical data, model-based projections of future (2020-2039) climate change, mainly temperature and precipitation (Table 3.2), obtained from GCMs used in the Coupled Model Inter-comparison Project Phase 5 (CMIP5) were used to estimate CWR. The models that were used in the CMIP5 project are presented in Table 3. Details of the CMIP5 project are given in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). Projections of climate models used in the above-mentioned project were based on four Representative Concentration Pathways (RCPs) scenarios (RCP2.6, RCP4.5, RCP6.0, and RCP8.5), but more attention was paid to RCP4.5 scenario due to its intermediate greenhouse gas forcing.

Downscaled future climate projections for Botswana were obtained from the Climate Change Knowledge Portal developed by the World Bank (Climate Change Knowledge Portal, 2019). For humidity, windspeed and sunshine hours data, it was assumed that the variables for future scenarios remained the same as present. This assumption was made due to the difficulties in obtaining the projections of the above-mentioned parameters from the GCMs. These values, which were assumed to be constant, together with precipitation and temperature projections

obtained from the models, were used as inputs into the CROPWAT model to estimate ETo and CWR as described for the baseline data set.

Table 3.2: Projected monthly mean maximum and minimum temperature and rainfall for 2020-2039; the assumption is that humidity, windspeed and sunshine hours remain the same as for the 1986-2017 period

Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Windspeed (m/s)	Sun (hours)	Rainfall (mm)
January	23.6	37.7	57	3.4	8.6	61.5
February	23.1	37.5	58	3.2	8.7	53.5
March	22.8	36.8	60	2.8	8.3	37.3
April	20.1	34.3	59	2.7	8.4	5.8
May	15.6	30.2	54	2.4	9.3	2.1
June	11.7	26.4	54	2.6	9.2	2.6
July	10.7	25.8	50	2.6	9.5	1.2
August	12.9	28.6	44	3.2	9.5	2.8
September	16.9	33.5	39	3.7	9.3	8.7
October	20	35.5	42	4.2	9	33.6
November	21.2	35.5	47	4	8.7	60
December	22.4	36.2	54	3.5	8.4	79.3
Average	18.4	33.2	52	3.2	8.9	348.3

Table 3.3: List of climate models used in the CMIP5 project. The model printed in bold is the selected driving model for the CROPWAT model (table adapted from The World Bank (2018)).

MODEL	MODELLING CENTER	INSTITUTION
BCC_CSM_1	BCC	Beijing Climate Center, China Meteorological Administration
BCC_CSM_1_M		
CCSM4	NCAR	National Center for Atmospheric Research
CESM1_CAM5	NSF-DOE-NCAR	National Science Foundation, Department of Energy, National Center for Atmospheric Research
CSIRO_MK3_6_0	CSIRO-QCCCE	Commonwealth Scientific and Industrial Research Organization in Collaboration with the Queensland Climate Change Center of Excellence
FIO_ESM	FIO	The first Institute of Oceanography, SOA, China
GFDL_CM3	NOAA GFDL	Geophysical Fluid Dynamics Laboratory

GFDL_ESM2M		
GISS_E2_H	NASA GISS	NASA Goddard Institute for Space Studies
GISS_E2_R		
IPSL_CM5A_MR	IPSL	The institute Pierre Simon Laplace
MIROC_ESM	MIROC	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and the National Institute for Environmental Studies
MIROC_ESM_CHEM		
MIROC5	MIROC	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
MRI_CGCM3	MRI	Meteorological Research Institute
NORES_M1_M	NCC	Norwegian Climate Centre

2.1.3 Crop data

Root depths and crop coefficients for different phenological stages were obtained from the literature (Suttrer, 2010; Rajaona *et al.* 2012) in order to estimate the rate of crop evapotranspiration (ET_c). Parameters used were K_c values: initial, development, mid-season and late season, critical depletion, yield response fraction and crop height. The planting date was set to the 1st of September, which is taken as the start of the growing season in Botswana. These crop characteristics were used to develop the crop file (*.CRO) in the CROPWAT model.

2.1.4 Soil data

The CROPWAT soil file (*.SOI) requires input parameters for total available soil moisture (field capacity (FC) – permanent wilting point (PWP)), maximum rain infiltration rate, maximum rooting depth, and the initial soil moisture depletion. Therefore, soil characteristics for Sebele were used to develop the soil file (*.SOI) in CROPWAT.

2.2 ETo and ET_c estimation

The CROPWAT model estimates crop water and irrigation water requirements based on decadal (dec) or monthly climate data, that is minimum and maximum air temperature, relative humidity, sunshine duration, and windspeed. Firstly ETo is computed (Equation 1); this is then used to calculate crop water requirement.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_a - e_d)}{\Delta + \gamma(1 + 0.34 U_2)} \quad (1)$$

Where:

ET = reference evapotranspiration [mm day⁻¹], R_n = net radiation at the crop surface [MJ m⁻² day⁻¹], G = soil heat flux density [MJ m⁻² day⁻¹], T = mean daily air temperature at 2 m height [°C], U₂ = wind speed at 2 m height [m s⁻¹], e_a = saturation vapour pressure [kPa], e_d = actual

vapour pressure [kPa], $e_a - e_d$ = saturation vapour pressure deficit [kPa], Δ = slope vapour, pressure curve [kPa °C⁻¹], γ = psychrometric constant [kPa °C⁻¹], 0.408 converts the net radiation expressed in MJ/m²/day to equivalent evaporation expressed in mm/day, 273 = Kelvin's constant

While ET_c or CWR of Jatropha was calculated as;

$$ET_c = K_c \times ET_o \quad (2)$$

Where:

ET_c = Crop evapotranspiration in mm/day

K_c = crop coefficient, dimensionless

ET_o = Reference crop evapotranspiration in mm/day

2.3 Effective rainfall

Rainfall data (monthly) is required to calculate the effective rainfall (Equation 3-5) (Allen *et al.* 1998). For this study, the USDA Soil Conservation Service method provided in the CROPWAT model was used to calculate the effective rainfall on a monthly basis using the following criteria:

1. When total rainfall is < 250mm, effective rainfall (ER) is given by the following equation:

$$ER = \frac{\text{Total Rainfall} \times (125 - 0.2 \times \text{Total Rainfall})}{125}$$

Equation (31)

2. When total rainfall is > 250mm, effective rainfall is given by the following equation;

$$ER = 125 + 0.1 \times (\text{Total Rainfall} - 250)$$

Equation (2)

2.4 Sensitivity analysis of CWR to varying planting dates and temperature increase

The study also performed a sensitivity analysis in order to understand better the CWR of Jatropha. Five (5) additional scenarios were achieved by changing the planting dates only. Other variables were left unchanged. At first, the growing season was set to the first (1st) of September which (see above) is taken as the start of the growing season in Botswana. The other planting dates used were the first day of the month and mid-month. Since the September first planting date was already computed, the next planting date to be computed was the 15th September. The same principle was applied with October and November (1st and the 15th day as planting dates). To further understand the effect of temperature on CWR, the current temperature scenario was increased by 1°C, 2°C and 3°C. The temperature variations were then used as inputs in the CROPWAT model.

2.5 Uncertainty in the simulations

To estimate the uncertainty associated with the Jatropha water requirements simulations, downscaled outputs of precipitation and temperature for the models presented in Table 3.3 were used as inputs into the CROPWAT model. A similar method as in the case of the selected bcc_csm1_1_m model was used in other models to calculate Jatropha ET_c. The obtained outputs from the different models were then averaged to calculate the ensemble mean which gives the spread of the models. The spread in the simulation of Jatropha WR based on the various climate models gives an estimate of the uncertainty in the simulations.

2.6 Statistical analyses

Following input files development, the CROPWAT model was run for the corresponding periods – baseline (1986-2017) and future (2020-2039). Model outputs were then subjected to statistical analyses in Excel 2016. Parameters of descriptive statistics such as means and percentages were used to evaluate the impacts of climate change on the water use of Jatropha. MATLAB R2019a software was also used. The baseline (1986-2017) was used for the purpose of comparing the impacts of climate change on crop water requirements.

3.0 Results

3.1 Reference evapotranspiration

The rates of the reference evapotranspiration (ET_o) for the current climatic conditions and future scenarios are presented in Figure 3.1. For the baseline scenario, ET_o varied from a minimum of 3.23 mm/day (June) to a maximum of 7.44 mm/day (October) from 1986-2017. A similar pattern to that observed in the baseline was also observed in S3. In S3 ET_o varied from 3.66 mm/day in June to 8.22 mm/day in October in the same period. The change between the scenarios shows a fluctuating pattern with the peak change estimated to be 18.6 % in April between the current (1986-2017) and future scenario (2020-2019). The model estimated an overall 12.6 % increase in ET_o between the baseline and S3. In general, both the baseline and S3 appeared to show an increasing trend in ET_o from September to October and a decrease thereafter from October to June, then a slight increase in July and August.

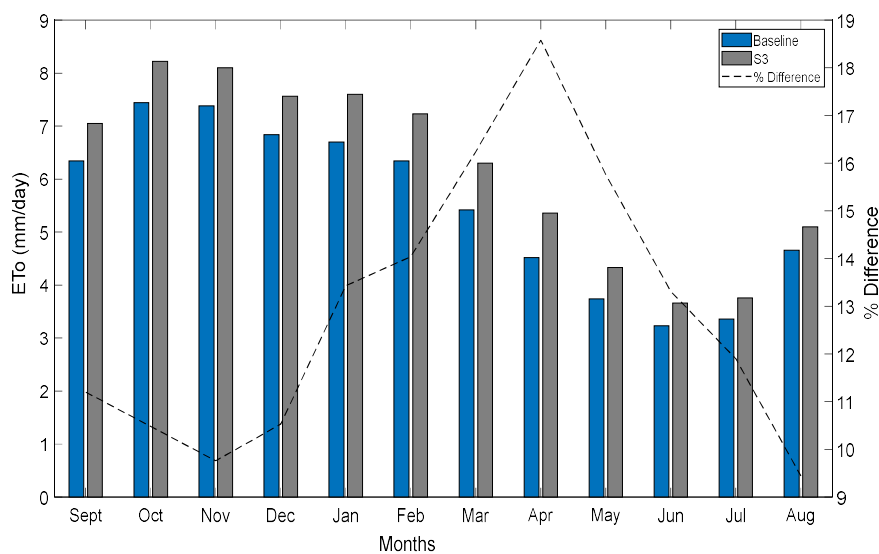


Figure 3.1: Change in reference evapotranspiration under the current and the future climatic conditions in Botswana. Baseline = ET_o at the current state of temperature and rainfall; S3 = ET_o at the projected temperature and rainfall patterns in 2020-2039

3.2 Effective rainfall

Figure 3.2 indicates variability in the effective rainfall across the months for both the baseline and S3. Under the current climate scenario (baseline), the maximum effective rainfall was 74.0 mm/month in January, whereas the minimum effective rainfall was 0.9 mm/month in August. In the projected climate scenario (S3), the maximum effective rainfall was 79.3mm/month in December, while the minimum was 1.2 mm/month in July. From September to January the

effective rainfall shows an increasing pattern, whereas from February to August the pattern is decreasing in both scenarios. The future scenario (S3) compared with the baseline generally shows a decreasing pattern except for September, December, July, and August which show a positive increase in the effective rainfall. More rain is projected for July and August in the future than the baseline, hence a positive difference. In the baseline the total effective rainfall calculated was 419.5 mm/annum whereas in S3 effective rainfall calculated was 317.8 mm/year, this implies that less rainfall is projected for the future.

3.3 Crop water requirements (CWR)

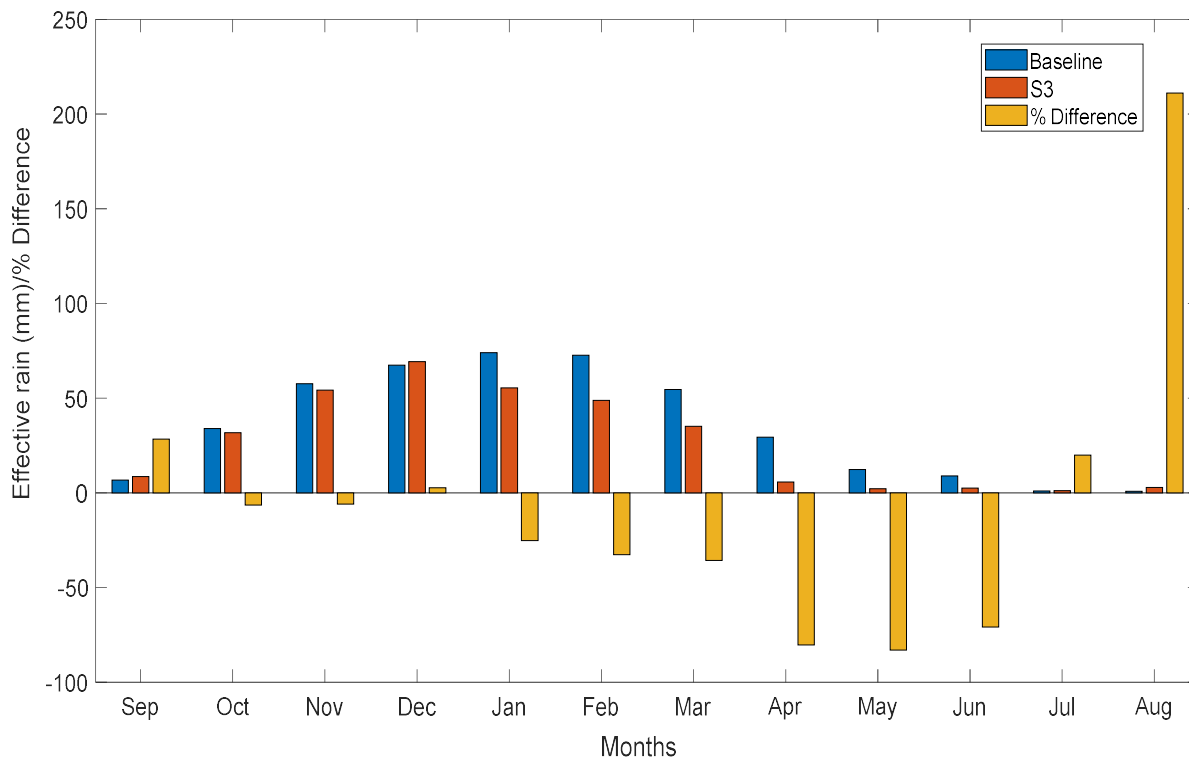


Figure 3.2: Change in effective rainfall under varying climatic scenarios in Botswana. Baseline = CWR at the current state of temperature and rainfall; S3 = CWR at the projected temperature and rainfall patterns in 2020-2039

Figure 3.3 indicates Jatropha water requirements under different developmental stages in varying climatic conditions. From September (Initial stage) to November (Middle stage) in both the baseline scenario and the projected climate scenario, S1, the water requirement shows an increasing trend with the peak reached in December and a decline thereafter. The same pattern is observed in S2 and S3 except that the peak for the two scenarios was observed in January. The possible explanation to the offset in peaks may be high temperatures and medium rainfall experienced and projected for both December and January. The Middle stage tends to require more water than other stages in all the scenarios.

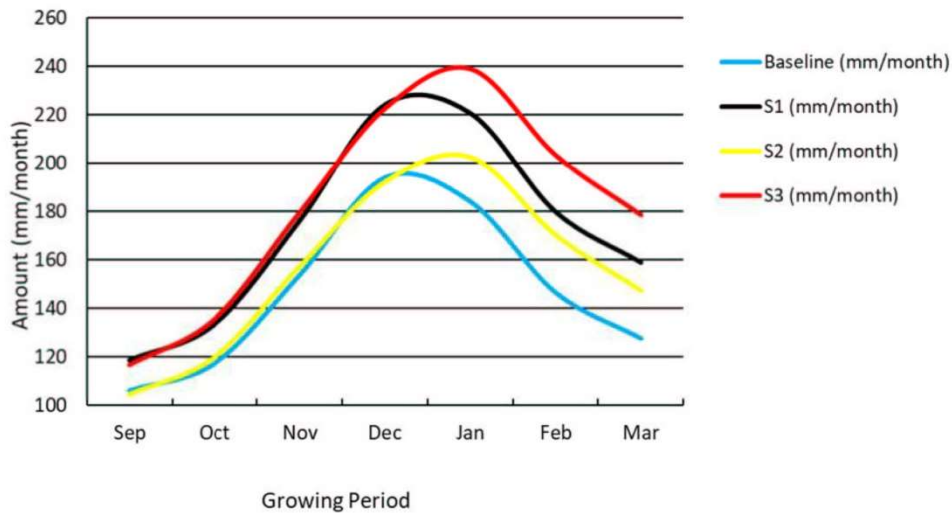


Figure 3.3: Jatropha water requirements for different developmental stages under varying climatic scenarios (Baseline to S3) modelled for Botswana conditions. Baseline = CWR at the current state of temperature and rainfall; S1 = CWR at the projected temperature and the current rainfall state; S2 = CWR at projected rainfall of 2020-2039 and current state of temperature; S3 = CWR at both the projected temperature and rainfall patterns in 2020-2039.

Total CWR varied according to different climatic scenarios (Figure 3.4). The projected scenario, S3, showed the highest CWR (12750m³/ha/year), followed by S1 (12110m³/ha/year), S2 (10937m³/ha/year) and lastly the baseline scenario (10300m³/ha/year). On the basis of scenarios S1, S2 and S3 Jatropha will require 17.6 %, 6.2 % and 23.9 % more water respectively, more than the baseline scenario. The results indicate that both future temperature and rainfall projected will influence the Jatropha water requirement in 2020-2039 as indicated by Figure 3.4.

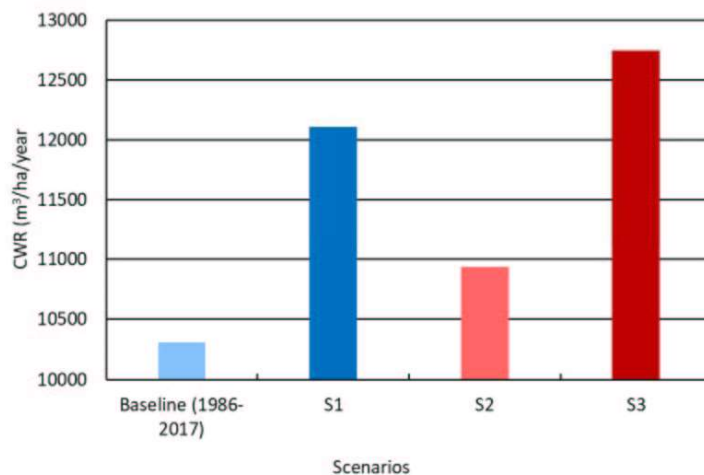


Figure 3.4: Jatropha total water requirements under varying climatic scenarios (Baseline-S3) modelled outputs for Botswana conditions. Baseline = CWR at the current state of temperature and rainfall; S1 = CWR at the projected temperature from 2020-2039 and

current state of rainfall; S2 = CWR at the projected rainfall of 2020-2039 and current state of temperature; S3 = CWR at the projected temperature and rainfall patterns in 2020-2039.

3.4 Sensitivity analysis of crop water requirements to varying planting dates

Figure 5 shows a slightly decreasing trend in CWR according to different planting dates in all scenarios, except for the baseline and S2 scenarios, which show an increasing trend when the planting date is shifted to the 15th November. The results indicate that to save irrigation water in Jatropha cultivation, shifting planting dates may be advisable for future Jatropha production. The results also indicate the effect of temperature increase on CWR. This is demonstrated in S3 where future projected temperatures were used. To further understand the effect of temperature on CWR, a sensitivity analysis was performed whereby the current temperature scenario was increased by 1°C, 2°C and 3°C (Figure 6). The results indicate an increasing CWR trend with an increase in temperature. At 3°C CWR increased to 1133.5 mm/ha/year compared to 1030.0 mm/ha/year predicted under the prevailing climatic conditions. This shows a positive increase. An increase of 1°C will result in a 3.35 % increase in CWR. The sensitivity results indicate that proper timing of planting is critical in water management and planning.

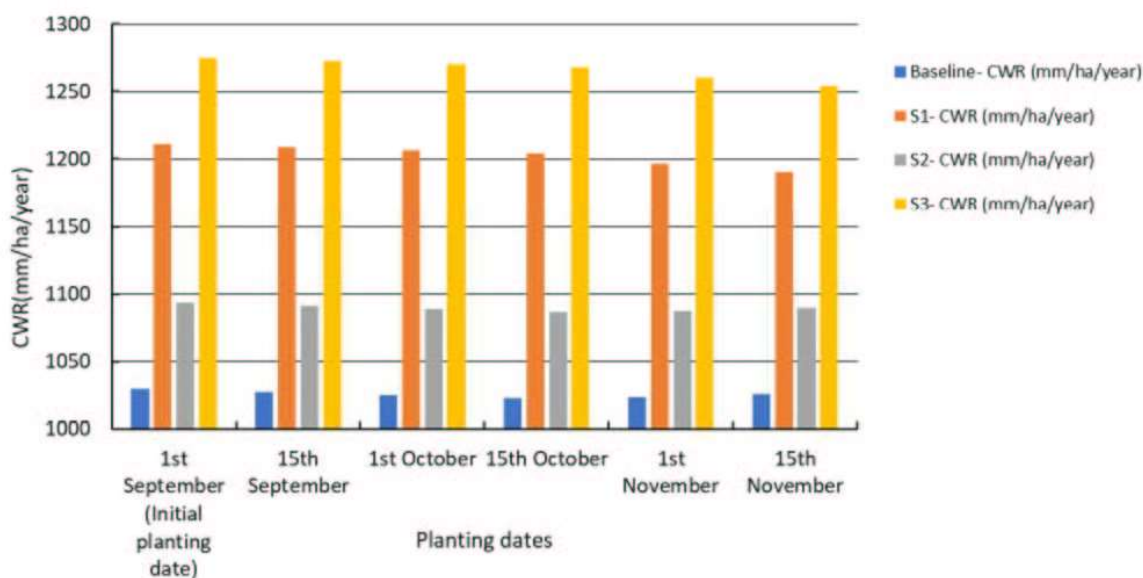


Figure 3.5: Sensitivity analysis of CWR to varying planting dates under changing air temperature and rainfall

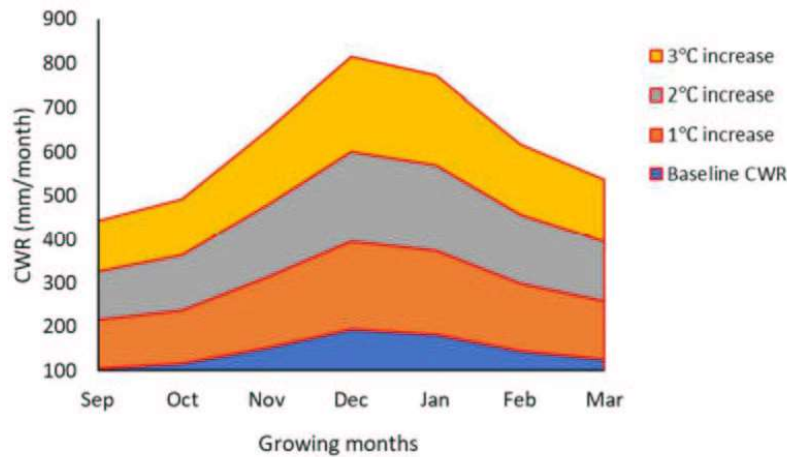


Figure 3.6: Effect of temperature variation on Jatropha water requirements in different developmental stages

3.5 Jatropha evapotranspiration rates from different GCMs

A simple quadratic regression was used to investigate the relationship between the crop developmental stages and ET_c/CWR from the different models' outputs. The scatterplot showed that there was a strong positive relationship between the ET_c of different model projections and the crop developmental stages (Figures 7a and 7b). All the models project a similar pattern of ET_c with an R-value of 68.4 %. They show an increase in ET_c with the peak reached in December and a decline thereafter. However, thirteen (13) models project ET_c that is generally higher than that of the selected model (bcc_csm1_1_m) while only two (2) models generally project a lower rate. The mean of the ensembles is also, in general, higher than the ET_c values projected by the selected model. Although the selected model gives projections that fall between the best and the worst scenarios presented, there is a likelihood that it is underestimating ET_c values since the ensemble mean and 13 of the 15 models (considered in the study) relatively project higher values in general. Model projections range between 224.56 mm/month and 112.21 mm/month. On average all models (ensemble mean) estimated water requirements of 190.00 ± 7.57 mm/month. When comparing the selected model (bcc_csm1_1_m) to the worst model, the selected model projected a monthly average of 182.14 mm whereas the worst model projected an average of 224.56 mm. As previously mentioned, the selected model might have underestimated ET_c for Jatropha by 42.42 mm when compared with the worst model.

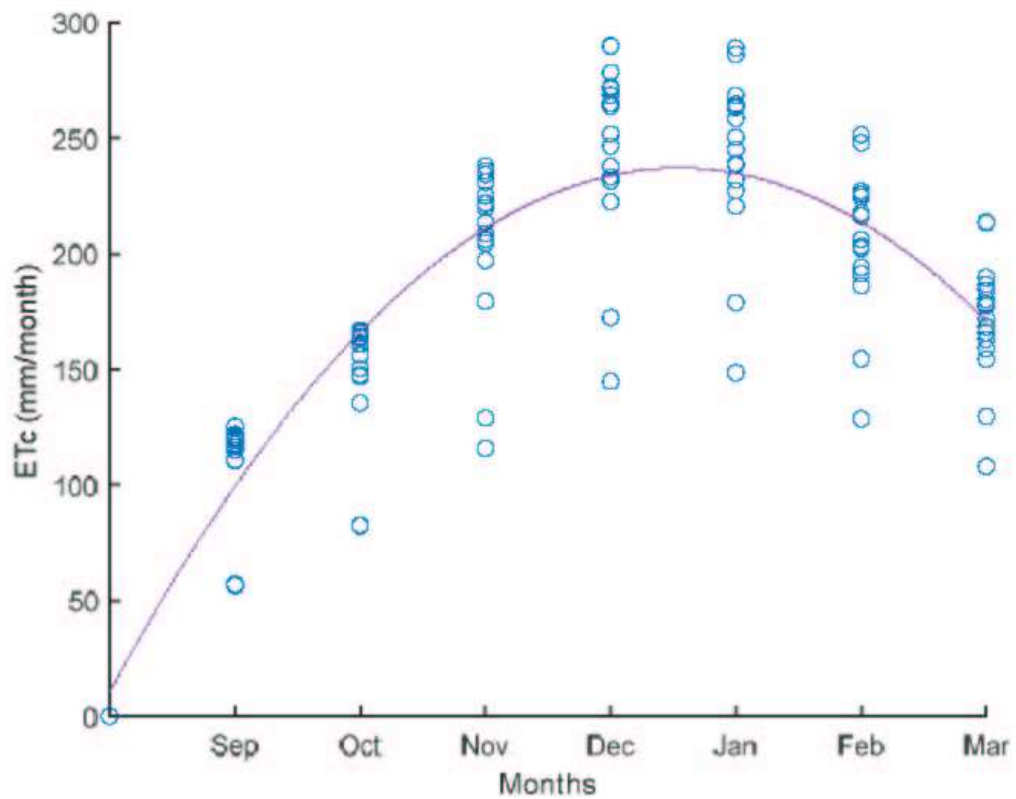


Figure 3.7a: Jatropha ETc as projected by different climate change models from the CMIP 5 project

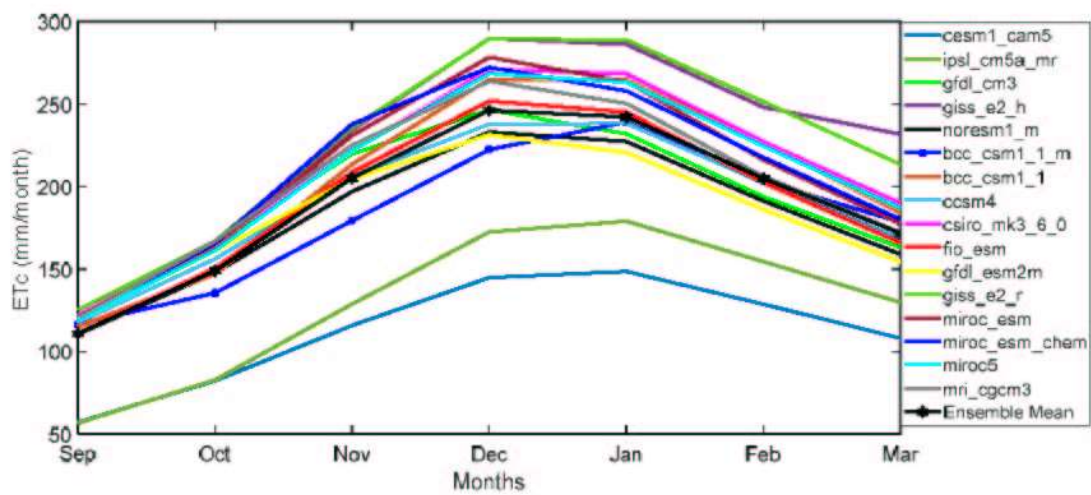


Figure 3.7b: Jatropha ETc in different developmental stages as projected by climate change models (bcc_csm1_1_m is used in this study)

4.0 Discussion

The study investigated the possible effects of climate change on ETo, effective rainfall and

consequently, *Jatropha* water requirements in the semi-arid conditions of Botswana. Temperature increase, high rates of evapotranspiration, variable rainfall patterns in synergy with other meteorological parameters may have detrimental impacts on crop water requirements (CWR) (Chowdhury *et al.* 2016) and available water (Manasa and Shivapur, 2016). Different scenarios were postulated and tested in this study. By generating a range of possible outcomes, this can show how likely different scenarios are to happen in the days ahead. The study indicated that ETo was in the range of 3.23 mm/day to 7.44 mm/day from 1986-2017 (baseline) and it was estimated to be in the range of 3.66 mm/day to 8.22 mm/day from 2020-2039 (S3). The highest ETo is mostly experienced between September and October, which is taken as the beginning of the growing season in Botswana. The variation in ETo is mainly attributed to high ambient temperature and low relative humidity coupled with meagre rainfall usually experienced throughout the year in the country. When temperatures are high, stomata open, therefore allowing the rate of transpiration to increase (Pallas *et al.* 1967; Mahajan *et al.* 2008). However, if temperatures remain high with limited water supply for long periods of time, eventually leading to drought, transpiration may be reduced to conserve water in the plant. In colder temperatures, the rate of transpiration is usually little as the stomata would have closed.

The results also indicate that effective rainfall will decrease due to climate change. Other factors influencing the effective rainfall include land topography, soil texture, fertility and structure, canopy cover or crop residue, storm intensity and duration (Dastane, 1974; Ali and Mubarak, 2017). If the rainfall is enough to meet the water needs of the crops, irrigation is not required. Conversely, if the rainfall is not enough to meet the water needs of the crops, irrigation water has to be supplied to supplement the rain in order to meet crop water needs (Ali and Mubarak, 2017). The reduction in the effective rainfall in the study area may indicate that much of the water received from the rain will be lost to the atmosphere through evapotranspiration due to high temperatures projected, rendering less water available for plant use. This indicates that irrigation water will be required.

After ETo, effective rainfall and CWR have been determined. From the results, CWR showed an increasing pattern from 10300 m³/ha/year to 12750 m³/ha/year under different climate scenarios with the same level of production. The high CWR is estimated to be during the middle stage development. During the middle stage, the canopy cover is expected to be at its peak; crop water requirements tend to increase at periods of active vegetative growth and yield formation due to the processes of cell division, cell enlargement and differentiation which together are responsible for cell growth and development. For these processes to be effectively carried out, sufficient water is required because of their dependence upon turgor (Hopkins, 1999; Jones, 2013; Tiwari *et al.* 2013). This is consistent with previous reports (Allen *et al.* 1998; Al-Kaisi and Broner, 2009) that the critical water requirements of crops tend to be high during the flowering and periods following yield formation.

The overall increase in CWR may be attributed to high temperatures and projected low rainfall in the future as shown in Figure 4. As the rate of evapotranspiration increases the amount of water needed to replenish the lost water also increases (Allen *et al.* 1998). An increase in CWR for the same level of production may increase water scarcity problems in countries with semi-arid conditions like Botswana. This implies that policymakers need to carefully plan and allocate water resources to avoid competition with other water users. Thus, increased agricultural production for water footprint intensive biofuels will have a significant impact on water resources in areas where they are already stressed. Additionally, there could be negative effects on water availability for general use by the growing population (National

Research Council, 2008; Diaz-Chavez *et al.* 2010). Results obtained from this study are consistent with those of the study conducted by Chowdhury *et al.*(2016) on the implications of climate change on crop water requirements of different crops in an arid region, specifically Saudi Arabia. In Saudi Arabia, ETo was estimated to be in the range of 2.6-10.9 mm/day in 2011 and the future (2020-2039) prognosis was in the range of 2.8-11.5 mm/day. The study suggested water-saving technologies such as greenhouse cultivation in the future to reduce the rate of evapotranspiration, subsequently, crop water requirements. Values obtained in Saudi Arabia are not surprising, as much of the country is a desert. In their study, they also found that CWR increased with the increasing temperature mainly due to the minimal change in rainfall patterns. They recommended alternative cultivation methods (e.g. greenhouse cultivation) to minimise the effects of temperature on the overall CWR. Studies conducted in India and Texas also showed that reference evapotranspiration values and crop water requirement will increase in the future climate as compared to the baseline scenario. The outcomes of these studies could help policymakers and water resource planners of the respective countries for future planning and ways to save water in satisfying crop water requirement (Manasa and Shivapur, 2016). The CWR of crops such as maize, wheat, sugarcane and cotton showed an increasing pattern in the future scenario (Parekh and Prajapati, 2013; Mohan and Ramsundram, 2014; Manasa and Shivapur, 2016; Awal *et al.* 2018). Similar results whereby crop water requirements increased with the changing future climate were obtained in Northern Taiwan (Lee and Huang, 2014).

Zhou *et al.* (2017) also conducted a study on the impact of future climate change on regional crop water requirements in China. They found that ETo would increase by 4% to 7%; ETc and CWR will also increase at different magnitudes depending on the crop type. The crop irrigation requirement would increase because of the coefficient of the increase of CWR and the decrease of effective precipitation. Thus, future climate change will bring greater challenges to regional agricultural water use (Zhou *et al.* 2017).

Different management practices are, however, currently being utilised to adapt crop production to a changing climate and increase crop water use efficiency (Ashofteh *et al.* 2017; Rivera *et al.* 2018). Adaptation strategies include the use of water-efficient irrigation systems, cultivation of stress-resistant varieties, and shifting of the planting dates (Iglesias and Garrote, 2015; Jägermeyr *et al.* 2016; Ashofteh *et al.* 2017). The latter is the strategy evaluated in this paper. Aligning the planting date to overlap with rainfall patterns is recognised as a strategy that is promising for water-stressed environments (Debaeke and Aboudrare, 2004; Nouri *et al.* 2017). Shifting the planting dates of *Jatropha* may also help in water conservation strategies as it has been demonstrated in S1 and S3. An exception is for baseline and S2; water requirement increased as planting dates were shifted. The results indicate that to save irrigation water in *Jatropha* cultivation, shifting planting dates may be advisable for future *Jatropha* production. However, other factors should be taken into consideration before shifting planting dates. These other factors include crop yield, pests, and diseases, winter period, fixed costs, and market. Temperature increase showed a positive influence on CWR. An increase of 1°C results in a 3.35 % increase in CWR. Plants have natural mechanisms that respond to high-temperature effects. Through a mechanism known as transpiration, plants cool themselves by removing water vapour from them through the stomata. High temperatures can cause a plant to exhaust water supplies in this process; or to close its leaf pores (stomata) to prevent water loss, but in so doing it reduces the potential for absorbing CO₂ which is needed for photosynthesis. This may result in low yields. To maintain the equilibrium between the plant and the atmosphere, more water may be needed which may be supplied by irrigation. This indicates that proper timing of planting is very crucial in water management and planning under the pressures of a

changing climate. Water management strategies will also help Botswana to achieve some of its water policy objectives: the promotion of effective, sustainable management of water resources and promotion of the equitable and efficient use of water resources.

Generally, future climatic conditions indicate a high-water requirement compared to the current conditions. Often models are used as a tool to foresee future scenarios. However, several uncertainties are always attached to the projected climate change scenarios (Haensler *et al.* 2013). To reduce uncertainties associated with models, several datasets from different models are used in studies to give the robustness of the selected model outputs (Haensler *et al.* 2013). The uncertainty associated with every forecast means that different scenarios are possible, hence different models are evaluated to reduce the dependence on one model which might be misleading. To assess the robustness of the projected changes, firstly different model projections have to be in agreement in terms of the direction of change and secondly, the magnitude of the projected change is considered. (Solomon *et al.* 2007). Results from different models used in this study followed the same pattern. This clearly indicates that consensus among models is an imperative factor to consider when assigning confidence to projections made. Model projections ranged between 224.56 mm/month and 112.21 mm/month. A range provides the possible outcomes of the projections made. To summarise the models, an ensemble mean was calculated. Individual climate model projections should not be viewed as an exact picture of future climate, especially since multiple projections even from the same model do not agree. The ensemble mean is therefore vital to give the general overview of the models.

5.0 Conclusion

This study provided baseline information on the possible implications of climate change on ETo, effective rainfall and Jatropha water requirements in the semi-arid conditions of Botswana. The findings suggest that the future projected temperature and rainfall will increase the rate of ETo, effective rainfall, and consequently Jatropha water demand. Therefore, there will be an increase in irrigation water requirements in the future as compared to the baseline period (1986-2017). High irrigation water needed in biofuel production may reduce water available for arable agriculture and this may jeopardise food production. Therefore, the allocation of resources to the production of Jatropha biofuel should be subjected to perusal and stringent cost-benefit analysis. Shifting planting dates of Jatropha could be adopted for future Jatropha cultivation, for the production to be sustainable provided other factors interacting with or influencing crop productivity are taken into consideration. There is confidence in GCMs as all the models used in the study followed the same direction and pattern; therefore, GCMs can confidently be used to give the future scenario projections.

6.0 Acknowledgments

This study was part of the co-research project between Botswana and Japan which aimed at creating a bio-energy (biofuel) production model based on biological resources available in Botswana. Therefore, the authors would like to acknowledge the financial support provided by Japan International Cooperation Agency (JICA) through the Government of Botswana for this project.

7.0 References

- Al-Kaisi, M.M., Broner, I. 2009. Crop water use and growth stages. Colorado State University Extension. Ali, M., Mubarak, S. 2017. Effective rainfall calculation methods for field crops: An Overview, Analysis and New Formulation. Asian Res. J.

- Agric 7, 1-12.
- Allen, M.R., Barros, V.R., Broome, J., Cramer, W., Christ, R., Church, J.A., Clarke, L., Dahe, Q., Dasgupta, P. and Dubash, N.K. 2014. IPCC fifth assessment synthesis report-climate change 2014 synthesis report.
- Allen, R.G., Pereira, L.S., Raes, D., Smith, M. 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Fao, Rome 300, D05109.
- Ashofteh, P.-S., Bozorg-Haddad, O., Loáiciga, H.A. 2017. Development of adaptive strategies for irrigation water demand management under climate change. *Journal of Irrigation and Drainage Engineering* 143, 04016077.
- Awal, R., Fares, A., Bayabil, H. 2018. Assessing Potential Climate Change Impacts on Irrigation Requirements of Major Crops in the Brazos Headwaters Basin, Texas. *Water* 10, 1610.
- Barrow, E., Maxwell, B., Gachon, P. 2004. Climate variability and change in Canada. Past, present and future. ACSD Science Assessment Series. Environment Canada, Toronto, Ontario.
- Chowdhury, S., Al-Zahrani, M., Abbas, A. 2016. Implications of climate change on crop water requirements in arid region: An example of Al-Jouf, Saudi Arabia. *Journal of King Saud University - Engineering Sciences* 28, 21-31.
- Climate Change Knowledge Portal. 2019. World Bank Group.
- Connor, R. 2015. The United Nations world water development report 2015: water for a sustainable world. UNESCO Publishing.
- Darkoh, M.B. 1999. Desertification in Botswana. Case studies of rangeland desertification. *Rekjavik, Agricultural Research Institute*, 61-74.
- Dastane, N. 1974. Effective rainfall in irrigated agriculture.
- Debaeke, P., Aboudrare, A. 2004. Adaptation of crop management to water-limited environments. *European Journal of Agronomy* 21, 433-446.
- Diaz-Chavez, R., Mutimba, S., Watson, H., Rodriguez-Sanchez, S., Nguer, M. 2010. Mapping Food and Bioenergy in Africa. A report prepared on behalf of FARA. Forum for Agricultural Research in Africa. Ghana. ERA-ARD, SROs, FARA, 3.
- Dieter, C.A. 2018. Water Availability and Use Science Program: Estimated Use of Water in the United States In 2015. Geological Survey.
- Downing, T.E., Ringius, L., Hulme, M., Waughray, D. 1997. Adapting to climate change in Africa. Mitigation and adaptation strategies for global change 2, 19-44.
- Elgaali, E., Garcia, L., Ojima, D. 2006. Sensitivity of irrigation water balance to climate change in the great plains of Colorado. *Transactions of the ASABE* 49, 1315-1322.
- Frenken, K. 2005. Irrigation in Africa in figures: AQUASTAT Survey, 2005. Food & Agriculture Org.
- Government of Botswana, 2016a. Botswana water accounting report 2014/15 Final report.
- Government of Botswana, 2016b. Draft National Development Plan 11 (April 2017- March 2023) Gaborone: Ministry of Finance and Development Planning.
- Haensler, A., Saeed, F., Jacob, D. 2013. Assessing the robustness of projected precipitation changes over central Africa on the basis of a multitude of global and regional climate projections. *Climatic Change* 121, 349-363.
- Hartmann, D.L. 2015. Global physical climatology. Newnes.
- Hopkins, W.G. 1999. Introduction to plant physiology. John Wiley and Sons.
- Huang, H., Han, Y., Song, J., Zhang, Z., Xiao, H. 2016. Impacts of climate change on water

- requirements of winter wheat over 59 years in the Huang-Huai-Hai Plain. *Soil and Water Research* 11, 11-19.
- Iglesias, A., Garrote, L. 2015. Adaptation strategies for agricultural water management under climate change in Europe. *Agricultural water management* 155, 113-124.
- IPCC, 1996. *Climate Change 1995, A report of the Intergovernmental Panel on Climate Change*. Geneva: World Meteorological Organization.
- Jägermeyr, J., Gerten, D., Schaphoff, S., Heinke, J., Lucht, W., Rockström, J. 2016. Integrated crop water management might sustainably halve the global food gap. *Environmental Research Letters* 11, 025002.
- Jensen, M.E., Allen, R.G. 2016. Evaporation, evapotranspiration, and irrigation water requirements. *American Society of Civil Engineers*.
- Jensen, M.E., Burman, R.D., Allen, R.G. 1990. Evapotranspiration and irrigation water requirements. *ASCE*.
- Jones, C., Robertson, E., Arora, V., Friedlingstein, P., Shevliakova, E., Bopp, L., Brovkin, V., Hajima, T., Kato, E., Kawamiya, M. 2013. Twenty-first-century compatible CO₂ emissions and airborne fraction simulated by CMIP5 earth system models under four representative concentration pathways. *Journal of Climate* 26, 4398-4413.
- Jones, M. 2013. *The grass crop: the physiological basis of production*. Springer Science & Business Media.
- Kweku, D.W., Bismark, O., Maxwell, A., Desmond, K.A., Danso, K.B., Oti-Mensah, E.A., Quachie, A.T., Adormaa, B.B. 2017. Greenhouse Effect: Greenhouse Gases and Their Impact on Global Warming. *Journal of Scientific Research and Reports*, 1-9.
- Lalic, B., Francia, M., Jacimovic, G. 2013. Assessment of climate change impact on crop water requirements in Serbia in 2030 using CROPWAT model. *International scientific conference environmental changes and adaptation strategies*. 9th-11th September.
- Lee, J.-L., Huang, W.-C. 2014. Impact of climate change on the irrigation water requirement in Northern Taiwan. *Water* 6, 3339-3361.
- Leggett, J. 1990. *Global warming: the Greenpeace report*. Oxford University Press.
- Mahajan, P., Oliveira, F., Macedo, I. 2008. Effect of temperature and humidity on the transpiration rate of the whole mushrooms. *Journal of Food Engineering* 84, 281-288.
- Manasa, H., Shivapur, A.V. 2016. Implications of climate change on crop water requirements in Hukkeri Taluk of Belagavi District, Karnataka, India. *Int J Res Eng Technol* 5, 236-241.
- Mitchell, J.F. 1989. The “greenhouse” effect and climate change. *Reviews of Geophysics* 27, 115-139.
- Mohan, S., Ramsundram, N. 2014. Climate change and its impact on irrigation water requirements on temporal scale. *Irrigation & Drainage Systems Engineering* 3, 1-8.
- Morison, J.I., Baker, N.R., Mullineaux, P.M., Davies, W.J. 2008. Improving water use in crop production. *Philos Trans R Soc Lond B Biol Sci* 363, 639-658.
- Moroke, T., Pule-Meulenberg, F., Mzuku, M., Patrick, C., Kashe, K. 2010. *Water Harvesting and Conservation Techniques for Dryland Crop Production in Botswana: A Review*. Ama, *Agricultural Mechanization in Asia, Africa & Latin America* 41, 9.
- National Research Council, 2008. *Water implications of biofuels production in the United States*. National Academies Press.
- Nouri, M., Homaei, M., Bannayan, M., Hoogenboom, G. 2017. Towards shifting planting date as an adaptation practice for rainfed wheat response to climate change.

- Agricultural water management 186, 108-119.
- Pachauri, R.K., Reisinger, A. 2007. IPCC fourth assessment report. IPCC, Geneva 2007.
- Pallas, J.E., Michel, B.E., Harris, D.G. 1967. Photosynthesis, transpiration, leaf temperature, and stomatal activity of cotton plants under varying water potentials. *Plant Physiology* 42, 76-88.
- Parekh, F., Prajapati, K.P. 2013. Climate change impacts on crop water requirement for Sukhi reservoir project. *Int. J. Innov. Res. Sci. Eng. Technol* 2, 2-10.
- Parry, M. 2002. Scenarios for climate impact and adaptation assessment. *Global Environmental Change* 12, 149-153.
- Parry, M., Parry, M.L., Canziani, O., Palutikof, J., Van der Linden, P., Hanson, C. 2007. Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCC. Cambridge University Press.
- Rajaona, A., Sutterer, N., Asch, F. 2012. Potential of waste water use for *Jatropha* cultivation in arid environments. *Agriculture* 2, 376-392.
- Rao, A.K., Wani, S.P., Singh, P., Srinivas, K., Rao, C.S. 2012. Water requirement and use by *Jatropha curcas* in a semi-arid tropical location. *Biomass and Bioenergy* 39, 175-181.
- Rao, V., Rao, A., Rao, G., Satyanarayana, T., Manikandan, N., Venkateshwarlu, B. 2011. Impact of climate change on crop water requirements and adaptation strategies. *Challenges and Opportunities in Agrometeorology*. Springer, pp. 311-319.
- Rivera, A., Gunda, T., Hornberger, G.M. 2018. Minimizing irrigation water demand: An evaluation of shifting planting dates in Sri Lanka. *Ambio* 47, 466-476.
- Sato, T., Kimura, F., Kitoh, A. 2007. Projection of global warming onto regional precipitation over Mongolia using a regional climate model. *Journal of Hydrology* 333, 144-154.
- Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., Schaeffer, M., Perrette, M., Reinhardt, J. 2017. Climate change impacts in Sub-Saharan Africa: from physical changes to their social repercussions. *Regional Environmental Change* 17, 1585-1600.
- Shibuo, Y., Jarsjö, J., Destouni, G. 2007. Hydrological responses to climate change and irrigation in the Aral Sea drainage basin. *Geophysical Research Letters* 34.
- Shiklomanov, I.A., Rodda, J.C. 2004. World water resources at the beginning of the twenty-first century. Cambridge University Press.
- Shindell, D., Myhre, G., Boucher, O., Forster, P., Breon, F.-M., Fuglestedt, J. 2013. Radiative Forcing in the AR5. Conference Proceeding in IPCC AR5 working group I, pp. 1-11.
- Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. 2007. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Song, L., Oeurng, C., Hornbuckle, J. 2015. Assessment of Rice Water Requirement by Using CROPWAT Model. The 15th Science Council of Asia Board Meeting and International Symposium. Botswana, 2018. INTERNATIONAL MERCHANDISE TRADE STATISTICS Monthly Digest.
- Stocker, T., 2014. Climate change 2013: the physical science basis: Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
- Sutterer, N. 2010. *Jatropha* cultivation using treated sewage effluent. Institute for Plant production and Agroecology in the tropics and Subtropics. Crop waterstress

- management in the Tropics and Subtropics. Hohenheim University. Germany. MSc. dissertation 59.
- The World Bank, 2018. Metadata of the Climate Change Knowledge Portal. The World Bank Documents.
- Tiwari, N., Purohit, M., Sharma, G., Nautiyal, A. 2013. Changes in Morpho-Physiology of *Jatropha curcas* grown under different water regimes. *Nat. Sci* 11, 76-83.
- Van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J.-F. 2011. The representative concentration pathways: an overview. *Climatic change* 109, 5.
- Watson, R.T., Zinyowera, M.C., Moss, R.H., Dokken, D.J. 1998. The regional impacts of climate change. An assessment of vulnerability: A Special Report of IPCC Working Group II, 517.
- Wu, T., Song, L., Li, W., Wang, Z., Zhang, H., Xin, X., Zhang, Y., Zhang, L., Li, J., Wu, F., 2014. An overview of BCC climate system model development and application for climate change studies. *Journal of Meteorological Research* 28, 34-56.
- Zhou, T., Wu, P., Sun, S., Li, X., Wang, Y., Luan, X. 2017. Impact of future climate change on regional crop water requirement—A case study of Hetao Irrigation District, China. *Water* 9, 429.

Chapter 4: Regards historiques et recents sur le contexte climatique de la region de Fatick au Sénégal

Ibrahima Mbaye

Université Assane SECK de Ziguinchor, UFR des Sciences et Technologies,
Département de Géographie, Laboratoire de Géomatique et d'Environnement; BP 523
Ziguinchor/Sénégal
Tél. : + 221 77 616 89 20
imbaye@univ-zig.sn

Introduction

En Afrique de l'Ouest, la plupart des projections inhérentes aux changements climatiques sont favorables à une récurrence de la sécheresse au Sahel (Biasutti et Giannini, 2006). L'importance du climat gagne donc, de plus en plus du terrain du fait des événements extrêmes (tempêtes, vagues de chaleur, nuages de poussières éoliennes en suspension dans l'atmosphère, ...), de la déprise agricole, du déplacement massif de population et des risques sanitaires, parfois traumatisants, qu'il induit (Mbaye, 2018). Dans les milieux secs soudano-sahéliens de l'Afrique de l'Ouest en général et du Sénégal en particulier, la sécheresse (notamment la raréfaction de l'eau et du capital végétal), constitue, le véritable déterminant climatique qui sous-tend les crises agricole alimentaire (Mbaye, 2017) Au Sénégal, la baisse de la pluviométrie moyenne annuelle varie entre 7 et 24 % (Niasse *et al.* 2004). Le contexte bioclimatique coercitif de la région de Fatick (déficit pluviométrique, profondeur accentuée de la nappe phréatique, salinisation des terres...), combiné à la précarité des conditions de vie, exposent les populations aux effets multiplicateurs du changement climatique et annihilent leur capacité d'adaptation et de résilience. L'Observatoire de Niakhar, site sentinelle en Population, Santé et Environnement de l'Institut de Recherche pour le Développement (IRD), est l'exemple le plus achevé.

Le site de Niakhar est situé au cœur du bassin arachidier, dans la région de Fatick. Il est sous l'influence du domaine climatique sahélien, correspondant à la partie la plus aride et la plus chaude du pays. Les précipitations sont très faibles et varient entre 100 et 500 mm/an sur une période de 3 à 4 mois (Leroux et Sagna, 2000). L'insécurité alimentaire et les problèmes nutritionnels y sévissent avec acuité. Les vents de sable, associés à des températures élevées et à la siccité de l'air ambiant pendant la saison sèche, sont caractéristiques du type de temps d'harmattan, favorable à l'apparition de la méningite. (Mbaye *et al.*, 2004).

L'objectif de Cette étude est de comprendre le contexte climatique de la région de Fatick à travers la production d'indicateurs environnementaux pertinents pouvant aider dans le plan d'actions décisionnel des autorités locales.

1. Présentation de la zone d'étude

La région de Fatick est située au centre du Sénégal, dans la zone écogéographique du bassin arachidier. Elle correspond historiquement au royaume du Sine et à une partie du Saloum. La région de Fatick est limitée à l'Est par la région de Kaolack, à l'Ouest par l'Océan Atlantique, au Nord et Nord Est par les régions de Diourbel et de Louga, au Nord-Ouest par la région de Thiès, au Sud par la Gambie (Figure 4.1). Elle compte trois Départements (Fatick, Foundiougne, Gossas), neuf (09) arrondissements (Diakhao, Fimela, Niakhar, Tattaguine, Djilor, Niodior, Toubacouta, Colobane, Ouadiour), vingt-huit (28) communautés rurales, et

de Grimm, hyènes tachetés, singes verts...), de l'avifaune sédentaire (tourterelles, pigeons verts, pintades Francolins...) et de celle migratrice (oies de Gambie, ibis sacrés, flamants roses, canards ...).

Depuis sa création en 1984, la population de la région a connu une croissance lente passant de 509 702 habitants en 1988 à 615 558 habitants en 2002. Selon les résultats du Recensement Général de la Population, de l'Habitat, de l'Agriculture et de l'Élevage (RGPHAE), réalisé en 2013, elle s'établit à 714 389 habitants, soit 5,3% de la population nationale. Elle représente ainsi, la septième région la plus peuplée du Sénégal derrière Dakar, Thiès, Diourbel, Kaolack, Saint-Louis et Louga.

Fatick est une région à vocation agro-pastorale avérée avec 90% d'agriculteurs et 69% d'éleveurs (RGPHAE, 2013). Comme la plupart des régions de l'intérieur du pays, Fatick est caractérisée par une morosité économique, marquée par une timidité des activités. Le tourisme, présente un intérêt manifeste pour le développement économique de la région. Cependant, malgré les immenses potentialités dont recèlent cette dernière, la salinisation des terres et l'avancée de la mer constituent de réels défis, compromettants l'activité agricole. Par ailleurs, l'aménagement et le développement du territoire constituent aussi un grand défi pour la région, confrontée à une désarticulation de son espace et des disparités dans la répartition spatiale des infrastructures et équipements de base. L'espace régional est fragmenté en 03 noyaux, adossés aux 03 Départements (Fatick, Foundiougne et Gossas), et leurs aires d'influence respectives. Gossas regroupe le pôle Nord avec Ouadiour et Colobane; Fatick concentre Diakhao, Niakhar et Tattaguine; Foundiougne polarise le pôle Sud avec Palmarin, Fimela et Diofior. Les conséquences de cette désarticulation sont assez lourdes, la région de Fatick souffre d'une grande discontinuité territoriale qui l'empêche de s'épanouir et d'exercer pleinement tous les rôles de pôle régional.

Aujourd'hui avec le nouveau contexte marqué par l'Acte 3 de la décentralisation et la territorialisation des politiques publiques, une nouvelle donne s'ouvre à la région. Il faudrait doter les Départements et les communes d'outils de planification spatiale en corrélation avec la planification économique.

2. Données et méthodes

Les données de pluviométrie et de température moyennes mensuelles que nous avons collectées concernent celles de la station météorologique de référence de Fatick et des postes pluviométriques de Foundiougne et de Gossas. Elles proviennent de l'Agence Nationale de l'Aviation Civile et de la Météorologie (ANACIM), basée à Dakar au Sénégal. Les données pluviométriques disponibles couvrent la série 1950-2014. Les données pluviométriques homogènes et cohérentes de Foundiougne et de Gossas couvrent respectivement les séries 1970-2011 et 1950-2008.

Les données relatives à la température et à l'humidité relative moyennes de l'air, collectées et disponibles pour la station de Fatick couvrent la série 1991-2014.

Nous avons lissé la pluviométrie standardisée avec une moyenne mobile décennale et utilisé l'indice sahélien de Lamb afin de mieux apprécier la variabilité interannuelle à inter-décennale de la pluviométrie dans les Départements de Fatick, Foundiougne et Gossas. Nous pouvons donc distinguer les anomalies positives (années humides), des anomalies négatives (années sèches) des différentes séries pluviométriques.

L'indice se calcule selon l'équation suivante : $I = \frac{(x_i - \bar{x})}{\delta}$; sachant que x_i est le cumul pluviométrique de l'année i ; \bar{x} est la moyenne de la pluie annuelle de la période considérée et

δ est l'écart type de la série pluviométrique. Par ailleurs, nous avons comparé des séries de température moyenne mensuelle de l'air à Fatick.

Existe-t-il des indicateurs environnementaux permettant d'apprécier l'évolution du contexte climatique de la région de Fatick ?

3 Résultats et discussion

3.1 Description du domaine climatique sahélien sénégalais

En Afrique de l'Ouest, les caractéristiques climatiques majeures sont entre autres, la variabilité spatiale et temporelle des précipitations (De Felice, 1999) et la baisse de la pluviométrie (Morel, 1988). Cette variabilité et ce déficit pluviométrique affectent à différentes échelles, aussi bien le régime des pluies que les hauteurs d'eau déversées par la mousson (Fontaine, 1986). A l'échelle nationale, le Sénégal ne se déroge pas de ces dynamiques géographique et aérologique (Leroux, 1983; Sagna, 2005). La première (dynamique géographique) s'exprime d'une part, par la latitude qui confère au territoire des caractères tropicaux et d'autre part, la position de Finistère Ouest africain du pays, qui détermine les conditions climatiques différenciées selon la localisation de la station météorologique (littorale ou continentale). En revanche, la deuxième (dynamique aérologique) s'exprime par l'alternance sur le pays des flux de mousson et d'alizé dont les déplacements sont facilités par la platitude du relief. Ainsi, la variabilité spatio-temporelle de la pluviométrie qui s'associe à ces dynamiques, permet de distinguer trois domaines climatiques au Sénégal : les domaines sud soudanien, nord soudanien et sahélien (figure 4.2).

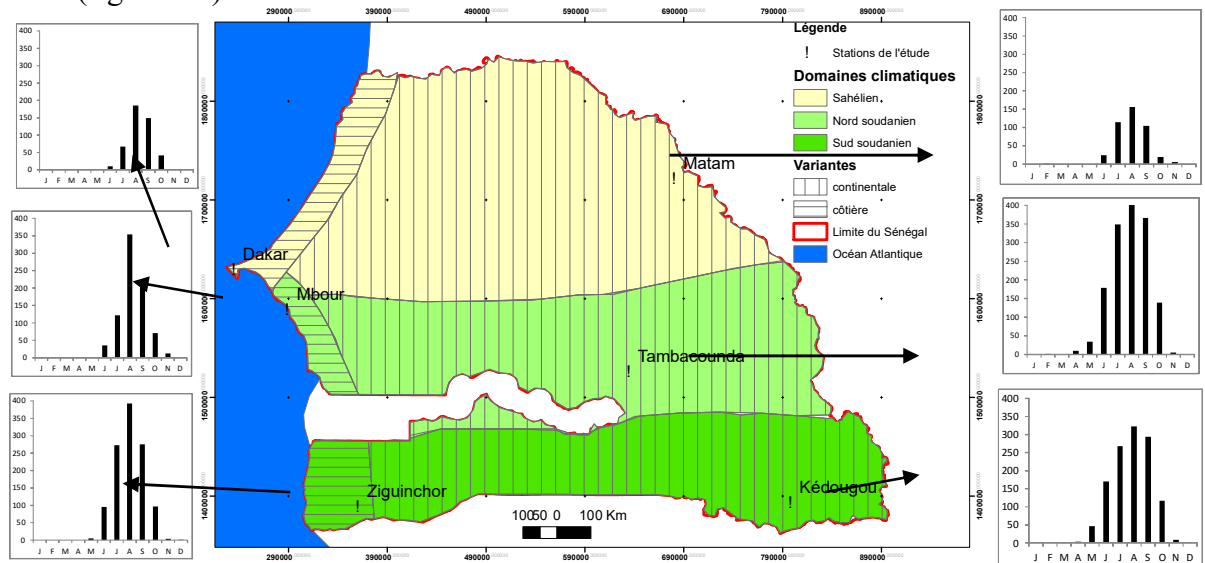


Figure 4.2: Localisation des domaines climatiques du Sénégal et des stations de l'étude

Le domaine sahélien sénégalais couvre le bassin arachidier, le Ferlo et une partie de la moyenne vallée du Sénégal. C'est la partie la plus aride et la plus chaude du pays. Les précipitations sont très faibles et varient globalement entre 100 et 500 mm/an sur une période de 3 à 4 mois (Leroux *et al.* 2000).

La faiblesse de l'apport pluviométrique irrégulier du flux de mousson, se traduit par l'avènement des vents de sable, particulièrement désastreux pour l'environnement et contraignants pour l'organisme humain. La station météorologique de Fatick, située au cœur du bassin arachidier est un exemple assez illustratif des caractéristiques climatiques du sahel sénégalais.

3.2 Caractérisation du contexte climatique de la région de Fatick

Le contexte climatique de la région de Fatick est caractérisé par une variabilité interannuelle de la pluviométrie et de la température moyenne de l'air dans les différents Départements qui la composent. La variabilité de la pluviométrie est marquée dans le domaine côtier maritime (Fatick et Foundiougne) par une tendance générale à la hausse (figures 4.3 et 4.4).

Dans le Département de Fatick, la saison pluvieuse de 2012 est marquée par des précipitations relativement appréciables avec une hauteur d'eau moyenne de 922,5mm (43 jours en moyenne sur période de 90 jours). Comparée à celle de 2011 qui est de 476,4mm, nous observons un excédent de 446,1mm.

Dans le Département de Foundiougne, l'hivernage de 2010 se distingue avec une hauteur d'eau moyenne de 819 mm (39 jours en moyenne sur une période 90 jours). Comparée à celle de 2009, qui est de 610,4mm, nous observons une importante augmentation de 209,4mm.

Ce contexte climatique est justifié par l'influence adoucissante de la mer, l'insularité du milieu (îles du Saloum), l'exubérance de la mangrove et les nombreuses ressources en eau pérennes de surface.

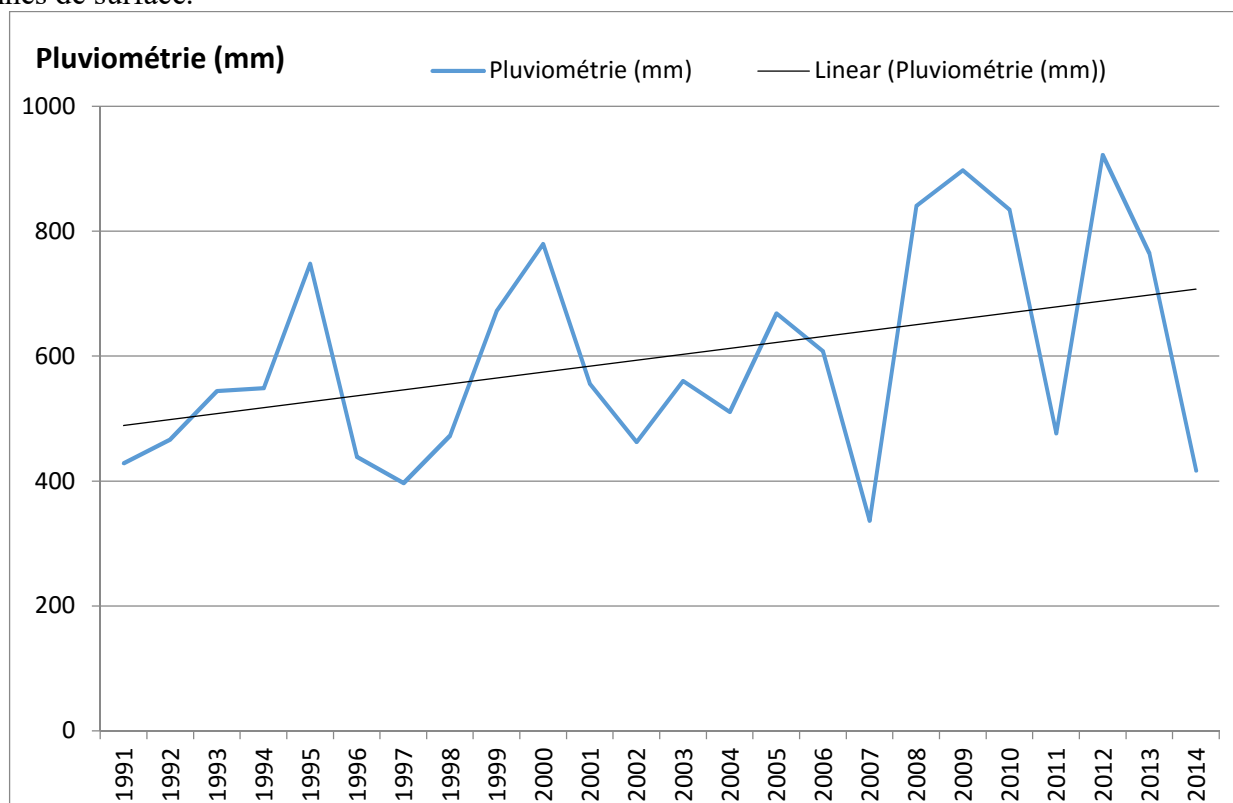


Figure 4.3: Variabilité interannuelle de la pluviométrie à Fatick de 1991 à 2014

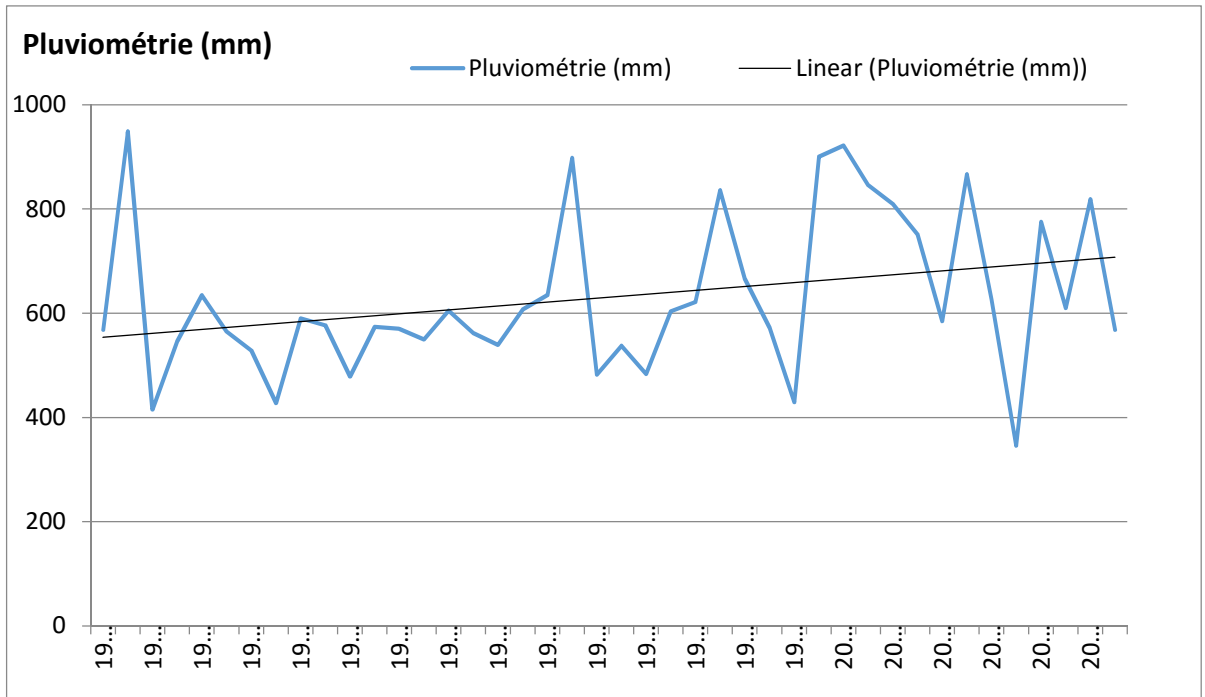


Figure 4.4: Variabilité interannuelle de la pluviométrie à Foundiougne de 1970 à 2011

Par exemple la dernière décennie de la série climatologique 1991-2014, est marquée par une période humide, attestée par la prédominance des anomalies positives (années humides) qui se distinguent avec 70% des observations, contre 30% pour les anomalies négatives (figure 4.5). Cela signifie que nous assistons à un retour progressif à la normale de la pluviosité dans le Département de Fatick.

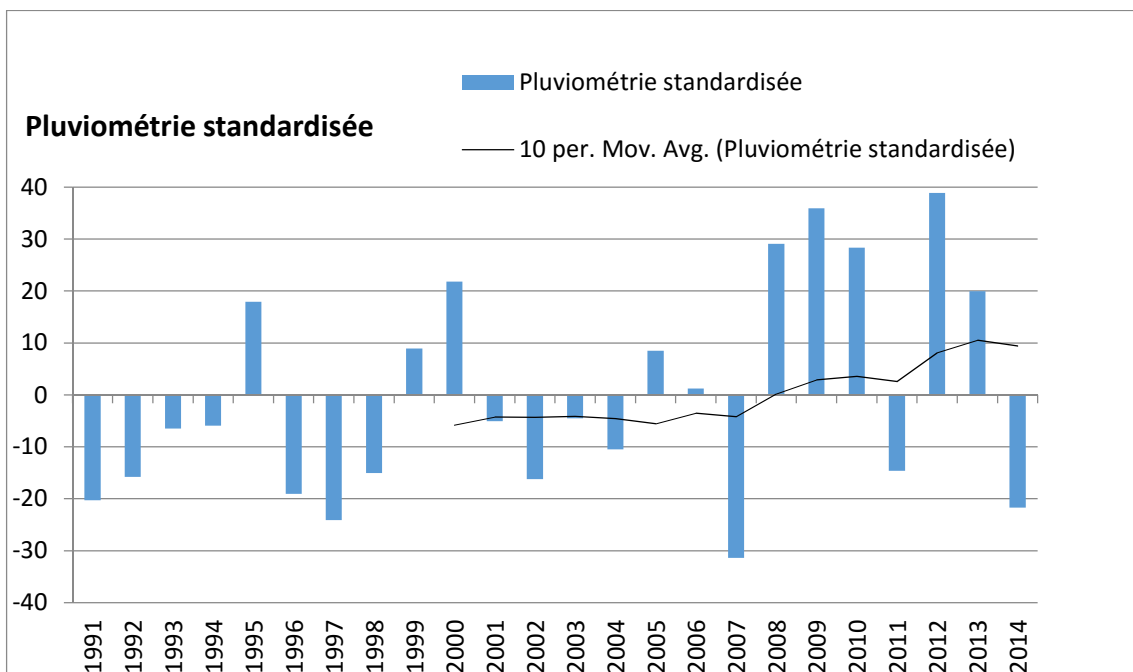


Figure 4.5 : Variabilité interannuelle de la pluviométrie standardisée à Fatick de 1991 à 2014

Dans le Département de Gossas, la baisse tendancielle de la pluviométrie (figure 4.6) est corrélée à la continentalité du milieu, très sec, caractérisé par une végétation rabougrie pendant la saison pluvieuse. Les ressources en eau de surface ne sont composées que de marigots et de mares temporaires. Toutefois, on note çà et là des années pluvieuses, comme c'est le cas en 2003, caractérisée par une pluviométrie relativement importante avec une hauteur d'eau moyenne de 547,3mm (42 jours en moyenne sur une période de 90 jours). Comparée à celle de 2002 qui est de 380 mm, nous observons une hausse de 167,3mm.

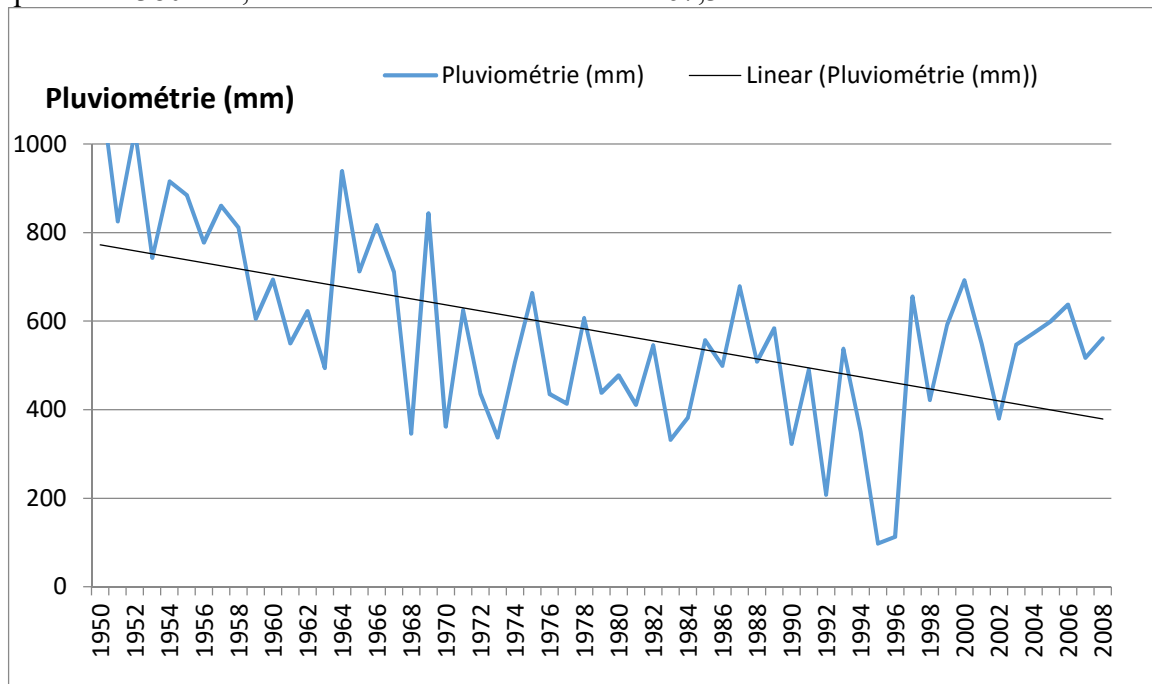


Figure 4.6: Variabilité interannuelle de la pluviométrie à Gossas de 1950 à 2008

L'analyse de l'évolution de la température moyenne de l'air à Fatick de 1991 à 2014, montre une légère augmentation tendancielle. Elle varie très faiblement entre 28 et 29° C (figure 4.7).

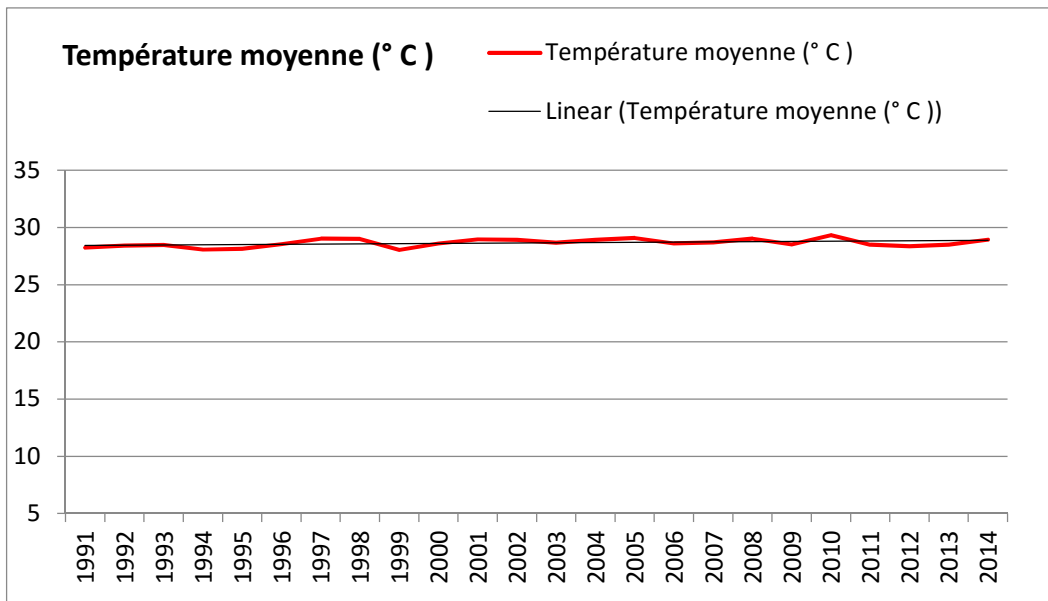


Figure 4.7: Variabilité interannuelle de la température moyenne de l'air à Fatick de 1991 à 2014

Par ailleurs, en comparant l'évolution de la température moyenne de l'air de la série 1991-2002 à celle de 2003-2014 (figure 4.8), nous avons constaté une variation positive de la température moyenne de l'air passant de 28,5°C à 28,7°C, soit une augmentation en moyenne de 0,2°C. Donc l'augmentation de la température de l'air semble être un indicateur environnemental de modification du contexte climatique de Fatick. Cette ambiance bioclimatique s'explique par l'avancée progressive de la désertification et du biseau salé, suite l'exploitation abusive du couvert végétal et de la recrudescence de l'érosion côtière.

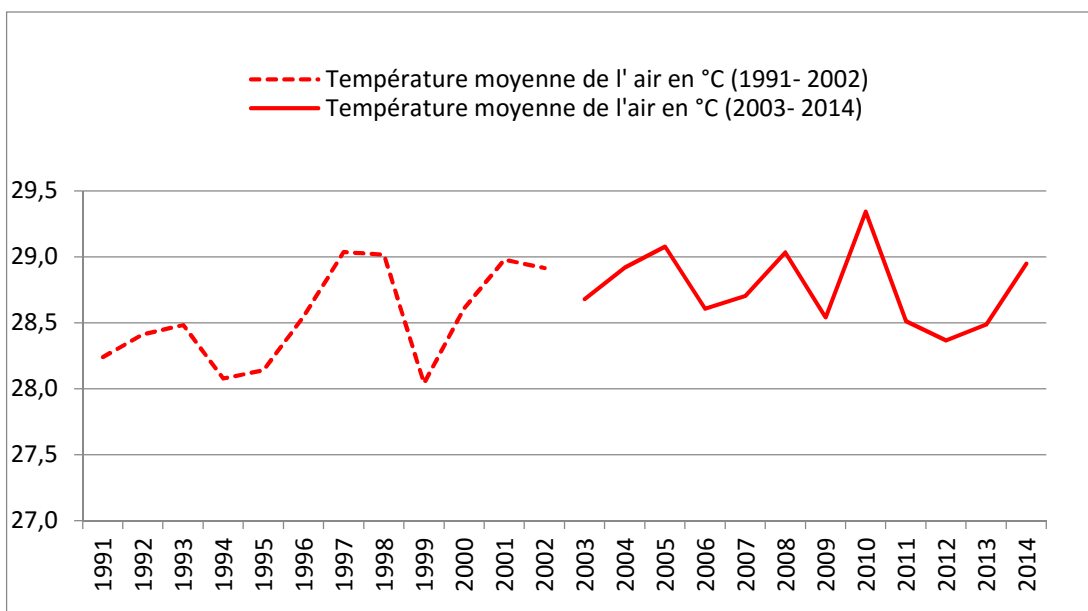


Figure 4.8: Variabilité interannuelle de la température moyenne de l'air à Fatick (1991-2002; 2003-2014)

Conclusion

En définitive, l'analyse du contexte environnemental de la région de Fatick, révèle dans son ensemble des caractéristiques climatiques hétérogènes selon les milieux, maritime ou continental.

Les Départements côtiers de Fatick et Foundiougne, sont caractérisés par une hausse tendancielle de la pluviométrie de 1970 à 2014 et un retour progressif de celle-ci à la normale. Dans le Département de Fatick, on passe de 476,4 mm en 2011 à 922,5 mm en 2012, soit une augmentation de 446,1 mm en valeur absolue et 48,35% en valeur relative. A Foundiougne, on passe de 610,4mm en 2009 à 819mm en 2010, soit une augmentation de 209,4mm en valeur absolue et de 34, 30% en valeur relative.

En revanche, au niveau du domaine continental, représenté par le Département de Gossas, nous constatons plutôt une baisse tendancielle, brutale et graduelle de la pluviométrie. On passe de 1131mm en 1950 à 562mm en 2008, soit une baisse de 569mm en valeur absolue et 50,30% en valeur relative.

La température moyenne de l'air se distingue à Fatick par une augmentation de 0,2°C. Cette hausse de la température, semble être un indicateur environnemental pertinent pour apprécier les modifications du contexte climatique de Fatick. Un tel indicateur peut probablement contribuer significativement dans le plan d'actions décisionnel de la gouvernance environnement durable de la région de Fatick.

Bibliographie

- Agence Nationale de la Statistique et de la Démographie, 2017. Recensement Général de la Population, de l'Habitat, de l'Agriculture et de l'Elevage (RGPHAE) de 2013. Rapport régional définitif, Région de Fatick, Avril, 114 P.
- Biasutti M, Giannini A. 2006. Robust Sahel drying in response to late 20th century forcings. *Geophys Res Lett* 33. doi: 10.1029/, GL026067.
- De Felice P. 1999. La pluie au Sahel. Harmattan. Collection Ecologie et Agronomie Appliquée, Paris, 146 p.
- Fontaine B. 1986. Précipitations soudano-sahéliennes et circulation estivale sur l'Afrique Occidentale et l'Atlantique-Nord. In *Etudes de climatologie tropicale*, éd. Masson. Centre de Recherches de Climatologie de l'Univ. de Dijon, 66-78.
- Leroux M. et Sagna P. 2000. Le climat du Sénégal. In *Atlas du Sénégal*. Ed. Jeune Afrique, Paris, : 16-19
- Leroux M. 1983. *Le climat de l'Afrique tropicale*, Thèse de doctorat d'Etat, Université, de Dijon, texte : 3 tomes, 1427 p, 1 atlas météorologique et climatologique, 250 cartes.
- Mbaye I. 2018. La recomposition des espaces urbain et périurbain face aux changements climatiques en Afrique de l'Ouest. Livre, Editions Harmattan, ISBN : 978-2-343-15410-7, EAN : 9782343154107, 293 p
- Mbaye I, 2017. Variabilité climatique et diffusion des rongeurs dans la région de Kédougou au Sud-Est du Sénégal. *Revue scientifique semestrielle, Territoires, Sociétés et Environnement/Faculté des Lettres et Sciences humaines/Université de Zinder*, N°009, Décembre, pp. 29-41.
- Morel R. 1988. Remarques à propos de l'effet des facteurs locaux sur la baisse de pluviométrie observée en Afrique de l'Ouest sur le Sahel. *Veille Climatique Satellitaire*, 23, pp 23-27.
- Mbaye I., Handschumacher P., Philippe J. 2004. Influence du climat sur les épidémies de méningite à méningocoque à Niakhar (Sénégal) de 1998 à 2000 et recherche d'indicateurs opérationnels en santé publique. *Environnement, Risques et Santé* ; 3 :

219-226.

- Niasse M., Afouda A., Amani A. 2004. Réduire la vulnérabilité de l'Afrique de l'Ouest aux impacts du climat sur les ressources en eau, les zones humides et la désertification – éléments de stratégie régionale de préparation et d'adaptation. Union Mondiale pour la Nature (UICN), 82 p.
- Sagna P. 2005. Dynamique du climat et de son évolution récente dans la partie ouest de l'Afrique occidentale. Thèse de Doctorat d'Etat, Université Cheikh Anta Diop de Dakar, 786 p.
- Sagna P. et Leroux M. 2000. Le climat. Les Atlas de l'Afrique : Sénégal. Paris, les Éditions Jeune Afrique, 4 p.

Section B: Environmental problems in Africa

Chapter 5: Influence of human management strategies on soil erosion in Nzhelele Valley, Limpopo Province, South Africa

Blessing Mavhuru^{1*}, Nthaduleni Nethengwe^{1*}, Hector Chikoore^{1*},
Onyango Beneah Daniel Odhiambo^{1*}

²University of Venda P/Bag X 5050, Thohoyandou, Limpopo Province, South Africa

*Corresponding author: bmavhuru@yahoo.com

Abstract

Strategies to combat soil erosion have been identified as one of the major solutions to providing means of production in many agricultural areas. However, modern technological advancement and increases in population growth present major environmental threats through increasing the rate of soil erosion. Understanding land use activities helps to determine factors that cause soil erosion. This research therefore aims to determine the influence of human management strategies on soil erosion in the Nzhelele Valley. Semi-structured questionnaires and interviews were employed to collect data from 120 systematically selected respondents. Exploratory factor analysis was used to identify the correlation between land use management strategies and environmental and economic factors. From the results obtained, a significant correlation was observed between land use management strategies and economic support systems. The physical characteristics significantly correlate ($p < 0.05$) with land use management strategies. However, there was no significant correlation between soil fertility and land use management strategies. The study recommends that, to improve land use management strategies in the Nzhelele Valley, there is a need for effective better investment in land, the improved availability of credit facilities that will allow farmers to invest in land use management strategies.

Keywords: Human; management; strategies; soil erosion.

Introduction

Most semi-arid and semi-humid areas of the globe are highly susceptible to erosion (Morgan 1990). Soil erosion was first recorded about 10,000 years ago, by the first farmers in the northern mountains of ancient Mesopotamia. Throughout history the main anthropogenic cause of soil erosion was land use change (Wild, 1996). Globally, about 1.1 million hectares of land have been affected by land use change related to soil erosion (Pathak *et al.* 2005). The causes of soil erosion worldwide include land use change, which ranges from rangeland to cropland, overgrazing, and the destruction of ecosystems due to anthropogenic activities (Slade, 1994).

The effects of soil erosion are long lasting and, if not addressed, can affect both the physical and chemical structure of the soil (Liu *et al.* 2011). Detachment of soil within terraces resulting in accumulation of soil has a negative impact of the physical structure of the soil (Xu *et al.* 2018). Due to the increase of agricultural activities, the rate of soil erosion has increased, resulting in the loss of fertile soil and changes in the physical and chemical structure of the soil (Amundson *et al.* 2015). Water erosion has slowly increased in Chinam washing away soil organic matter and black soils, creating ephemeral gullies (Xie *et al.* 2019).

Studies have illustrated that compaction, caused by agricultural machinery, increases soil erodability (Alaoui *et al.* 2018; Schaffer *et al.* 2008; Stoessel *et al.* 2018). This causes a reduction of soil productivity and fertility, illustrating onset impacts of soil erosion. This problem is most prevalent in the tropical and sub-tropical agroecosystem of Asia, Africa and South America, where soil loss averages 30 to 40 t/ha/year (Taddese, 2001). The main objective of this study is to assess the human influence on soil erosion in the Nzhelele Valley. Off-set impacts of soil erosion seem to be a greater problem within the tropical regions. The impacts of soil erosion may become a more substantial problem as future changes in climate will impact the extent, frequency and magnitude of soil erosion in different ways (Pruski and Nearing 2002).

Description of the study area

The Nzhelele Valley is situated in the Vhembe District located in the Limpopo Province of South Africa. The area is located within two municipalities, Musina and Makhado municipalities. The Musina section has farmland located within flat land, whereas the Makadho section has farmland predominantly located within sloped areas of the Nzhelele Valley. Small scale farming and mixed agriculture are the chief land use activity in the Nzhelele Valley. In general, small scale farmers depend on farming and off-farm activities. The area is very densely populated with a high demand for land. The study area receives low rainfall and is situated along the Soutpansberg Mountains. The study is conducted in the Nzhelele Valley which comprises a number of villages, namely : Maangani, Fondwe, and Mauluma, Ha-Mandiwana, Dididi, Tshikikinini, and Biaba. The Nzhelele River is the main river, with its drainage from the northern slopes. Also, the Nzhelele Dam is found within the lower parts of the Nzhelele River collecting water from the main river and its tributaries such as the Mutamba River, the Mutshedzi River, and the Tshiruru River. (See Appendix A1).

Research methodology

Data collection

For data collection, the Nzhelele Valley was divided into two sections, the Makhado and Musina sections. Within these two sections, a semi-structured questionnaire and interviews, as well as observations, were used to elicit primary data. Data was collected from small scale farm holders within the Nzhelele Valley with the help of research assistants. From the study area, a total of 120 questionnaires were distributed within the two sections of Nzhelele Valley.

Land use management investment strategies that were considered for this study include soil conservation methods such as the total number of terraces available on a farm, and the size and length of cut-off drains within a particular farm area. Other management investment considered was the length and height of the bunds created within each farmland. These values were converted into standard units (Adimassu *et al.* 2012). Investments in land use management strategies were obtained by summing up the soil conservation for each farmland.

Using the Factor analysis and Spearman Rank Correlation coefficient farmholds were grouped into three groups (low, medium and high) (Appendix B). Characteristics of the farmholders were considered through observation and information from the farm owners. For statistical analysis, 14 characteristics were considered and grouped into the following classes; physical characteristics, soil fertility, economic support system and accessibility of resources.

Data analysis

Exploratory factor analysis was used on 14 variables to identified environmental-economic

factors on land use management strategies. Variables were grouped based on their inter-correlation among farmholders. The Varimax orthogonal rotation was utilised to obtain a rotated component matrix, which assists in interpreting environmental-economic factors. All variables were retained due to a factor loading of 0.4 or more (Field, 2005 and Kessler, 2006) using the screen plot test. Spearman rank correlation coefficient was used between land use management strategies investment and scores for each environmental-economic factor to identify determining factors. The level of significance was set at 0.05.

Results

Environmental and economic factors and land use management strategies

Factor Analysis generated four major land use strategies that influence investment in land use management (Appendix C1). These factors all combined explained 60% of the total variance. Results of the land use strategies analysis, with the four generated major environmental and economic factors (physical characteristics of farmland, soil fertility, economic support system and accessibility to resources) and corresponding names (Appendix C1). Scores indicated in Table C1 illustrate the statistical relationship (correlation) between land use variables and the generated factors. Based on the included land use variables and their scores, each factor was given a name.

From the Factor Analysis, only 14 characteristics were established, as they had value loading which was greater than 0.4. These four factors were identified after Factor Analysis was completed, and these 4 factors explained 60% of the total variance (Table C1). The first factor, the physical characteristics, explains 18% of the total variance. It constitutes characteristics such as topographic features of farmland (explains whether the farmland is located on a steep or flat land), the size of farmland (in hectares) and the total number of farmlands within the location. Also the number of farmlands a farmer held was considered.

The second factor, the soil fertility, is comprised of characteristics such as soil type, soil fertility, the vulnerability of the soil to soil erosion and availability of manure. The availability of manure determines whether there is organic manure, from compost or inorganic manure which the farmers were using at that time. This factor constituted 22% of the total variance. This factor indicates the vulnerability factors which farmland experienced from land use activities during the period of farming. Soil type within farmland with regard to the soil structure and how well the soil produces from the crop yield harvested was also a characteristic used within the study.

The third factor, economic support systems, constituted 16% of the variance. This factor is comprised of characteristics such as the accessibility of credit facilities, availability of money and accessibility of information. Credit facilities involve aspects such as a loan from the private or government sector which can help the farmers to be fully equipped and enable them to invest in management strategies. Information availability is regarded in terms of the greater availability of skills and information through research and new innovative technological science that can assist farmers to invest in land.

The fourth factor, accessibility of resources, comprises characteristics such as the availability of labor, training and management, age of farmers and equipment available on the farm. This factor accounts for 14% of the variance. The labour availability characteristic illustrates the amount of labour available and if it is skilled hired or family labour that the farm uses. Furthermore, equipment available on the farm involves the type of machinery farmers use and how sophisticated it is in terms of land use investment on land use management. Lastly,

the age factor demonstrates the age of the farm owner illustrating management and decision making based on experience and level of investment into land use management strategies.

Spearman correlation analysis

The Spearman rank correlation coefficient was computed to investigate the significant correlation of environmental and economic factors on land use management strategies (Appendix C2). The table illustrates the correlation analysis between land use strategies and environmental and economic factors. A significant correlation was observed between strategies of land use and physical characteristics of farmland in Makhado at $P < 0.01$ level of significance. More-so, a significant correlation was observed between land use management strategies and physical characteristics of farmland in Musina areas of the Nzhelele Valley at 0.05 level of significance as illustrated in Table C2.

Furthermore, the correlation between land use management strategies and soil fertility was analysed. The results indicated that there is no significant correlation at $P < 0.01$ and 0.05 level of significance between land use strategies and soil fertility for both Musina and Makhado areas within the Nzhelele Valley. However, a significant correlation was observed between land use strategies and economic support system for the Makhado area at 0.05 level of significance. Furthermore, a correlation analysis observed a significant correlation of land use management and economic support system for the Musina area at 0.01 level of significance demonstrated in Table C2.

Moreover, the Spearman Rank Correlation Coefficient was also computed to analyse the relationship between the stages of development and accessibility of resources. The results showed a significant correlation between land use management and accessibility of resources in the Makhado area of Nzhelele at 0.05 level of significance. Additionally, a significant correlation was observed between land use management strategies and accessibility of resources at 0.01 level of significance in the Musina area of the Nzhelele Valley.

Discussion

Economic support system on land use management strategies

Economic support system, with regard to land use management strategies, involves the accessibility of assistance in financial form and knowledge that can assist farmers to deal with soil erosion problems and improve the quality of farming. Results demonstrate a significant correlation between an economic support system and land use management strategies at $P < 0.05$ and at 0.01 significant level in both Musina and Makhado areas of the Nzhelele Valley. This illustrates that there is a positive correlation between economic support system and land use management strategies in the Nzhelele Valley. High accessibility to economic support has improved the ability to invest in land use management strategies through purchasing of new technologies such as new drip irrigation equipment and chemical fertilisers has improved the agricultural practices, reducing the problem of soil erosion (Rahman, 2002). Furthermore, the development of new online applications that deal with agricultural problems such as soil erosion improved the knowledge and dissemination of information from agricultural extension officers to local farmers. The availability of income positively contributes to land use investment by farmers (Wambugu 2011). Economic support for the small scale farmers in Nzhelele reduces the risk of soil degradation as they can afford to purchase better equipment and advanced techniques which assist in solving soil degradation problems.

From the findings of this study, farmers in the Nzhelele Valley have better access to information and credit facilities. Reliance on information from programmes, training and

agricultural extension officers improved the understanding of environmental problems such as soil erosion and land degradation. Results are similar to the findings by Adimassu *et al.* (2012) who found that in Ethiopia the availability of information influences farmers' decision on investment in land use management. This fosters better and improved techniques that can be applied to solve issues of soil fertility and soil erosion, especially in areas where erosion is very prevalent. Similarly, findings by (Wambugu *et al.* 2011) suggest that dissemination of information through facilitators in central Kenya improved the investment management strategies of farmers in erosional control measures. Accessibility to the economic support system for small scale farmers in Nzhelele improves the accessibility of information which is best used in land use management strategies, such as contour lines and terracing in upland fields to avoid soil erosion problems. More-so, smooth dissemination of information from agricultural extension officers to the local subsistence farmers improved the level of implementation of technologies of agriculture (Sulo *et al.* 2012). Accessibility to capital promotes cooperative behaviour and facilitates the flow of information that can be relevant to land management investment (Adesina *et al.* 2000).

The availability of an economic support system, such as credit services, plays a very important part of land use management strategies. Credit services in the Nzhelele Valley assist farm owners to purchase much-needed inputs that can address soil erosion problems such as labour and advanced technology (drip irrigation). This result correlates with that from other studies which generally observe a positive correlation between income and investment in agricultural technologies (Sulo *et al.* 2012; Kessler, 2006; Iheke *et al.* 2012; Illukpitiya and Gopalakrishnan, 2004). Economic support improves the investment capacity of farmers in soil production, hence investing in land use management strategies such as organic fertiliser. Similarly, in Ethiopia stated by Adimassu *et al.* (2012), farmers invest in land management from their financial agricultural gains. The availability of money has provided farmers with better access to information that allows them to identify soil degradation problems such as soil fertility, soil structure and improved ways of management.

Influence of physical characteristics of farmland

Results demonstrate a significant correlation between the physical characteristics of farmland and land use management strategies. Large farmlands in the Nzhelele Valley contribute immensely to the high levels of soil erosion, unlike small farm areas which require low investment, whereas large farm areas require high capital investments. This result is in line with findings in Ethiopia where on a small scale biophysical conditions such as slope, soil fertility status and size of plots influence the decision on where to invest (Adimassu *et al.* (2012). Observations from the study illustrate that low land use management strategies such as the application of manure, terracing and contour ridges are implemented in large farm areas due to the high cost of investment resulting in the high vulnerability of farmlands to soil erosion and land degradation. Small farm areas do not require huge investment, hence it is not difficult to access some of the required resources such as capital inputs, and manure necessary for land use management.

The physical structure of the farmland strongly impacts the investment of land use management strategies. Most small-scale farms are found within the flatlands in the Nzhelele Valley where there is a low vulnerability to soil erosion which explains the correlation. Within the bottom farm areas at the Valley, manure is applied more liberally than in the upland fields (Tenge, 2005). In steep slopes of the Valley, less investment is observed due to high rates of soil erosion due to runoff causing gully development. In vulnerable plots, farmers hardly invest

in erosional control areas (Adimassu and Kessler 2012). A study by Clay *et al.* (1998) indicated that steep slopes are very costly to maintain and require much less erosive forms of land use. Small-scale farmers in the Nzhelele Valley practise much of their farming on flat land where there is less risk of erosion. However, in a study by Maro (1988) it was stated that in Tanzania farmers have invested in steep slope farms by the use of terraces as a measure to control erosion.

Land use management strategies in the Nzhelele Valley are mainly influenced by the size of the farm, where more implementation and investment is highly favorable to small farms with fewer expenses and better management. Similarly, Clay *et al.* (1998) concluded that small-scale farmers have high labour accessibility, enough to build and maintain land conservation. The size of farmland in Nzhelele Valley has a big labour pool which provides sufficient labour that allows farm holders to invest in management strategies such as terracing, contour ridges, cover plants and a supply of organic manure that supports land conservation.

Impact of soil fertility on farmland

The ability of farmers to invest in land management strategies is often influenced by the fertility of the soil. Results from the study show an insignificant correlation between soil fertility and land use management strategies for both sections of the Nzhelele Valley. This is because small-scale farmers with infertile land tend to invest considerably in land in order to improve the soil composition. This result differs from that of Clay *et al.* (1998) and Amsalu and Degraaff (2007), who observed that in Rwanda and Central highlands of Ethiopia, farmers invest more management strategies in fertile soils than in infertile soil. Farmers' investment in land use management strategies such as the application of organic fertiliser and construction of waterways within infertile soil is much influenced by the risk of soil erosion and low yield.

Investment in farmland in Nzhelele is influenced by soil fertility. Similarly, Amsalu and de Graaff (2007) suggest that farmers invest in plots where they expect more benefits from management strategies. Regardless of high levels of soil infertility, farmers' influence on investment management strategies is based on the availability of economic support services.

Soil fertility influences investment management strategies in the Nzhelele Valley. This explains the insignificant correlation of the result. Similarly, findings by Amsalu and De Graaff (2007) suggest that farmers invest in farms which they expect to benefit from. Small-scale farmers provide management strategies such as terracing, manure and contour ridges in infertile and water-prone erosion areas. Investment in land use management strategies within fertile soil is influenced by the size of farms. Due to their level of available labour and capital, most small-scale farmers with small farmlands in Nzhelele are able to provide manure and fertilisers to their farms. The study results are in line with the findings by Adimassu *et al.* (2012) which established that farmers are able to provide manure and labour to small-scale farms to control land degradation and soil erosion. Large areas vulnerable to water erosion have limited water control measures.

Land management strategies to combat current soil erosion and soil fertility problems in the Nzhelele Valley such as infiltration ditches and cut-off drain are limited within infertile farmland. The land use management strategies invested in fertile soil are mainly used to protect crops and obtain a high yield from the farm. There is an increased level of soil erosion vulnerability within infertile farmland due to a low investment in land use management strategies.

Impact of accessibility of resources on land use management strategies

The accessibility of resources in land use management mainly involves the availability of

training and management support, availability of skilled labor and the importance of age in management strategies. Results indicate a significant correlation between the accessibility of resources and land use management strategies. This is mainly because older farmers have experience in farming and they provide better strategies to address land use problems. Research works offer mixed results with regards to age in affecting land management strategies (Baidu-Forson 1999 and Bekele and Drake, 2003). Farmers of older age in the Nzhelele Valley invest in land use management strategies that continuously allow land to provide for their basic needs such as terracing in sloppy farmlands which prevents soil erosion and application of manure that reduces soil degradation. These findings are supported by Amsalu and Graff (2007) who observed that age influences investment in land use. Other studies indicated that older farmers invest more in land use management practices as they are regarded as wealthier and have the means to supply knowledge and labour on soil erosion control (Udayakumara *et al.* 2010).

Furthermore, farmers in the Nzhelele Valley invest in labour, programmes, and training. This is mainly influenced by the topographic location of farmland and the soil type. Programmes provide channels where information can be diffused and shared through groups, which in turn influences investment in land use (Wambugu *et al.* 2011). Most of the farmers within the Nzhelele Valley through programmes and training obtain better management strategies to deal with erosion such as contour lines and waterways. Further analysis observed that investment in skilled labour is central to a farmer's decision on land use management strategies. Similarly, Wambugu and Booth (2010) suggest that in Kenya inexpensive labour has been considered by farmers before investing in land for agricultural practices. Farming in fertile soils allows small-scale farmers to invest in information and labour that assist in solving soil erosion problems through educating programmes and hiring skilled labour that understands soil degradation. This is in line with a study by Wambugu *et al.* (2001) who indicated that in Kenya, the availability of skilled labour assisted 150 farmer groups, which constituted 2600 farmers in land use plant cover management.

The correlation of accessibility of resources and land use management strategies is better explained by the fact that older farmers are better equipped with knowledge and experience that enables them to manage soil erosion problem. Similar findings were reported by Montgomery (2007), who alluded that knowledge of agricultural practices can limit the magnitude of soil erosion. The presence of older farmers in farming allows them to invest more in land use management strategies such as shifting cultivation and monoculture, which improves soil structure. However, in a study by Illukpitiya and Gopalakrishnan (2004), young farmers are found to be more aware of soil erosion problems as they are better educated and have knowledge of land use management practices.

Accessibility to training and management programmes also influences farmers to invest in land use management strategies as they gain much better knowledge of soil and land degradation. This result correlates with the findings of Wambugu *et al.* (2011) who suggested in their study that the existence of programmes and farm groups is crucial for investment as they are key entry points for dissemination and training for farmers. However, Pimental *et al.* (1995 and Crosson (2007) argue that the application of agricultural inputs, no-tillage systems, and fertilisers are costly and are unaffordable to local subsistence farmers and might result in them accruing losses in farming in their bid to prevent soil erosion.

Conclusion

The study has illustrated that investment in land use management strategies involves various factors such as an economic support system, accessibility to resources and favourable topographic structure of the farmland. Identified environmental-economic factors can assist in

the investment of land use management strategies such as manure, terracing and the construction of waterways which can improve soil structure and crop yield. On the other hand, land use activities increase the vulnerability of soil to erosion without any investment. From the factor analysis results physical characteristics, economic support system and accessibility of resources factors were significantly correlated to land use management strategies, while soil fertility factor was insignificantly correlated to land use management strategies. Therefore, the study concluded that the environmental-economic factors are very important in influencing land use management strategies.

Acknowledgments

The authors are grateful for the financial assistance from the National Research Fund (NRF). It was also sponsored by the University of Venda Research and Publication committee. Also Dr Carl Palmer from ACCESS.

References

- Adesina, A.A., Mbila, D., Nkamleu, G. B. and Endamana, D. 2000. Economic analysis of determinants of adoption of alley farming by farmers in the forest zone of Southwest Cameroon. *Agriculture, Ecosystem and Environment*, 80:255-265.
- Adimassu, Z., and Kessler, A. 2012. Farmers' investments in land management practices in the Central Rift Valley of Ethiopia. In *Paper presented to the "8th International Symposium Agro Environ 2012 1-4 May 2012*. Wageningen, the Netherlands.
- Adimassu, Z., Kessler, C.A. and Hengsdijk, H. 2012. Exploring determinant of farmers' investments in land management in the Central Rift Valley of Ethiopia. *Applied Geography*, 35: 191-198.
- Adimassu, E., Kessler, A. and Hengsdijk, H. 2012. Exploring determinants of farmers' investments in land management in Central Rift Valley of Ethiopia. *Applied Geography*, 35 (1-2): 191-198.
- Alaoui, A., Rogger, M., Peth, S. and Bloschl, G. 2018. Does soil compaction increase floods? A review. *Journal of hydrology*. 557: 631-642.
- Amsalu, A. and De Graaff, J. 2007. Determinants of adoption and continued use of stone terracing for soil and water conservation in an Ethiopian Highlands watershed. *Ecological Economics*, 61: 294-302.
- Amundson, R., Berhe, A. A., Hopmans, J. W. and Olson, C. 2015. Soil and Human security in the 21st Century. *Science*, 348: 647-653.
- Baidu-Forson, J. 1999. Factors influencing adoption of Land-Enhancing Technology in the Sahel: Lessons from a case study in Niger. *Agricultural Economics*, 29: 321-239.
- Bekele, W., and Drake, L. 2003. Soil and Water Conservation Decision Behavior of Subsistence Farmers in the Eastern Highlands of Ethiopia: A Case Study of the Hunde-Lafto Area. *Ecological Economics*, 46: 437-451.
- Clay, D., Reardon, T., and Kangasniemi, J. 1998. Sustainable intensification in the Highlands: Rwandan farmers' investment in land conservation and soil fertility. *Economic development and cultural change*, 46: 351-377.
- Crosson, P. 2007. Soil quality and agricultural development. In: Envenson, R and Pingali, P., eds. *Handbook of agricultural economics. Agricultural development: Farm production and farm markets*. Amsterdam North-Holland, 3: 2911-2932.
- Field, A. 2005. *Discovering statistics using SPSS 2nd edition*. London: SAGE Publications Ltd.
- Iheke, O. R., Nto, P. and Onyenorah, C. O. 2012. Economics of soil conservation practices in

- Abia state of Nigeria. *Indian Journal of Agricultural Resources*, 46: 293-300.
- Illukpitiya, P. and Gopalakrishnan, C. 2004. Decision making in soil conservation: application of behavioral model to potato farmers in Sri Lanka. *Land Use Policy*, 21: 321-331.
- Kessler, C. A. 2006. Decisive key-factors influencing farm households' soil and water conservation. *Applied Geography*, 26: 40-60.
- Lui, X., Zhang, S., Zhang, X., Ding, G., and Cruse, R. M. 2011. Soil erosion control practices in Northeast China: a mini review. *Soil Tillage Research*, 117: 44-48.
- Maro, P.S. 1988. Agricultural land management under population pressure. The Kilimanjaro Experience, Tanzania. *Mountain Research and Development*, 8 (4): 273-82.
- Morgan, R.P.C. 1990. *Soil Erosion and Conservation*. London: Longman Group Limited.
- Montgomery, D. R. 2007. Soil erosion and agricultural sustainability. *Proceedings of the National Academy of Science*, 104: 13268-13272.
- Pathak, P., Wani, S. P., and Sudi, R. 2005. Gully Control in SAT Watersheds Global Theme on Agroecosystems. *An Open Access Journal*, 15 (6): 28 - 34.
- Pimental, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, N., Crist, S., Sphpritz, L., Fitton, L., Saffouri, R., and Blair, R. 1995. Environmental and economic cost of soil erosion and conservation benefits. *Science*, 267: 1117-1123.
- Pruski, F.F. and Nearing, M. A. 2002. Climate-induced changes in erosion during the 21st century for eight U.S. locations. *Water Resources Research*, 38: 34-1 – 34-11.
- Rahman, S. 2002. Technological change and food production sustainability in Bangladesh agriculture. *Asian Profile*, 30: 233-246.
- Schaffer, B., Schulin, R., and Boivin, P. 2008. Changes in shrinkage of restored soil caused by compaction beneath heavy agricultural machinery. *European Journal of Soil Science*, 59: 771-783.
- Slade, G.P., Schulman, M.B. and John, A. 1994. Effective erosion rates for selected contact materials in low-voltage contractors. *Microelectronics Reliability*, 37: 530-536.
- Stoessel, F., Sonderegger, T., Bayer, P. and Hellweg, S. 2018. Assessing the environmental impacts of soil compaction in Life Cycle Assessment. *Science Total Environment*, 630: 913-921.
- Sulo, T., Koech, P., Chumo, C. and Chepngemo, W. 2012. Socio-economic factors affecting the adaptation of improved agricultural technologies among women in Marakwet Country, Kenya. *Journal of Emerging Trends Economic Management Science*, 3: 312-317.
- Taddese, G. 2001. Land degradation: A Challenge to Ethiopia. *Environmental management*, 27 (6): 815-824.
- Tenge, A., Sterk, G. and Okoba, B.O. 2011. Farmers' preferences and physical effects of soil and water conservation measures in the East African highlands. *Journal of Social Science*, 2: 84-100.
- Uduyakamara, E. P. N., Shrestha, R. P., and Schmidt-vogt, D. 2010. People's perception and socioeconomic determinants of soil erosion: A case study of Samanalawewa watershed, Sri Lanka., *International Journal of Sediment Research* 25 (4): 323- 339.
- Wild, A. 1996. *Soils and the Environment*. London: University Press Cambridge.
- Wambugu, C., Place, F. and Franzel, S. 2011. Research, development and scaling-up the adoption of fodder shrub innovations in East Africa. *International journal of Agricultural Sustainability*, 9 (1): 100-109.
- Wambugu, C. and Booth, B. 2010. Marketing of Fodder planting materials in the Central

- region of Kenya. Unpublished research report, Academy for Education Development, Washington, DC.
- Wambugu, C., Franzel, S., Tuwel, P. and Karanja, G. 2001. Scaling up the use of fodder trees in Central Kenya: *Development in Practice* 11, 487-94.
- Xu, X., Zheng, F., Wilson, G.V., He, C., Lu, J. and Bian, F. 2018. Comparison of runoff and soil loss in different tillage systems in the Mollisol region of Northeast China. *Soil Tillage Resource*, 177: 1-11.

Appendix A

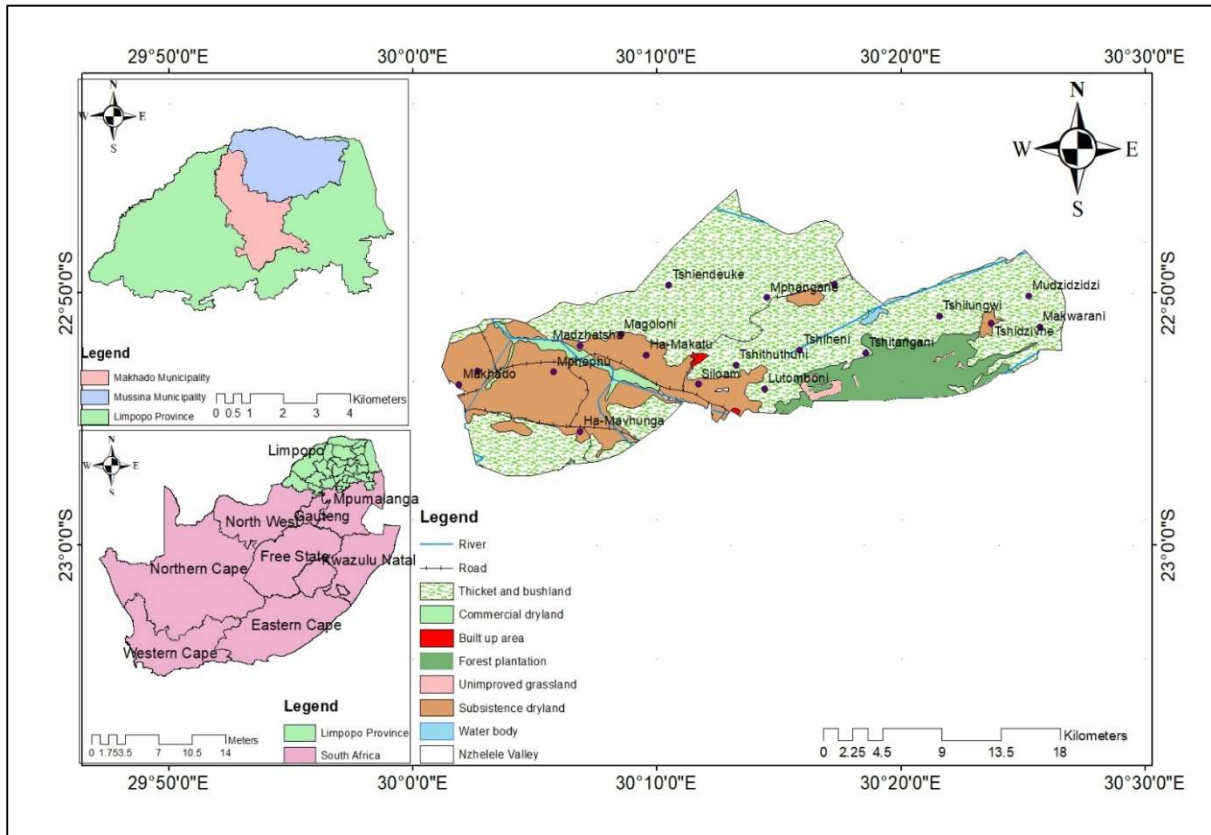


Figure 5.1: Map of South Africa showing study site Nzhelele Valley

Appendix B

: Farmland characteristics on land use management strategies

Farm characteristics considered

1. Age of the farm owner (between 20 to 30; 30 to 45 or <45)
2. Availability of manure (type of manure and its accessibility low; medium and high)
3. Size of the farm- the total area of the farm in hectares (>1 ; 1 to 2 or <2)
4. Topographic structure of the field (flat; medium or steep slope)
5. Soil fertility (soil fertility quality i.e. low, medium or high)
6. Type of soil erosion (vulnerability to soil erosion i.e. low; medium or high)
7. Availability of labor (low, medium or high)
8. Type of soil type (Soil depth if it's shallow; medium or Deep)
9. Soil type (bad; good or better)
10. Training and management accessibility (low; medium or high)
11. Programs for land use management (Ha-Mandiwana irrigation conservation program and Nzhelele communal agricultural plan and Dzanani forest conservation program)
12. Accessibility to credit facilities (low; medium or high)
13. Equipment used for land management (low; medium or high)
14. Available training on land use management strategies (low, medium or high)

Appendix C1

Table C1: Rotated component matrix for subsistence farm characteristics

Farmland characteristics	Environmental & economic factors produced from Factor analysis			
	Physical characteristic	Soil fertility	Economic support system	Accessibility of resources
Topographic location of farmland	0.732			
Size of farmland	0.652			
Total number of farmland	0.721			
Soil type		0.764		
Soil fertility		0.861		
Vulnerability to soil erosion		0.871		
Availability of manure		0.721		
Accessibility of credit facility			0.839	
Availability of income			0.769	
Availability of information			0.821	
Availability of labour				0.751
Training and management				0.753
Age				0.736
Equipment				0.814
Explained variance (60 %)	18	22	16	14

Appendix C2

Table C2:

Illustrates the Spearman rank correlation coefficient of investment strategies within Nzhelele Valley from the Factor analysis. Environmental-economic factors and their correlation with land use management strategies are given.

Table C2: Spearman rank correlation coefficient on land use management strategies		
Factor	Nzhelele Valley	
	Makhado-Nzhelele	Musina-Nzhelele
Physical characteristics of farmland	0.213*	0.209**
Soil fertility	-0.042	0.002
Economic support system	0.230**	0.115*
Accessibility of resources	0.251**	0.220*
<p>*Spearman rank correlation coefficient is significant at 0.01 level</p> <p>** Spearman rank correlation coefficient is significant at 0.05 level</p>		

Chapter 6: A time series analysis of land cover change: A case study of Bewaarkloof Nature Reserve, Limpopo, South Africa

Nesisa Analisa Nyathi and Thendo Mugwena

Corresponding author: Ms. T. Mugwena
thendom@uj.ac.za

Abstract

Land cover change is a phenomenon which is prevalent all over the world. Although both natural and anthropogenic factors are responsible for land use and land cover change, human alteration around the world has recently appeared unmatched, profoundly affecting the earth's ecological and natural systems. Reducing the impacts of land cover change requires knowledge of the spatial phenomena of landscape components including vegetation dynamics. This can be achieved through spatio-temporal analysis methods. Remote sensing and GIS techniques have become efficient tools to carry out such analysis. This study aimed at mapping and quantifying the dynamics in land cover change from the period of 20 years, from 1998 to 2018, in the Bewaarkloof Nature Reserve, Limpopo, South Africa. The specific objectives were to (i) spatially map the change in land cover within the given period of time, (ii) assess performance of supervised classification scheme, and (iii) quantify the spatial extent of changes as identified in the above-mentioned objective. The study also seeks to assess the utility of NDVI in determining these dynamics. Landsat imagery acquired in 1998, 2003, 2008 and 2018 will be used to derive land cover classes and NDVI maps respectively. The derived maps (classified and NDVI) will be compared graphically and statistically. The expansion in land cover change and the corresponding decrease in vegetation cover will be attributed to population increase in the area over the years. It is finally envisaged that the findings of this study will provide useful information to decision-making and further studies.

Introduction

Approximately 71% of Earth's surface is covered with water, consisting mostly of oceans (FAO, 2012). According to FAO, 2014, 0.6% of Earth's land surface is defined as 'artificial surfaces'; these are areas that have an artificial cover due to human activities such as construction (cities, towns, transportation), extraction (open mines and pits) or waste disposal. The World Bank land policy of 2017 noted that the total surface area of South African land was reported at 1 219 090 km² in 2016. 40% of this total land surface area is used for agricultural activities, both at subsistence and commercial levels. 20% of the land in South Africa is unregistered (Toulmin, 2008), 30% comprises urban areas and 10% protected areas. Anthropogenic influences on the landscape such as alteration in land use through agriculture, forestry, urbanisation and the introduction of invasive alien plant (IAP) species have a profound effect on the functioning of the landscape and ecosystems in South Africa, (Gibson *et al.* 2018).

Land cover change is a phenomenon which is prevalent all over the world (Robson, 2005). It is one of the most important indicators of how humans interact with the environment (Dewan *et al.* 2012). Land cover change is influenced by both natural and anthropogenic factors; however, the human alteration around the world has recently appeared unmatched, profoundly affecting the earth's ecological system (Dewan *et al.* 2012). The changes in land cover that are happening at a rapid pace, particularly in developing nations, are often characterised by widespread urban sprawl, land degradation, or the alteration of agricultural

land to privatised land used for settlements, protected areas used for mining or informal and illegal settlements. This entails a massive cost to the environment (Hegazy *et al.* 2015). This peripheral dependence means that the human system is not restricted by the constraints of local ecosystems but extends the ecological footprint of human influence past the boundaries of the environment, especially in protected areas (Bhatta, 2010). Human-induced changes in land cover influence the global carbon cycle and contribute to the increase in atmospheric CO₂ (Alves and Skole, 1996; Hegazy, 2015). It is, therefore, crucial to examine the changes in land use/cover, so that its effect on the terrestrial ecosystem can be distinguished, and sustainable land use planning can be articulated (Hegazy, 2015).

Effects of land/use or land cover change on the environment

Land cover change has several effects on the natural vegetation and the earth's landscape. Land cover transformation due mainly to anthropogenic activities usually results in landscape disintegration in which the ecosystem composition and structure are conceded (Matsika, 2007). Vegetation loss or depletion is a typical indicator of ecosystem weakening (Rands *et al.* 2010). The loss of biodiversity is also a problem often associated with land cover change (Rands *et al.* 2010). Biodiversity loss can be in terms of the damage of genetic diversity and ecosystem services both on a natural and physical scale. In addition, the reduction of natural vegetation through urban expansion, development or simply natural causes leads to a loss of habitat for wild animals. Furthermore, land cover change leads to deforestation that in turn results in loss of carbon appropriation potential (Olson, 2013).

Sustainable land use strategies

Land use/cover change detection is very essential for understanding the landscape dynamic during a known period having sustainable management (Rawat *et al.* 2015). Sustainable development is seen as an instrument that equilibrates economic development, social equity and environmental protection for current and future generations (Paek, 2006). Based on the extended Metabolism Model of Human Settlement, which focuses on resource inputs and waste outputs from cities, Paek (2006) defined sustainability as the decrease in the exploitation of natural resources and production of waste. Protected areas must maintain an equilibrium between economic activities and population growth so that urban system dynamics can evolve in harmony with fewer chances of environmental dilapidation (Robson, 2005).

It was proved that sustainable urban land use was an effective way to promote the sustainable expansion of China's urban areas facing the challenges of sustainable urbanization within protected areas and urban areas, (Lu and Ke, 2017). Many cities in China have implemented a sustainable urbanisation policy and they have accumulated much experience within these decades (Lu and Ke, 2017). The Sustainable Urban Land Use Policy (SULUP) is one of the key policies which was implemented, as it included the policies of concentrated use, low carbon emissions, environmental governance and economic expansion of the urban land (Lu and Ke, 2017). The document of the Ministry of Land and Resources Guidance about Promoting Land Conservational and Intensive Use marked the beginning of the second round of the high tide of sustainable land use (Lu and Ke, 2017).

In the South African context, the Native Land Act of 1913 played a key role in the control of native people of South Africa (SA) to occupying only 13% of the country's land (Netshipale *et al.* 2017). The land reorganisation has social, economic, environmental, and political objectives (Netshipale *et al.* 2017). The prominence each of the objectives receives is often a political issue, and mostly depends on prevailing societal and environmental circumstances (Netshipale *et al.* 2017). "The SA land reform programme is being executed

through three major ways, land restitution, land redistributions and land tenure reform” (Netshipale *et al.* 2017). Land tenure reform aims to secure the rights of those who are already occupying land with insecure occupation rights in both protected and unprotected areas (Netshipale *et al.* 2017).

The Protected Areas Act of South Africa co-management has occupied the centre stage in natural resource management policy and practice since the 1990s (Cundill *et al.* 2013). Its main mandate was to redress past injustices based on land redistribution and at the same time respond to national and international obligations to maintain and expand protected areas, therefore, co-management became seen as the answer to preservation and development challenges (Cundill *et al.* 2013).

As of July 2010, according to the Department of Rural Development and Land Reform, (2010), there were 139 protected areas in South Africa that had land claims either lodged against them or established throughout the country, and in roughly 90% of these cases the applicants have opted for restoration of the land as their preferred settlement option (Cundill, 2013). This constitutes roughly a third of all protected areas in the country and when considered in combination with the Memorandum of Agreement of the constitutional Bill, the urgency with which the state is currently attempting to settle all outstanding claims, it means that a third of the country’s conservation estate is likely to be under co-management in the next five years (Cundill *et al.* 2013).

The application of remotely sensed data has made it possible to study the changes in land cover in less time, at a low cost and with better accuracy (Rawat *et al.* 2015). Remote sensing is the knowledge and art of obtaining information about an object through the analysis of data acquired by a device that is not in contact with the object (Lillesand and Kiefer, 2008). The method employs sensors that can be hand-held or mounted on terrestrial, aerial or space vehicles (Rawat *et al.* 2015). The latter two are the most common systems for natural resource assessment. Satellite remote sensing techniques have been widely used in detecting and monitoring land use or land cover changes on various scales with useful results, (Soffianian *et al.* 2010).

Remote sensing is progressively used for monitoring land use/land cover dynamics with several advantages. One of these is its cost-effectiveness as compared to the traditional field inventory methods (Soffianian *et al.* 2010). Remote sensing also provides spatially continuous information that covers a large spatial area (Lillesand and Kiefer, 1994). Remote sensing can also provide reliable, antique data, that allows a time-series analysis (Soffianian *et al.* 2010).

Remote sensing and Geographic Information Systems (GIS) have the potential to provide accurate information concerning land use and land cover changes that are finalised with an accuracy assessment (Alqurashi and Kumar, 2013). Land cover change detection mapping and analysis can be simplified through the use and clarification of multi-temporal aerial and satellite data (Lillesand and Kiefer, 2008). The process of land use or land cover change detection involves the evaluation of spatial, spectral and temporal characteristics of spatial data in order to derive statistics that indicate the presence or absence of land use, land cover and other types of changes (DiGirolamo, 2006).

Digital change detection is, therefore, quantifying temporal phenomena of an area using images assimilated at different times (Coppin *et al.* 2004). There are diverse types of change detection methods. Among many, one of them is image subtraction. This involves the "subtraction of the digital pixel values of an image from one date of the corresponding pixel values for a different date" (DiGirolamo, 2006). An additional method is posted classification in which "images of different dates are classified and interpreted separately, the resultant

classes of the different dates are then compared against each other" (Maselli *et al.* 2001). One of the advantages of classifying images separately is the fact that there is no need for radiometric standardisation of images (Coppin *et al.* 2004). Therefore, the spatial framework of change can be recorded as growth, reduction and adjustment in shape and change or shift in the position of features (Coppin *et al.* 2004).

The Bewaarkloof Nature Reserve, which is one of the many nature reserves in Limpopo, appears to have been neglected by the government. There are signs of inattention, abandonment, unmonitored boundaries and illegal human activities. The authorities of both the province and the country have not done enough to ensure that the nature reserve is best monitored. As a result, a trail of unmonitored housing and illegal grazing have altered the natural environment into a possibly irreversible cause for concern. In addition, there is limited to no information documenting the extent to which the damage has occurred in the years that have passed. There is a lack of spatial and temporal maps that show the extent to which the nature reserve has been altered by human occupation. The main aim of this study is to assess the dynamics of land cover using a time series analysis technique over a period of 19 years (1999-2018).

Study area

The study was conducted in the Bewaarkloof Nature Reserve 24° 9' 4.32" S and 29° 51' 7.2" E in Limpopo province. (Figure 6.1). The nature reserve is located adjacent to the Wolkberg Mountains within the same area. The 28 133-hectare study area was delineated specifically for this study for its proximity to human settlements and to the Kruger National Park, as well as its diverse range of both flora and fauna. The average monthly maximum temperature varies between 12.6 °C and 22.5 °C. The highest temperatures were recorded between January and February at temperatures greater than 28 °C (Figure 6.2). Average monthly minimum temperature varied between 8.4 °C and 4.3 °C. The lowest temperatures were recorded between May and July at temperatures less than 10 °C (Figure 6.2). Annual rainfall over the past 20 years varied between 367.1 mm and 816.7 mm and averaged 548.4 mm. Most of the rain fell between November and March, and varied between 79.8mm and 65.1 mm. There are two generic vegetation types found in the study area : the savanna biome and the grassland biome.

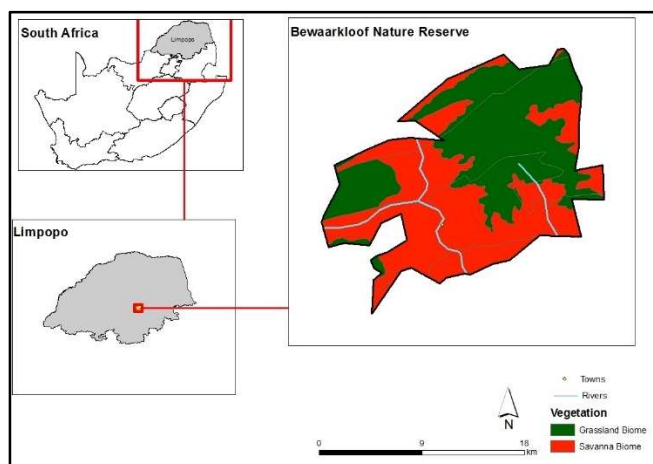


Figure 6.1: An illustration of the random points that were used to classify the Landsat image

Datasets

Field data

The decision on where to collect ground sample data is an important step in remote sensing during the data collection stage. The process of ground sampling is highly dependent upon the design of the sampling scheme (Muzein, 2006). Sample selection in the study was assisted by visual observation of high spatial resolution, orthorectified imagery of the study area acquired in 2018. The image was obtained from the Earth Explorer website (<http://www.earthexplorer.usgs.gov>) of the United States Geological Survey. The spatial resolution of the image is approximately 30M. The image has three bands (Red, Green, and Blue) and covered approximately 5 km in the east-west and 6 km in the north-south direction.

The area was first classified as a natural environment. As time went by, evidence of human built-up areas was sighted in the study area from 2009 to 2018. 107 samples were obtained and were all randomly dispersed on the study area with no equal number of samples given to a specific class (Figure 6.4). In addition to randomness, various factors such as accessibility and proximity to the water source were considered in the selection of samples.

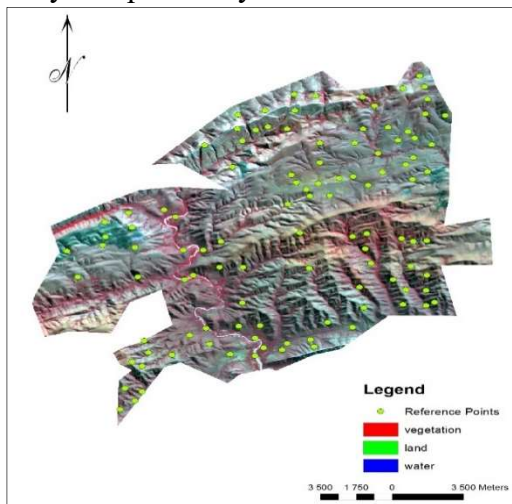


Figure 6.2: Highest temperatures were recorded between January and February

A Global Positioning System (GPS) was used to locate the sample points. In instances where the sample points were considered incorrect due to inaccessibility, they were replaced by points near the original points. A plot of 30-metre radius centred at each sample point was established to make clear observations. This size is approximately equivalent to four-pixel sizes of a Landsat image. Having more than one pixel was necessary in this case to minimise locational and spectral error. In each plot, visual observations of features were made to relate to the land cover classifications of the study. Observations in the natural area included identification of generic vegetation type, visual estimation of dominant vegetation cover and observation of overall vegetation cover both wet and dry. The classes observed in the natural area were identified as bare land, bare rock, water, grassland and dense vegetation.

Classes observed in the manmade area comprised built-up area. In both natural and built-up manmade areas, the classes were approximated according to Thompson (1996) that standardised land cover types for interpreting remotely sensed data. Table 6.1 presents the class

definitions used for this study. These observations were then populated in the attribute table of each sample point using ArcGIS software.

Table 6.1: Land cover classes defined in the field	
Land cover class	Class definition
Water	-Perennial water
Grassland (dry)	-Sparse, barren and stunted vegetation
Vegetation (dense)	-Thick woods
Bare land	-Physical cover of the earth's surface -Without any crops or vegetation
Bare rock	-Areas of active erosion -Situated above mountainous areas
Built-up area	-Buildings -Roads -Houses

Remotely sensed data

Change detection and monitoring encompass the use of multi-temporal images to evaluate differences in land cover due to environmental conditions and human actions between the acquisition dates of images (Mundia and Aniya, 2005). It is highly recommended that images acquired using the same sensor or sensors with similar characteristics are used in change detection analysis to eliminate error that would result from different types of images (Mundia and Aniya, 2005). Sources of errors may be the result of combining different images from different sensors, for example Landsat and SPOT, as this can result in the variation of spectral characteristics. Landsat satellite imagery was chosen for this study for several reasons:

- The imagery has a long history with uninterrupted data available since 1972. This is useful to undertake long-term time series analysis.
- The spatial resolution of the imagery is relatively good for most landscape level assessments (30M).
- Landsat is freely available, can readily be downloaded from the Internet, and takes a relatively short time to request and acquire.
- Landsat imagery has several bands in the visible and near-infrared regions of the electromagnetic spectrum. These bands have been used for numerous land use/land cover assessments.

Pre-processing of Landsat image

All Landsat images were orthorectified and projected to the local coordinate system (WGS_UTM_ZONE_35S) by the USGS. Two analyses were carried out on the extracted images to achieve the objectives of the study. The first analysis is classifying the composite image of each date and subsequently comparing the difference in classes among the dates. This analysis addresses the first two objectives of the study. The second analysis focused on exploring the potential of NDVI to assess the presence and absence of land cover change in the

study area.

Image classification

Land cover classes are characteristically mapped from remotely sensed data through digital image classification and interpretation. The overall objective of the image classification procedure is to inevitably categorise all pixels in an image into land cover classes or themes (Lillesand *et al.* 2008). For this study, an unsupervised classification approach was adopted because it allows spectral clusters to be identified with a reasonable amount of independence. The classification was done in ArcGIS using the unsupervised classification algorithm and, in this software, there are combinations of iso-cluster and maximum likelihood classification tools (ArcMap, 2018).

The Landsat imagery for the years 2004, 2008, 2016 and 2018 was classified into three classes following the number of classes specified by the visual observations on reference data. These classes were then interpreted using the definitions given in Table 6.1. Different band combinations such as true colour and false colour combinations of the image were used in the interpretation of the classes. The specific band combination that was used in this case is the Near InfraRed (NIR) band (5,4,3). The classes were subsequently assessed using reference data with the objective of validating the effectivity of Landsat sensors for this study. The assessment focused on 20m radius plots due to the small size of the study area.

Normalized Difference Vegetation Index (NDVI)

NDVI was used first at the Remote Sensing Centre of Texas University (Rouse *et al.* 1973). The index uses the value that states that healthy vegetation engrosses most of the visible light that strikes it and reflects a large portion of the near-infrared light (Keifer and Sutherland, 2003). In contrast, sparse vegetation reflects more visible light and less near-infrared light. Other surfaces such as bare land, bare rock and impervious surfaces reflect fairly equally in both the red and infrared portion of the electromagnetic spectrum (Holme *et al.* 1987). NDVI is therefore calculated using equation 1.

$$\frac{NIR-R}{NIR+RED} \dots \dots \dots \text{Equation 3}$$

According to Equation 1, NDVI values range from -1 to 1. Characteristically, extreme negative values signify water; values around 0 represent impervious surfaces and NDVI values close to 1 represent dense green vegetation, (Holme *et al.* 1987). Therefore, the water class in this study is expected to be in the range of -1, the impervious class is 0, vegetation is 0.2 to 0.6 respectively. NDVI was computed for each Landsat image. The computed images were then used to indicate change detection for different dates using visual interpretation and the NDVI range values.

Results

A comparison was made between reference data that was obtained in 2018 and land cover classes derived from a Landsat image that was acquired in 2018. The 2018 imagery was classified and subsequently interpreted using both false and natural (true) colour band combinations of the original 2018 image. These band combinations enabled relatively easy identification of features as illustrated in Figure 6.7. The figure shows examples of areas that are dominated by the built-up area and dense vegetation.

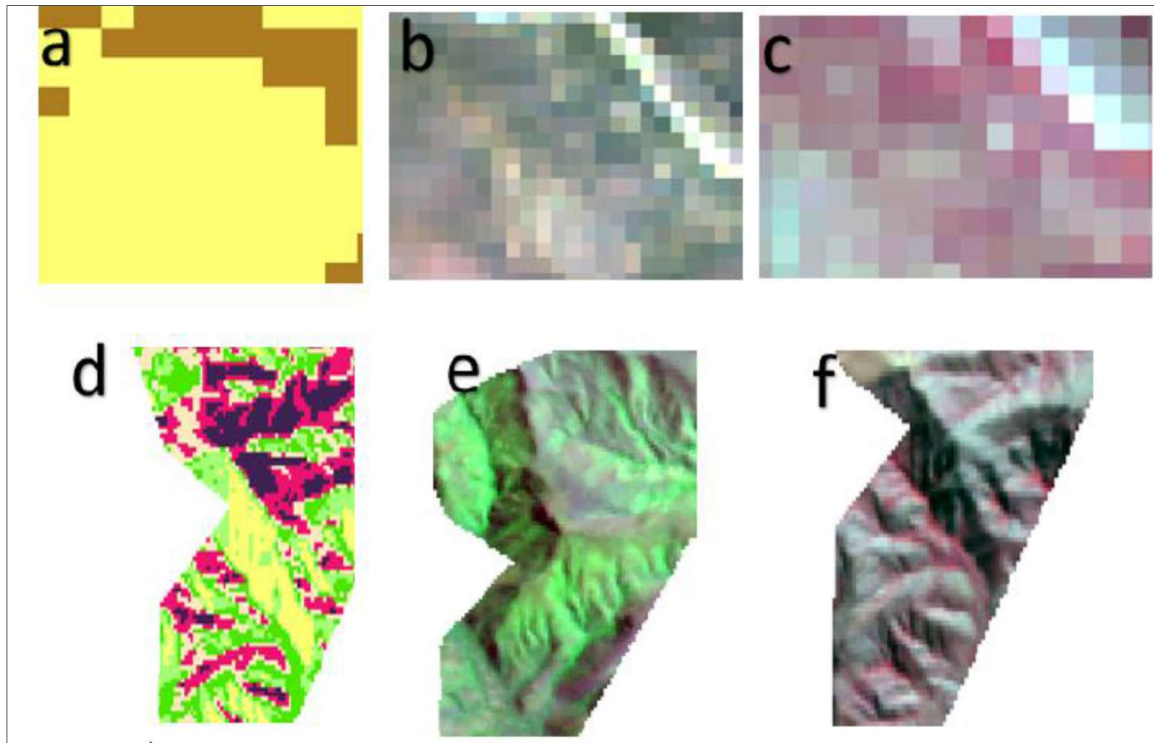


Figure 6.3: An illustration of natural and false colour composites. (a) Classified (b) natural colour and (c) false colour showing an area dominated by built-up areas. (d) Classified (e) natural colour and (f) false colour showing areas that are dominated by vegetation

Eighteen samples were allocated from the built-up stratum, and fifteen samples from the vegetation stratum were used for assessing the accuracy of the classification. The comparison showed that seventeen sample points in the built-up stratum were correctly classified by the interpretation of Landsat image as shown in Table 6.4, whereas only ten of the fifteen samples were correctly classified for dense vegetation. Twenty-two samples were allocated for the grassland stratum ; however, only thirteen were correct. Twenty-seven points were allocated for bare land and a total of eighteen points were accurate. Thirteen points were allocated for the water and only nine were correct.

Land cover types of each date

Six classes were produced for each date (1999, 2004, 2009, 2016 and 2018). These are water, dense vegetation, grassland, bare land, bare rock and built up area as shown in the figure (Figure 6.8). Statistics indicating the magnitude of areal coverage of each land cover type for all dates are given in Table 6.5. In the year 1999, dense vegetation had the highest cover with 11286 ha (40%) of total area, while the built-up area had the smallest coverage with 0. In the

year 2004, bare land had the highest cover of 9962 ha (35%) of the total area, while the built-up area had the smallest coverage of 0. In 2009, dense vegetation had the highest coverage with 8159 ha (29%) of the total area, while the built-up area occupied the least with 0. In the year 2016, bareland occupied the area with 7410 ha (26%), while water occupied the least with (1776 ha, 6%). In 2018, bareland and dense vegetation occupied equal amounts of the area with 6600 ha and 6592 ha respectively and that is (23%) with water covering the least at (2356 ha, 8%).

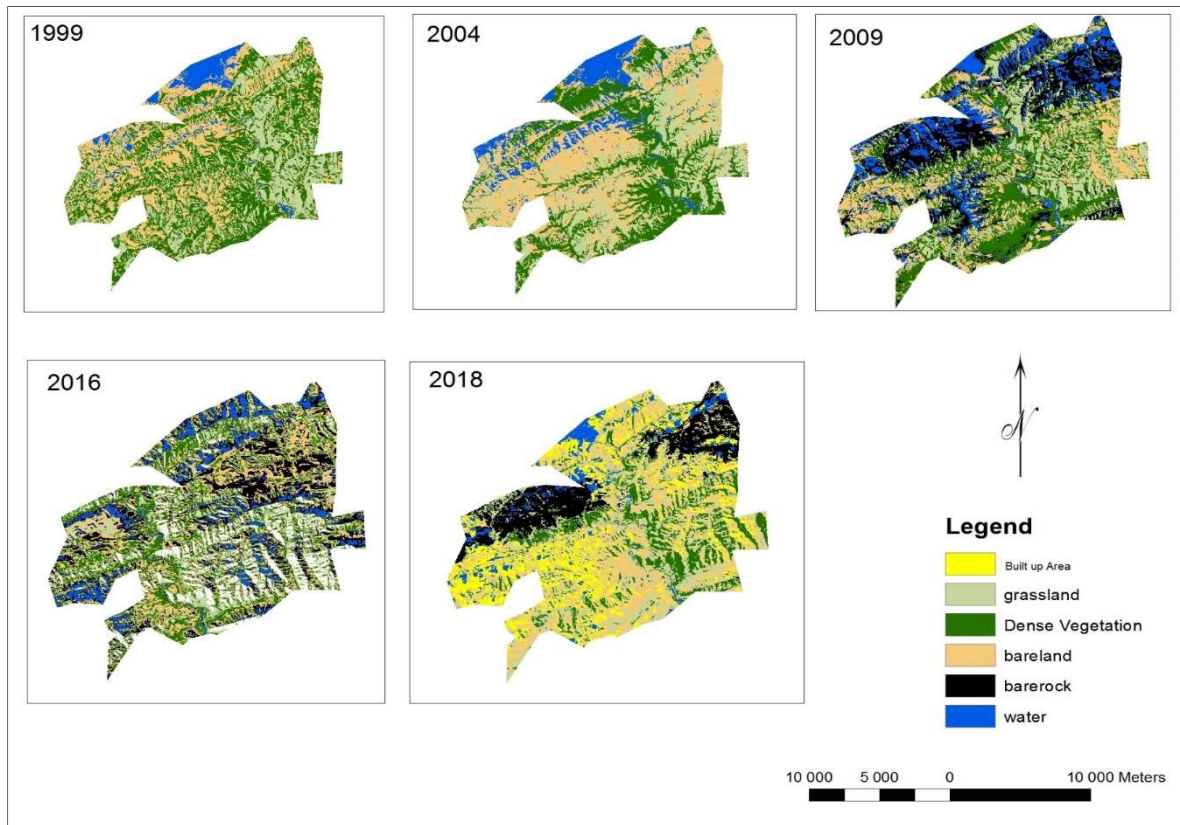


Figure 6.4 :Map showing the different land cover types for the stipulated years

The results have shown that there were changes in all the classes from 1999 to 2018 (Table 5). The grassland class, for example, decreased steadily from 6656 ha in 1999 to 4522 ha in 2018. The bareland cover type also decreased continuously from 8582 ha in 1999 to 5653 ha in 2009, and further decreased to 6592 ha in 2018. Dense vegetation covered 11286 ha in 1999 and decreased to 6600 ha in 2018. In 1999, built-up area classification increased from 0 ha to 2679 ha in the year 2018. Water increased from 1999, 2004 to 2009 with 1649ha, 2943 ha and 3981 ha respectively. It then decreased to 1776 ha in 2016 but increased to 2356 ha in 2018.

Classes	1999		2004		2009		2016		2018	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Built up Area	0	0	0	0	2679	9.3	2679	9.3	2679	9.3
grassland	6656	23.2	4522	16.1	4522	16.1	4522	16.1	4522	16.1
Dense Vegetation	11286	39.7	6600	23.2	6592	23.2	6592	23.2	6592	23.2
bareland	8582	29.8	5653	19.8	6592	23.2	6592	23.2	6592	23.2
barerock	0	0	0	0	0	0	0	0	0	0
water	1649	5.7	2943	10.3	3981	13.9	1776	6.3	2356	8.3

Grass-land	6656	24	7131	25	4593	16	5974	21	4522	16
dense vegetation	11286	40	8159	29	8119	29	3915	14	6600	23
bare land	8582	30	9962	35	5653	20	7410	26	6592	23
bare rock	0	0	0	0	5826	21	3741	13	5441	19
Water	1647	6	2943	10	3981	14	1776	6	2356	8
built-up area	0	0	0	0	0	0	5376	19	2679	10

Figure 6.9 shows the percentage change of all the classes. The changes are reported per class type in the different consecutive dates. A positive percentage indicates an increase in coverage while a negative percentage or no value indicates a decrease in coverage. Water, for example, decreased in all the consecutive dates from 1999 to 2018. None of the decreases in water was more than 57%. Bare-land decreased by more than 23% from 1999 to 2018. There was, however, an increase of built-up area by approximately 52% from 2016 to 2018. Dense vegetation decreased by approximately 36% from 1999 to 2018. There was a decrease of more than 10% of bare rock from 2009 to 2018. Built-up areas increased by more than 100% from 2009 to 2016, while they decreased by 52% from 2016 to 2018. Grassland coverage decreased by 40% since 1999 to 2018.

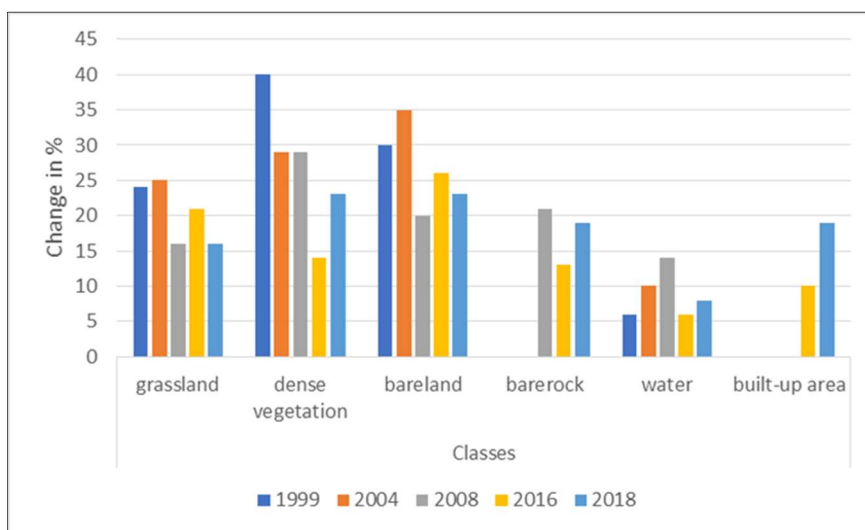


Figure 6.5: A graph showing different percentage changes according to class types and years

Accuracy assessment

An accuracy assessment of the different values was conducted in this study. In many instances, an accuracy assessment requires clear reference data or ground truthing or even through physical appearance in the study site. In cases where the study site is not visited due to expense or other unforeseen circumstances, high-resolution images that are of recent years are used as

reference data for an accuracy assessment. Due to limited funds and immobility, this study used high-resolution live imagery from the Google Earth (www.earthexplorer.com) website as reference data for an accuracy assessment on one of the latest Landsat images that were classified. A random sampling method was used on Google Earth to identify the different features as per image classification.

The total process was done by comparing the reference image with the classified image with some random points. Random sampling was adopted to calculate the classification accuracy of each land cover image. The logic to use this sampling method is each land cover class found the equal probability to be observed. 107 random points were used for accuracy assessment of one classified image. This was done solely because it was the most recent image of the whole dataset that had been classified; also, Google Earth is live reference data, therefore, a recent image had to be used. The data was summarised and quantified by using an error matrix. Four different accuracy results were formulated (Figure 10) this includes user accuracy, producer accuracy, total accuracy and predictions which helped to understand the accuracy of the classification.

The overall classification accuracy showed that: of the 27 predictions that were made for bareland, only 18 were accurate, producing a producer's accuracy of 66.67% and a user's accuracy of 81%. A total of 14 predictions were made for bare rock; however, only 9 were accurate, constructing a producer's accuracy of 64.29% and a user accuracy of 45%. Within the built-up area, a total of 18 predictions were made, with only 17 that were accurate, that tallied a producer's accuracy of 94.44% and a user accuracy of 100%. 15 predictions were made for the dense vegetation land cover class and only 10 were accurate, computing 66.67% of producer's accuracy and 55% user accuracy. 22 random samples were given to the grassland class and 13 were accurate; this produced a producer's accuracy of 59% and 61% user accuracy. 13 predictions were made for water and only 9 were accurate; this resulted in a producer's accuracy of 69.23% and a user's accuracy of 81%. In total, 107 predictions were made, and a total of 79 were accurate; this gave an overall 70% accuracy assessment for the random sampling classification.

		Classified Data							
Reference Data	CLASS_NAME	bareland	barerock	built_up_a	Dense_Veg	grassland	water	Producer Accuracy %	Predictions
	bareland	18	5	0	0	3	1	66.67	27
	barerock	3	9	0	0	1	1	64.29	14
	built-up area	0	0	17	0	1	0	94.44	18
	Dense Vegetation	1	1	0	10	3	0	66.67	15
	grassland	0	1	0	8	13	0	59.09	22
	water	0	4	0	0	0	9	69.23	13
	User Accuracy %	81	45	100	55	61	81		109 total points
	Overall Accuracy %								70

Figure 6.6: Accuracy assessment of the classified image

Comparison of NDVI values

Normalised Difference Vegetation Index (NDVI) values were computed to illustrate the vegetated areas as compared to the non-vegetated areas from 1999 to 2018. NDVI values falling within -1.0 and 1.0. (Table 6.6) show NDVI values for the sampled areas. Positive values show areas that are vegetated while negative values show areas that are not vegetated. Figure 6.7 shows a visual illustration of the NDVI values where the colour green shows high NDVI

values and red shows low NDVI values.

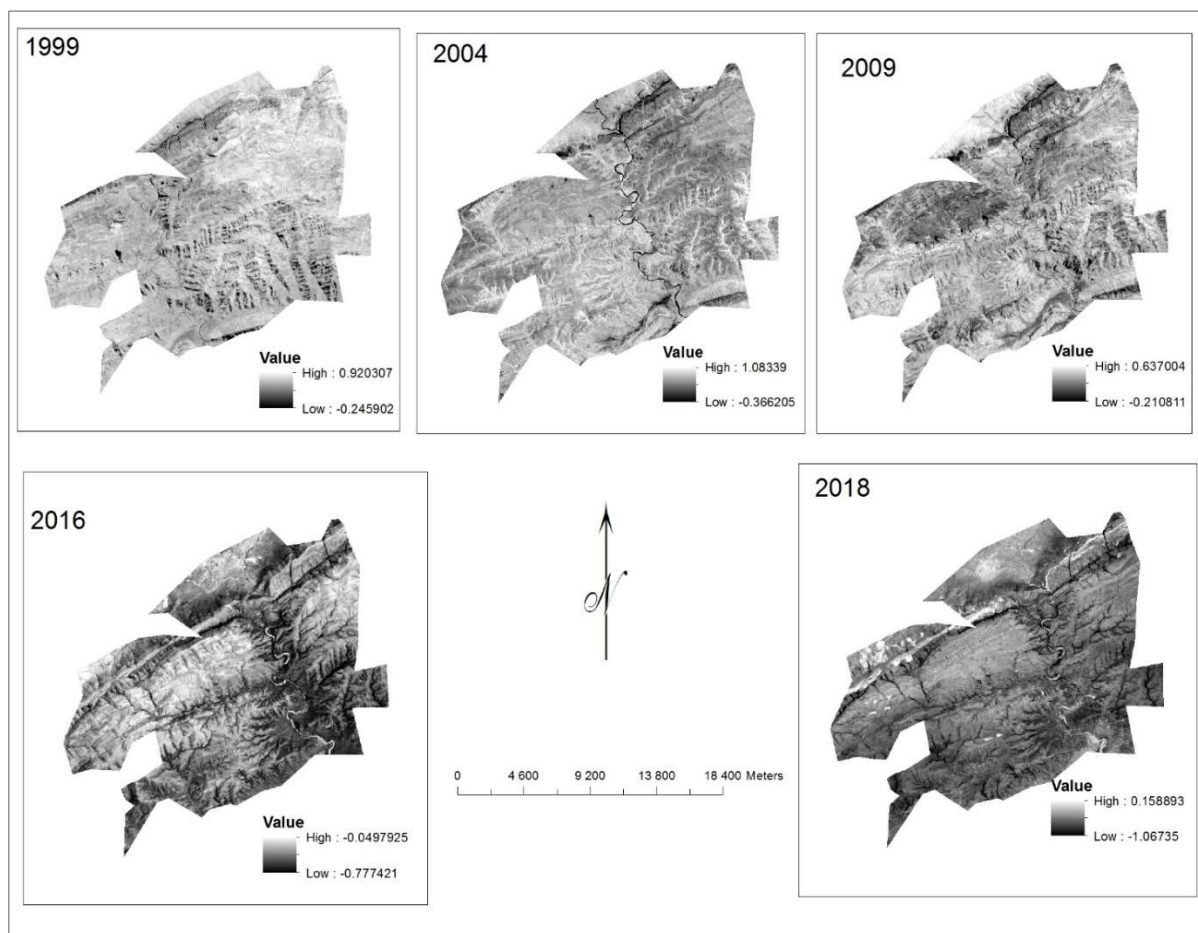


Figure 6.7: NDVI maps of study area showing the different NDVI values on the stipulated dates, (1999, 2004, 2009, 2016 and 2018)

NDVI was used to show the vegetation dynamics of the study area from 1999 to 2018. Figure 6.7 shows NDVI maps derived from the Landsat images of 1999, 2004, 2009, 2016 and 2018. In the year 1999, NDVI recorded the lowest value of -0.24 and the highest value of 0.92. In the year 2004, the lowest recorded value of NDVI was -0.3 and the highest value was 1. In the year 2009, the lowest recorded value of NDVI was -0.21 with the highest value at 0.63. In the year 2016, the lowest value was -0.77 while the highest value was -0.04. In 2018, the lowest recorded value was -1 and the highest value was 0.15. Typically, extreme negative values represent water; values around 0 represent impervious surfaces and NDVI values close to 1 represent dense green vegetation on all maps.

Table 6.3: NDVI values of the different years within the same study area. Range represents the NDVI values of each land cover types.

Year	Range
1999	-0.24 to 0.92
2004	-0.3 to 1
2009	-0.21 to 0.63

2016	-0.77 to -0.04
2018	-1 to 0.15

Discussion and conclusion

Land cover change is a global phenomenon that is driven by natural phenomena, population growth and migration from rural areas to urban areas. In most cases, land cover change in a protected area is the result of a failure in the governmental system or laws. Land cover change influences the natural environment in both positive and negative ways. Vegetation dynamics is one example that can be influenced by the land cover change. Monitoring of changes in land cover and associated effects on vegetation distribution through spatial analysis is important to understand the overall dynamics of a given protected area. Remote sensing can be used to quantify the spatial extent of these dynamics. Equally, regular and up-to-date information on changes in the protected area is required for urban planning or land use management. Remote sensing and GIS can be used as a tool in the appropriate allocation of services and infrastructure within the protected area (Mundia and Aniya, 2005).

This study set four objectives. The first objective was to spatially map the change in land cover within the given period of time (1999 – 2018). Different land cover and land use classes were determined by producing maps showing classes for different years. The second objective was to assess the performance of unsupervised classification scheme. In this regard, the changes of different classes were calculated in hectares for different years using the ISO cluster unsupervised classification scheme. The third objective was to quantify the spatial extent of changes as identified in the above-mentioned objective. This was achieved by computing an error matrix and graphs that showed the difference in change statistically according to the years that were stated (1999 – 2018).

The fourth objective was to test the utility of the Normalized Difference Vegetation Index (NDVI) in mapping the changes in land cover from 1999 to 2018. This was achieved by calculating NDVI for all the years (1999, 2004, 2009, 2016 and 2018). Satisfactory findings of this study are significant in a number of ways. For example, it provides a database of land cover distribution in the study area. The database will store the land use/land cover classes information, showing the dynamics in each class over the study period from 1999 to 2018. Such a database will be very critical in the management of the protected area in terms of environmental monitoring. In addition, the database can be input into long-term time series analysis of land cover dynamics within the study area. Furthermore, the database can be used as an input to the land use/land cover classification over a long period of time at the provincial level. The information can as well be used by a local and district municipality for designing management strategies, especially on sustainable development assessing areas which require vegetation conservation and firm laws on sustaining protected areas.

Comparison of reference data and classes derived from Landsat image

Eighteen samples were allocated from the built-up stratum, and fifteen samples from the vegetation stratum were used for assessing the accuracy of the classification. The comparison showed that seventeen sample points in the built-up stratum were correctly classified by the interpretation of Landsat image as shown in Table 6.4, whereas only ten of the fifteen samples were correctly classified for dense vegetation. Twenty-two samples were allocated for the grassland stratum ; however, only thirteen were correct. Twenty-seven points were allocated for bareland and a total of eighteen points were accurate. Thirteen points were allocated for the water and only nine were correct. This misclassification is attributed to the spectral confusion between the shadow and the water class in Landsat images. Most of the points that were

misallocated were due to a high level of spectral reflectance that looked either the same or similar in the different classes. Most of the misclassification in the classified images is due to the spectral reflectance that is similar and the different spatial reflectance in the images.

Overall, the accuracy level of Landsat for land cover classification in the study area was satisfactory (Table 6.5). It is important to note that the contribution of the broad classification approach used in the study was for high accuracy classification. For example, the study attempted to discriminate between dense vegetation and grassland instead of discriminating different types of species that constitute vegetation. Such broad classification was considered sufficient for the study.

Land cover change using classified maps

The study produced six generic classes (water, bareland, bare rock, dense vegetation, grassland and built-up areas) for each date from images acquired in 1999, 2004, 2009, 2016 and 2018. The generic classes that were computed for the first 5 years, (1999 – 2004). This was because the spectral reflectance that was statistically added did not show built-up area and bare rock during those times in the nature reserve. Nonetheless, comparisons of the classes across time show various dynamics in all classes during the study period. The water class occupied the least coverage (6%) in the 1999 and gradually increased over the years to 10% in 2004 and 14% in 2009, then decreased to 6% in 2016, then increased to 8% in 2018. Dense vegetation occupied 40% in 1999 and decreased to 29% in 2004 and 2009, then further decreased to 14% in 2016 but picked up in 2018 to 23%. The decrease in dense vegetation class could be caused when vegetation was cleared to create space for infrastructure development as can be seen in Figure 6.8.

Grassland class occupied 24% of the total area in 1999 and increased to 25% in 2004. This could be explained by the date at which the data was acquired: it was during the summer period and therefore most of the bareland was covered by grasslands and sparse vegetation. However, the grassland class decreased from 2004 to 2009 by 9% (from 25% to 16%). The appearance of bare rock and bare land due to issues like erosion might have contributed to this phenomenon. Another reason that there could be different statistics in the data is the different sensors that were used for different dates. This was unavoidable because there was no available data on the dates that were needed on either Landsat 8 or Landsat 5. For example, Landsat 5 did not have data for the study area during the summer seasons of the later dates and Landsat 8 did not have data for 1999 to 2004 in the designated study area.

According to Thompson (1996), the grassland class in this study comprises short grass, managed grass and tall herbaceous plants. There was a 5% increase in the grassland class coverage from 2009 to 2016 (16% to 21%). This is highly likely to be related to the awareness of conservation within the area and the date of acquisition of the Landsat images. That is, the image in 2009 was acquired in September, during which time there is more vegetation greenness (vigour) than in the month of March when the 2016 image was acquired. Comparison of maps derived from images were acquired at the same season but in different months. The grassland class further declined from 2016 to 2018 by a further 5% (from 21% to 16%). This was most likely due to the increase in built-up area as people started occupying the territory of the protected area.

Built-up area class increased from 0% in 1999, 2004 and 2009 to 19% coverage in 2016. The relative increase between 1999 and 2016 was particularly significant (100%) and may be attributed to the abandonment of the nature reserve by authorities and law. This is related to a dramatic increase in an urban settlement following the fall of apartheid. During this period, both grassland and dense vegetation decreased. The decrease in the built-up area from 2016 to

2018 was considerable (9%) and was related to a considerable increase (9%) in dense vegetation cover. This shows that the decrease in the coverage of built-up areas corresponded to the increase of vegetation covers both herbaceous and grassland.

The bare land class increased from 30% in 1999 to 35% in 2004 and decreased to 20% in 2009 to 26% coverage in 2016 and 23% in 2018. That the relative decrease between 1999 and 2016 was particularly significant may be attributed to the increase in grassland, dense vegetation and built-up areas. This is also related to a dramatic increase in an urban settlement following the fall of apartheid as well as different seasonal changes. During this period, bare rock had not been seen at 0% from 1999 to 2004. The class then dramatically increased, by 100% to 21% coverage in the area in 2009 and a further decrease to 13% in 2016, following an increase of 6% (19%) in 2018. This fluctuation is attributed to the increase in the similarity in spectral reflectance in the classified Landsat images of bare rock and built-up areas as well as an increase in built-up areas.

The findings of this study are consistent with various studies on urban growth and neglected protected areas. The beginning of unrestricted rural-urban movement saw an increase in urban migration (Christopher, 2001). In the case of Bewaarkloof Nature Reserve, the increase in built-up areas and buildings might be due to the increase in population size and the accompanying development of infrastructure as seen recently in hotel infrastructure. According to climate information obtained from South African Weather Services (www.saws.org), the nature reserve had an average of 98mm and 22mm of rainfall during the summer months of September to March respectively. The temperatures were averaging 32°C and 28°C during the same period. This may suggest that the weather aided to the growth in population and vegetation. From a further look into the reference data, it was observed that currently, the people living in the nature reserve practise subsistence farming and lodges and hotels have been established. It is then logical to argue that the vegetation was subsequently affected by the increase in built-up areas.

The total vegetation class (a combination of dense vegetation and grassland classes) covered 64% of the area in the year 1999 and decreased to 39% in the year 2018. This loss was inversely related to the increase in built-up areas. Therefore, it can be detected that an increase in urban expansion leads to the decrease in vegetation area. In 2004 the vegetation covered 54% of the area, showing a 10% decrease from 1999, while the built-up area increased by 100%. This could be explained by the increase in undocumented housing practices in the nature reserve. However, the decrease, though in a small amount, of built-up areas from 2016 to 2018 is unlikely to be a true reflection of the reality. One possible reason for this unlikely result could be more greenness during March (immediately after the rainy season) than in September of the 2018 and 2016 acquisition dates respectively. The combined vegetation decreases from 1999 to 2018 was 37%, while the built-up area increased by 65%. In general, vegetation coverage decreased from 1999 to 2018 by 49%. This result can be explained by the overall increase in population that invaded the natural vegetation areas.

Utility of NDVI to assess land cover change

NDVI was used to show the vegetation dynamics over the years as considered in the study. Although Landsat has a resolution of 30m, NDVI was effective in mapping the areas with high vegetation density and no vegetation at all. The NDVI results were interpreted both statistically and visually (Figure 6.11 & Table 6.6). Table 6.6 shows that in 1999 the highest NDVI value was 0.92, resembling high vegetation cover. The visual interpretation shows increased vegetation cover, especially in the low-lying areas. In 2004, the image shows an NDVI range of -0.3 to 1, showing an increased amount of vegetation. This can be attributed to the decrease

in bare land and the increase in grasslands during that year. In 2009, the highest NDVI value was 0.63, with a low of -0.21 which shows an abundance of non-vegetated areas as well as vegetated areas. 2016 and 2018 had very low NDVI values, with a high of -0.77 in 2016 and a low of -1 in 2018. This shows that in 2018 there was an abundance of bare-land and built-up areas.

In general, notwithstanding the difference in acquisition months and dates of the Landsat images, the NDVI values were effective in showing the dynamics of land cover in the study area. Thus, the vegetation dynamics maps of the NDVI threshold were not overly affected by the difference in months or years of the acquisition dates. This is supported by a study conducted by Douglas *et al.* (2012) that showed that NDVI values are not completely affected by different acquisition dates of scenes.

Conclusion

Four approaches were used to assess the dynamics of land cover change for the years of 1999, 2004, 2009, 2016 and 2018 in the Bewaarkloof Nature Reserve, Limpopo. In the first approach, a Landsat image of each date was classified using the maximum likelihood of the unsupervised classification and they were interpreted as water, dense vegetation, grassland, bareland, bare rock and built-up areas. A random sampling method was used. Subsequently, the interpreted classes of the different years were compared and an error matrix was produced. The results showed an increase in built-up areas and a decrease in the vegetation, bareland and water class from 1999 to 2018. Classes such as the bare rock showed a steady increase as time went by. This was attributed to an increase in unmonitored population growth in the nature reserve. This clearly indicates that new houses and infrastructure were constructed in an area that was previously occupied by natural vegetation types and land. Such alteration has a negative effect on the natural biodiversity of the area. The second approach utilised NDVI to assess land cover dynamics between the five dates that were considered in the study. The NDVI demonstrated its effectiveness in discriminating between the different land use/land cover types and the difference between vegetated areas and non-vegetated areas.

Finally, this study provides useful information that can be generalised as follows: remote sensing can be used effectively to determine the extent of generic vegetation types and urban growth over a given time period. In addition to the mapping of land use and land cover change, it can be useful in assessing vegetation degradation since natural areas are being threatened by urban expansion and population growth. Landsat imagery is suitable enough in assessing land use, and land cover dynamics gave the long-term and free availability of the images. In addition to the large spatial coverage it provides, it permits Landsat data to be used in studies that have wide spatial coverage. This study also has great potential in assisting informed decision-making. Although this study demonstrated the utility of Landsat in monitoring land cover change, a number of drawbacks have been noted; the dissimilarity of image acquisition months. The images were available for different months and this had an effect on the spectral reflectance. Unfortunately, images could not be obtained for similar months for the chosen dates of the study. There was an inability to obtain all images in summer or high vigour time. To obtain the true vegetation vigour, summer seasons were considered. This study could not obtain images acquired during summer seasons for all dates however, this produced a relatively coarse spatial resolution that might have limited the accuracy level. The 30m spatial resolution of the Landsat images poses challenges in correctly discriminating features especially in protected areas, which comprises features with varying reflectance properties.

References

- Ahmad, F. 2012. Detection of change in vegetation cover using multi-spectral and multi-temporal information for district Sargodha, Pakistan. *Sociedade & Natureza*, 24(3), 557-571.
- Aly, A. A., Al-Omran, A. M., Sallam, A. S., Al-Wabel, M. I. & Al-Shayaa, M. S. 2016. Vegetation cover change detection and assessment in arid environment using multi-temporal remote sensing images and ecosystem management approach. *Solid Earth*, 7(2), 713-725.
- Ashraf M. Dewan, Yasushi Yamaguchi, & Md. Ziaur Rahman. 2012. Dynamics of land use/cover changes and the analysis of landscape fragmentation in Dhaka metropolitan, Bangladesh. *GeoJournal*, 77(3), 315-330.
- Bharathkumar, L. & Mohammed-Aslam, M. A. 2015a. Crop pattern mapping of Tumkur taluk using NDVI technique: A remote sensing and GIS approach. *Aquatic Procedia*, 4, 1397-1404.
- Bontemps, S., Langner, A. & Defourny, P. 2012. Monitoring forest changes in Borneo on a yearly basis by an object-based change detection algorithm using SPOT-VEGETATION time series. *International Journal of Remote Sensing*, 33(15), 4673-4699.
- Brisco, B., Schmitt, A., Murnaghan, K., Kaya, S. & Roth, A. 2013. SAR polarimetric change detection for flooded vegetation. *International Journal of Digital Earth*, 6(2), 103-114.
- Cheng, M., Jin, J., Zhang, J., Jiang, H. & Wang, R. 2018. Effect of climate change on vegetation phenology of different land-cover types on the Tibetan plateau. *International Journal of Remote Sensing*, 39(2), 470-487.
- Chesnel, V, Merino-Tom, Fernandez, L. P., Villa, E. & Samankassou, E. 2016. Isotopic fingerprints of Milankovitch cycles in Pennsylvanian carbonate platform-top deposits: The valdorria record, northern Spain. *Terra Nova*, 28(5), 364-373.
- Cundill, G., Thondhlana, G., Sisitka, L., Shackleton, S. & Blore, M. 2013. Land claims and the pursuit of co-management on four protected areas in South Africa
doi://doi.org/10.1016/j.landusepol.2013.05.016
- Drobyshev, I., Bergeron, Y., Girardin, M. P., Gauthier, S., Ols, C. & Ojal, J. 2017. Strong gradients in forest sensitivity to climate change revealed by dynamics of forest fire cycles in the post little ice age era. *Journal of Geophysical Research: Biogeosciences*, 122(10; 10), 2605-2616.
- Dubovyk, O., Menz, G., & Khamzina, A. 2012. Trend analysis of MODIS time-series using different vegetation indices for monitoring of cropland degradation and abandonment in central Asia. Paper presented at the IEEE International Geoscience and Remote Sensing Symposium.
- Dutta, D., Kundu, A., Patel, N. R., Saha, S. K., & Siddiqui, A. R. 2015. Assessment of agricultural drought in Rajasthan (India) using remote sensing derived vegetation condition index (VCI) and standardized precipitation index (SPI). *The Egyptian Journal of Remote Sensing and Space Science*, 18(1), 53-63.
- Faramarzi, M., Heidarijadi, Z., Mohamadi, A., & Heydari, M. 2018. Detection of vegetation changes in relation to normalized difference vegetation index (NDVI) in semi-arid rangeland in western Iran. *Journal of Agricultural Science & Technology*, 20(1), 51-60.
- Fensholt, R., Rasmussen, K., Nielsen, T. T., & Mbow, C. 2009. Evaluation of earth

- observation based long term vegetation trends - intercomparing NDVI time series trend analysis consistency of Sahel from AVHRR GIMMS, Terra MODIS and SPOT VGT data. *Remote Sensing of Environment*, 113(9), 1886-1898.
- Gandhi, G. M., Parthiban, S., Thummalu, N. & Christy, A. 2015. Ndvi: Vegetation change detection using remote sensing and gis – A case study of Vellore district. *Procedia Computer Science*, 57, 1199-1210.
- Gaoru Zhu, Xuegong Xu, Zongwen Ma, Lifen Xu, & John H. Porter. 2012. Spatial dynamics and zoning of coastal land-use change along bohai bay, china, during 1979-2008. *Journal of Coastal Research*, 28(5), 1186-1196.
- Han, C., Maolin, C., Jincheng, S., Run, H., & Jun, Y. 2011. The detection of vegetation change in wuhan city based on object-oriented method. Paper presented at the [???
- Haque, M. I. & Basak, R. 2017. Land cover change detection using GIS and remote sensing techniques: A spatio-temporal study on tanguar haor, sunamganj, Bangladesh. *The Egyptian Journal of Remote Sensing and Space Science*, 20(2), 251-263.
- Harris, E. B., Stromberg, C. A. E., Sheldon, N. D., Smith, S. Y. & Vilhena, D. A. 2017. Vegetation response during the lead-up to the middle miocene warming event in the northern rocky mountains, USA. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 485, 401-415.
- Kent W. Hilbert. 2006. Land cover change within the grand bay national estuarine research reserve: 1974-2001. *Journal of Coastal Research*, 22(6), 1552-1557.
- Khan, D. & Samadder, S. 2016. Allocation of solid waste collection bins and route optimisation using geographical information system: A case study of dhanbad city, india. *Waste Management & Research*, 34(7), 666-676.
- Kurnaz, S., Rustamov, R. B., Gambarova, Y. M., Gambarov, A. Y., Zeynalova, M. H., Ilarslan, M., Ince, F., Kaynak, O. & Basturk, S. 2011. Rare vegetation change detection in the gobustan conservation area, azerbaijan. Paper presented at the Proceedings of 5th International Conference on Recent Advances in Space Technologies - RAST2011.
- Kyung-Soo Han, Youn-Young Park, & Jong-Min Yeom. 2015. Detection of change in vegetation in the surrounding desert areas of northwest china and mongolia with multi-temporal satellite images. *Asia-Pacific Journal of Atmospheric Sciences*, 51(2), 173-181.
- Le, P.V.V. & Kumar, P. 2017. Interaction between eco-hydrologic dynamics and microtopographic variability under climate change. *Water Resources Research*, 53(10; 10), 8383-8403.
- Li, F., Song, G., Liujun, Z., Yanan, Z. & Di, L. 2017. Urban vegetation phenology analysis using high spatio-temporal NDVI time series. *Urban Forestry & Urban Greening*, 25, 43-57.
- Lin, Z., Chunmei, M., Leipe, C., Long, T., Liu, K., Lu, H., Lingyu, T., Yu, Z., Wagner, M., & Tarasov, P. E. 2017). Holocene vegetation dynamics in response to climate change and human activities derived from pollen and charcoal records from southeastern china. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 485, 644-660.
- Liu, Y. 2018. Introduction to land use and rural sustainability in China
doi://doi.org/10.1016/j.landusepol.2018.01.032
- Lu, X., & Ke, S. 2017. Evaluating the effectiveness of sustainable urban land use in China from the perspective of sustainable urbanisation. *Habitat International*, 77, 90-98.
- Markogianni, V., Dimitriou, E., & Kalivas, D. P. 2012. Land-use and vegetation change

- detection in plastira artificial lake catchment (Greece) by using remote-sensing and GIS techniques. *International Journal of Remote Sensing*, 34(4), 1265-1281.
- Martinez, B. & Gilabert, M. A. 2009. Vegetation dynamics from NDVI time series analysis using the wavelet transform. *Remote Sensing of Environment*, 113(9), 1823-1842.
- Michelsen, O., Syverhuset, A. O., Pedersen, B. & Holten, J. I. 2011. The impact of climate change on recent vegetation changes on dovrefjell, Norway. *Diversity*, 3(4), 91-111.
- Netshipale, A. J., Oosting, S. J., Raidimi, E. N., Mashiloane, M. L. & de Boer, Imke J. M. 2017. Land reform in South Africa: Beneficiary participation and impact on land use in the Waterberg district [doi://doi.org/10.1016/j.njas.2017.07.003](https://doi.org/10.1016/j.njas.2017.07.003)
- O'Connell, J. L., Mishra, D. R., Cotten, D. L., Wang, L. & Alber, M. 2017. The tidal marsh inundation index (TMII): An inundation filter to flag flooded pixels and improve MODIS tidal marsh vegetation time-series analysis. *Remote Sensing of Environment*, 201, 34-46.
- Oliveira, L. M. T., Frana, G. B., Nicacio, R. M., Antunes, M. A. H., Costa, T. C. C., Torres, A. R., J. & Frana, J. R. A. 2010. A study of the el nio-southern oscillation influence on vegetation indices in brazil using time series analysis from 1995 to 1999. *International Journal of Remote Sensing*, 31(2), 423-437.
- Panigrahi, S., Verma, K. & Tripathi, P. 2016. An efficient approach to detect sudden changes in vegetation index time series for land change detection. *IETE Technical Review*, 33(5), 539-556.
- Pellikka, P. K. E., Heikinheimo, V., Hietanen, J., Schäfer, E., Siljander, M. & Heiskanen, J. 2018. Impact of land cover change on aboveground carbon stocks in afro-montane landscape in Kenya [doi://doi.org/10.1016/j.apgeog.2018.03.017](https://doi.org/10.1016/j.apgeog.2018.03.017)
- Pillai, A.A.S., Anoop, A., Sankaran, M., Sanyal, P., Jha, D. K. & Ratnam, J. 2017. Mid-late holocene vegetation response to climatic drivers and biotic disturbances in the banni grasslands of western india. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 485, 869-878.
- Pladsrichuay, S. & Mongkolsawat, C. 2016. Integrated satellite-derived indices to estimate change detection of vegetation canopy density in the lower chi basin, northeast Thailand. Paper presented at the 2016 International Computer Science and Engineering Conference (ICSEC).
- Quamar, M. F. & Bera, S. K. 2017. Pollen records related to vegetation and climate change from northern chhattisgarh, central India during the late quaternary. *Palynology*, 41(1; 1), 17-30.
- Rawat, J. S. & Kumar, M. 2015. Monitoring land use/cover change using remote sensing and GIS techniques: A case study of hawalbagh block, district almora, uttarakhand, india. *The Egyptian Journal of Remote Sensing and Space Science*, 18(1), 77-84.
- Renza, D., Martinez, E., Molina, I. & Ballesteros L, D. M. 2017. Unsupervised change detection in a particular vegetation land cover type using spectral angle mapper. *Advances in Space Research*, 59(8), 2019-2031.
- Sakarya, U. & Demirpolat, C. 2017. SAR image time series analysis in vegetation classification using global and local information based linear discriminant analysis. Paper presented at the 25th Signal Processing and Communications Applications Conference (SIU).
- Shuyu, W. & Jun, L. 2015. Characteristics of milankovitch cycle in eocene formation, eastern depression of the north yellow sea basin. *Earth Science - Journal of China University of Geosciences*, 40(11), 1933-1944.

- Sruthi, S. & Aslam, M. A. M. 2015. Agricultural drought analysis using the NDVI and land surface temperature data; a case study of Raichur district. *Aquatic Procedia*, 4, 1258-1264.
- T'shaus, J., Dubovyk, O., Khamzina, A. & Menz, G. 2014. Comparison of medium spatial resolution ENVISAT-MERIS and terra-MODIS time series for vegetation decline analysis: A case study in central asia MDPI Publishing. doi:10.3390/rs6065238
- Tao, J., Kong, X., Wang, Y. & Chen, R. 2016. A study of vegetation phenology in the analysis of urbanization process based on time-series MODIS data. Paper presented at the IEEE International Geoscience and Remote Sensing Symposium (IGARSS).
- Teng, S. P., Chen, Y. K., Cheng, K. S. & Lo, H. C. 2008. Hypothesis-test-based landcover change detection using multi-temporal satellite images – A comparative study doi://doi.org/10.1016/j.asr.2007.06.064
- Van Hoek, M., Jia, L., Zhou, J., Zheng, C. & Menenti, M. 2016. Early drought detection by spectral analysis of satellite time series of precipitation and normalized difference vegetation index (NDVI). *Remote Sensing*, 8(5), 422.
- Yang, L., Homer, C., Brock, J. & Fry, J. 2013. An efficient method for change detection of soil, vegetation and water in the northern gulf of Mexico wetland ecosystem. *International Journal of Remote Sensing*, 34(18), 6321-6336.
- Yuting, M., Weiming, W., Jianfang, H., Jixiao, Z. & Yangjun, L. 2017. Vegetation and climate changes over the last 30 000 years on the Leizhou peninsula, southern China, inferred from the pollen record of huguangyan maar lake. *Boreas*, 46(3; 3), 525-540.
- Zhang, C., Smith, M., Lv, J. & Fang, C. (2017a). Applying time series landsat data for vegetation change analysis in the Florida everglades water conservation area 2A during 1996-2016. *International Journal of Applied Earth Observation and Geoinformation*, 57, 214-223.
- Zhang, M., Li, Z., Tian, B., Zhou, J. & Tang, P. 2016. The backscattering characteristics of wetland vegetation and water-level changes detection using multi-mode SAR: A case study. *International Journal of Applied Earth Observation and Geoinformation*, 45, 1-13.
- Zhao, W., Tarasov, P. E., Lozhkin, A. V., Anderson, P. M., Andreev, A. A., Korzun, J. A., Melles, M., Nedorubova, E. Y., & Wennrich, V. 2018. High-latitude vegetation and climate changes during the mid-Pleistocene transition inferred from a palynological record from lake el'gygytgyn, NE Russian arctic. *Boreas*, 47(1; 1), 137-149.
- Zhou, J., Yu, B. & Qin, J. 2014. Multi-level spatial analysis for change detection of urban vegetation at individual tree scale. *Remote Sensing*, 6(9), 9086-9103.

Chapter 7: A spatial analysis of the influence of infrastructural planning on solid waste management: Lessons from Peleng township in Lobatse, Botswana

Nametso D. Phonchi-Tshekiso,^{a1} Patricia K. Mogomotsi,^a
Goemeone E.J. Mogomotsi^a and Reniko Gondo^a

^a Okavango Research Institute, University of Botswana, Maun, Botswana.
phonchi41@gmail.com

Abstract

Like most urban settlements in developing countries, Lobatse, a town in Botswana, experiences poor solid waste management. The town's hilltop-located informal settlement and its associated household accessibility, poses a threat to effective service provision in this locality. There is infrequent solid waste collection, illegal dumping and uncollected heaps of waste in the alleys and streets, which threaten the environment's aesthetic appeal and public health. Even though solid waste management is widely researched, there is scanty literature addressing the influence of physical environmental attributes on solid waste management service provision in informal settlements. The aim of this study is to investigate the nexus between physical infrastructural planning and waste management service in Peleng township. A total of 91 randomly selected households are interviewed, together with Lobatse Town Council officials and the Ward development committee in Peleng. ArcGIS is used for household mapping and visualisation of the physical infrastructure in the informal settlement. This study concludes that the community of Peleng is at the forefront of dealing with waste problems in their settlement, but their interventions have fallen short of becoming profitable and sustainable due to an initial failure of government to integrate solid waste management into mainstream urban development planning. Findings of this study showed that there is minimal government intervention for improved solid waste management in the area. It recommends that adequate attention be given to road infrastructure and physical developments to order solid waste management in Peleng, Lobatse.

Keywords: ArcGIS, informal settlements, infrastructural planning, solid waste management, topography, urban development, Lobatse, Botswana

Introduction

Poor management of solid waste is a global issue that should be of concern to every urban resident (Subbash, 2010) in both formal and informal settlements. The management of solid waste is faced with enormous expenditure challenges, especially in developing countries (Sharholy *et al.* 2007), because it is not only a technical problem, but a phenomenon surrounded by complex factors such as political, legal, socio-cultural, environmental and economic factors (Mmereki, 2018). Urban areas experiencing population growth and urbanisation in developing countries often lack resources and institutional capacity to provide adequate solid waste

¹ Corresponding author: Nametso D Phonchi-Tshekiso, Okavango Research Institute, University of Botswana, P/Bag 285 Maun, Botswana. Email: *phonchi41@gmail.com*

management services (Hagos *et al.* 2012).

A diverse range of inefficiencies, such as low collection coverage, irregular collection, dumping and burning of domestic waste, impede sustainable waste management systems (Thomas-Hope, 1998; Manaf *et al.* 2009). In fact, about two billion people in the world's population have no regular access to a solid waste collection service (Besen & Fracalanza, 2016), despite the fact that solid waste collection cost accounts for 70-80% of total costs for solid waste management in most developing countries (Cointreau & Hornig, 2003). There are limited financial capacities for governments and low priorities assigned to solid waste management (Wang *et al.* 2014).

Studies have found that the functionality of solid waste management service is largely contingent on how well the services adapt to the social, economic, environmental and political context of a city or a country (Schubeler *et al.* 1996). Of all the factors found to be challenging solid waste management, there is limited research investigating the influence of environmental or physical factors on solid waste management in informal settlements. This study is significant to point physical planners, policy makers and waste management stakeholders towards the waste management challenges faced by this township due to its physical attributes, and to broadly investigate how limited infrastructure in unplanned settlements challenges waste management efforts. Government interventions are often missing and inadequate to solve the problem of waste in this informal settlement, therefore this study relevantly informs future designing and planning of solid waste management provision by highlighting alternative approaches on how to improve solid waste management in informal settlements.

Literature review

Waste management has become a global problem and the situation is deteriorating in urban areas in developing countries (Manaf *et al.* 2009; Subbash 2010; Subhan *et al.* 2014). Solid waste management is a broad and highly researched area among various scholars (Schubeler *et al.* 1996; Asnani 2006; Manaf *et al.* 2009; Subbash, 2010; Hagos *et al.* 2012), who emphasise that effective and efficient solid waste management is vital for preventing environmental and health hazards which have harmful consequences for the communities and the ecosystem (Schubeler *et al.* 1996; Subhan *et al.* 2014). Rapid uncontrolled and unplanned urbanisation in developing countries brings untoward hostile effects of environmental degradation (Subbash, 2010; Kwetey *et al.* 2014; Gutberlet *et al.* 2017).

Informal settlements mainly in the global South face severe health consequences and environmental impacts as a result of ineffective solid waste management (Gutberlet *et al.* 2017). The collection and transportation of waste in Botswana is limited by inadequate equipment, personnel and financial resources facing all local authorities (Kgosiesele & Zhaohui, 2010). Peleng ward, an informal settlement in the town of Lobatse, Botswana, is faced by environmental problems such as illegal waste dumping and burning of waste, which are recurrent within the haphazardly scattered neighbourhood, with dilapidated household structures.

The haphazard expansion of informal settlements is said to be one of the recurring problems in developing countries, which causes unnecessary costs for the provision of basic infrastructure such as roads, water mains, and sewer and drainage pipes in existing networks (Areola *et al.* 2014). Equally so, there are poor drainages systems, inaccessible households and a physical manifestation of waste and other consequent development problems in the Peleng township, which have a negative impact on public health, the environment, as well as service provision for such a place. Studies on the physical attributes of informal settlements in relation to solid waste management service provision are generally unknown in Botswana. However,

research has revealed that uncontrolled urbanisation is responsible for many problems experienced by urban centers today, resulting in a substandard living environment, acute problems of drinking water pollution, unsafe disposal of waste and traffic congestion (Verma *et al.* 2009).

Methods and materials

Description of the study area

Lobatse is an expatriate-initiated town located approximately 70 km south of Gaborone, the capital city of Botswana. It is surrounded by hills, leaving 46% of it undevelopable (Areola *et al.* 2014), with an oddity of spatial distribution of households across its limited space. It has a population size of about 29007 (CSO, 2011). Peleng was the first and oldest settlement in Lobatse, established as a crowded squatter camp by Africans who were then restricted from living in areas reserved for the White European settler population (Areola *et al.* 2014). It is the largest and most populated area in Lobatse, located on the hill slope east of the town with non-uniformly planned households stretching across the hill slope. The households are connected by both tarred and untarred road infrastructure as illustrated in Figure 7.1. Road infrastructure is mainly made up of untarred roads, comprising gravel and concrete slab pavements especially in areas on high elevations, and on the steepest locations.

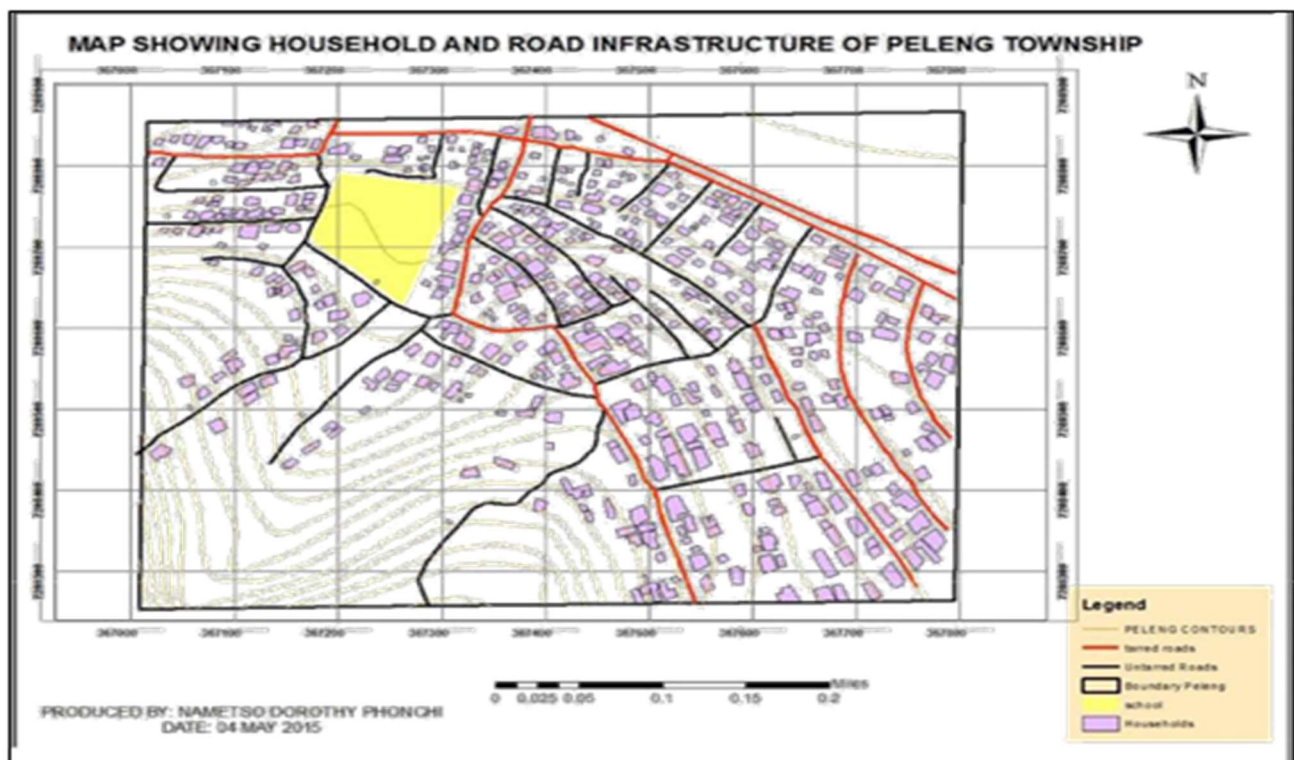


Figure 7.1: Map showing household and road infrastructure of Peleng township

Source: Creation of the first author

Data collection and sampling criterion

This study used a mixed method approach by using a quantitative approach vis-à-vis a Geographic Information System (GIS) map-based analysis. A structured questionnaire and an

interview guide were used to collect primary data from households and key informants, respectively. A structured questionnaire allows for research to study large numbers of people whose results are representative of a much wider population and could be generalised (McNeill, 2006), whereas key informant interviews give information that otherwise could be deemed confidential, helping to extract even more information from respondents through probing (Kumar, 1989).

Using a purposive sampling technique, key informant interviewees were selected from officials from the Lobatse Town Council and the Department of Waste Management and Sanitation, based on knowledge and interviewees' expertise. Three senior officials at the Department of Waste Management and Sanitation were interviewed face-to-face to solicit their perceptions, experiences and judgements on solid waste management service provision, strategies as well as solid waste management practices, in Peleng. Using a simple random sampling method, survey questionnaires were administered to 91 households in Peleng to ensure a representation of households and to substantiate the spatial data. Data saturation was reached with the 91st respondent. The study used the plot number list of Lobatse households derived from enumeration maps. Thereafter, a simple random selection using random number tables was employed to administer the survey questionnaire. A total of 468 households on the southern side of Peleng ward were mapped and analysed, using an ArcGIS application. Since solid waste management parameters such as transportation networks and location of households are essential to this study, they were mapped. With its unique physical properties, the south side of the hill slope was selected using a purposive sampling method. This targeted households that spread across both the gentle and the steepest slope. Households with both tarred and untarred road access were mapped. ArcGIS Application

The study utilised ArcGIS because of its visualisation capacity, to map and capture the spatial context of households in Peleng. ArcGIS consists of a geo-referenced spatial database including solid waste management parameters such as transportation networks and location of households, essential for the study. The study utilised ArcGIS as shown below.

Integration of three ArcGIS applications

ArcMap, ArcCatalog and Arc Toolbox for making maps were integrated for displaying, querying and editing, creating and analysing ArcGIS data. ArcCatalog organised and managed all ArcGIS data, where ArcCatalog tools were used for finding geographic information and defining structure for geographic data layers. ArcToolbox provided necessary tools for conversion of data, managing coordinate systems, as well as changing map projections.

GIS Query

Spatial data was queried using *select by location* to find out location and accessibility of households to road infrastructure so that the interaction between multiple data sets, (roads and households) was visualised. This selection was used to retrieve households within distances of a tarred or distances of an untarred road access.

Data analysis

Qualitative data was analysed systematically by sorting, organising and cleaning the data ; thereafter coding it into recurrent themes. It was then thematically arranged into patterns of similarity, summarised and reported as textual data.

Distance analysis

Analysis of spatial data was based on distance analysis. Interaction between household location, distances and accessibility of households by solid waste collectors was assessed using ArcGIS *select by location* analysis. The selection focused on households within the maximum distance of 20m from the road and a minimum distance of 10m from the road. These selections ensured selection of houses which have access to the road infrastructure, leaving out those with no access to reveal the relationship between inadequate physical infrastructural planning and poor waste management practices in Peleng.

Digital Terrain Analysis

Digital Terrain Analysis was applied to the data to create a three-dimensional digital elevation model of maps, to show the distribution of households across the slopes. A digital terrain analysis allowed for interpolation from point data (usually elevations), derivation of slopes and slope aspects. These physical attributes of varying topographic surfaces of Peleng make it possible to relate the data to real-world elevations and analyse how these varied surfaces might affect solid waste collection.

Validity and reliability

External Validity is considered in this study because the research design applied allows for coverage and measurement of all aspects of what this research intends to investigate. The samples selected were representative of all households in Peleng, Lobatse, thus results can be generalised. Reliability was satisfied by pre-testing the questionnaire prior to the survey, which ensured stability and consistency of the results.

Results and discussion

Physical environment and solid waste management practice

Basic infrastructure in Peleng township is characterised by a haphazard expansion of human settlements across a hill slope. Generally, the households are inaccessible when ascending the hill slope, whilst households at the foot of the slope have access to mainly tarred roads. The roads between households are very narrow when ascending the hill, due to inaccessibility of households. There are untarred roads of gravel and pavements especially in high and the steepest locations. Information gathered from ground truthing showed that there are narrow paved roads of poor quality, which are cracked and bumpy, with potholes. According to Benna & Benna (2017), poor urban infrastructure in informal settlements is common, and often located in undesignated or vulnerable locations.

According to the key interviewees from the Ward Development Committee (WDCs), the general environmental concerns in Lobatse are illegal dumping of household waste, and dirty streets. There is commonly a poor solid waste management practice in this informal settlement, characterised by poverty and low socio-economic status. About 90% of household respondents reported that they face a challenge of baboons, cows and dog scavengers in waste bins and on illegal waste heaps, from farms located in the hilltop. About 85% households did not have waste bins for solid waste disposal, while 15 % still had waste bins that were provided free by the Town Council.

Households that did not have waste bins reported that their waste bins were dilapidated or had been destroyed by animal scavengers, so they resorted to burning and illegal dumping in nearby bushes. When responding to waste management services in the town, the council officers reported that there was limited finance and institutional capacity to provide efficient

bins and to repair their fleet for regular solid waste collection. Simatele and Etambakonga (2015) have observed that a lack of financial resources does not only make it hard to manage waste effectively but hinders communities from solving urban challenges and problems such as pollution. They further believe that limited available resources contribute to deterioration in road maintenance, waste management infrastructure, sewage and water systems, which are nonetheless vital elements for solid waste management (Simatele & Etambakonga, 2015).

Influence of infrastructure on waste management

In Lobatse, solid waste collection service is characterised by a door to door pick up from solid waste bins. Key informants from the Town Council reported that previously there were open skips and dumping sites in the town, but their operation was stopped due to mismanagement by residents. Most households (68%) nonetheless perceived that even though skips encouraged filth and mishandling of waste, solid waste did not accrue for long in their yards. It therefore appears that Peleng households were in favour of open skips and did know why the old open skips and dumping sites were no longer in operation. Good governance, however, entails informing the community of policy or service changes. Furthermore, urban environmental management is concerned with the provision of a safe human habitat and environment through the provision of adequate sanitation and regular collection and safe disposal of waste (Wokekoro & Inyang, 2014).

About 87% of households reported that they were not satisfied with solid waste management service provision in Peleng township. Only 5% of households reported that they received solid waste collection twice a week, and these were households located at the foot of the hill, which had access to tarred road infrastructure. To analyse this data, spatial data was queried using the *select by location* function in ArcGIS, to investigate the location and accessibility of households to road infrastructure (Figure 7.2 below). Selection was based on households with a distance of 10m, 15m and 20m from the road, in view of the minimum distance requirements of households in urban areas in Botswana.

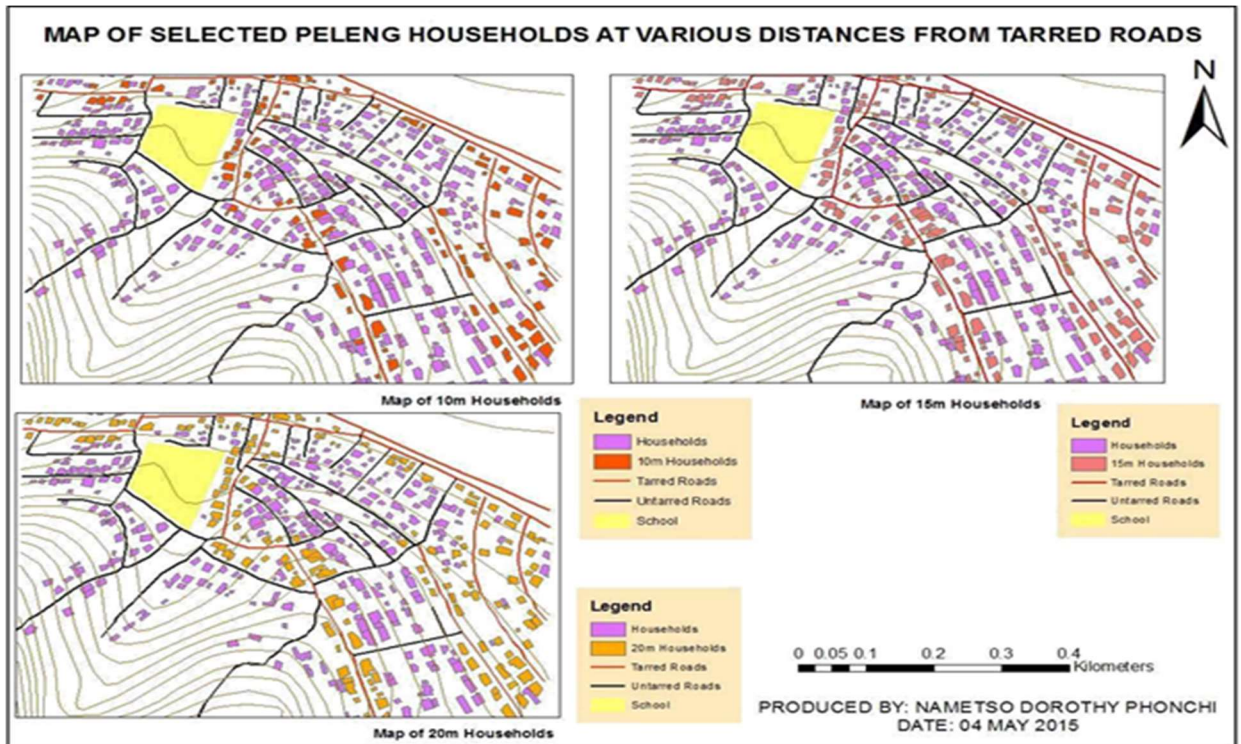


Figure 7.2: Selected households at 10m, 15m & 20m

In the selection of households within 10m from the road, only 96 (21%) households (in red) were selected (Figure 7.2, top left). At 15m from the road, 139 (28%) households selected, while at 20m, 168 (36%) households were selected. About 65 (15%) households were left unselected, which indicates that they are located 20m away from tarred road access. This visually depicts that most households in Peleng do not have road infrastructure access, except narrow and untarred roads, which results in infrequent solid waste collection and increases the risk of poor waste management both at source and at service provision level. Previous research emphasises that inefficient sewage systems, filthy streets, illegal dumping and non-existent solid waste collection constitute a crisis in informal areas of inadequate infrastructure (Benna & Benna, 2017).

As observable from Figure 7.2 above, most of the unselected inaccessible households were located within a valley, which makes door to door waste collection impractical. The selection applied depicts an increasing trend of inaccessibility of households with increasing distance from road infrastructure, which implies that there is minimal planning for service provision in this locality. In fact, only a few city governments are said to recognise the importance of improved infrastructure for supporting the diverse and largely populated informal communities (Nunan & Satterthwaite, 2001). Tan *et al.* (2005) observes that a poorly planned urban expansion leads to inefficient service provision and environmental pollution. The inaccessibility of households and inadequate infrastructure in informal settlements furthermore poses threats to public health and urban environmental upkeep (Zapata Campos & Zapata, 2013).

Governance structure for solid waste management in this township is weak and shaped by the discordance of solid waste services such as poor solid waste collection and disposal services caused by a lack of infrastructure and finance by the Lobatse Town Council. However, according to Oduro-Kwarteng & Pieter van Dijk (2017) the enabling environment for

regulating efficient solid waste collection is concerned with the use of policies, strategies, legal instruments, regulation, political will, as well as commitment to good SWM. In the current times, however, it seems that the Town Council is mainly concerned with solid waste collection in their service provision; however, they were still failing this community.

Solid waste collection services

Solid waste collection is one of the current priorities of Lobatse Town Council and is one of the strategies in which the Council provides for waste management in the town (Kwailane *et al.* 2016). One of the Lobatse Town Council officials interviewed reported that in 2014 the solid waste collection function was outsourced to private companies on short contracts to alleviate challenges of continuous fleet breakdown that were experienced by the Council. Nevertheless, this one-year contract was not renewed in 2015 due to budgetary constraints. Consequently, Lobatse Town Council collects household waste in Peleng Ward, but continuous fleet breakdowns remain. For instance, at the time of the interview, the entire town of Lobatse was serviced with only two vehicles, while seven had broken down and were awaiting repairs.

A digital terrain analysis was therefore established by mapping a Digital Elevation Model (DEM) of Peleng township, using Triangulated irregular networks (TINs) to reveal accessibility, or lack thereof, of some households in the area (Figure 7.3). A digital terrain analysis allows for interpolation from point data (elevations), derivation of slopes and slope aspects. These topographic surfaces of Peleng have the power to relate the data to real-world elevations and analyse how these varied surfaces may affect solid waste collection. Figure 7.3 reveals that Peleng households are distributed across even gentle and uneven steep slopes, which this study concluded contributes to the continuous breakdown of fleet which were alluded to by the Council key informant.

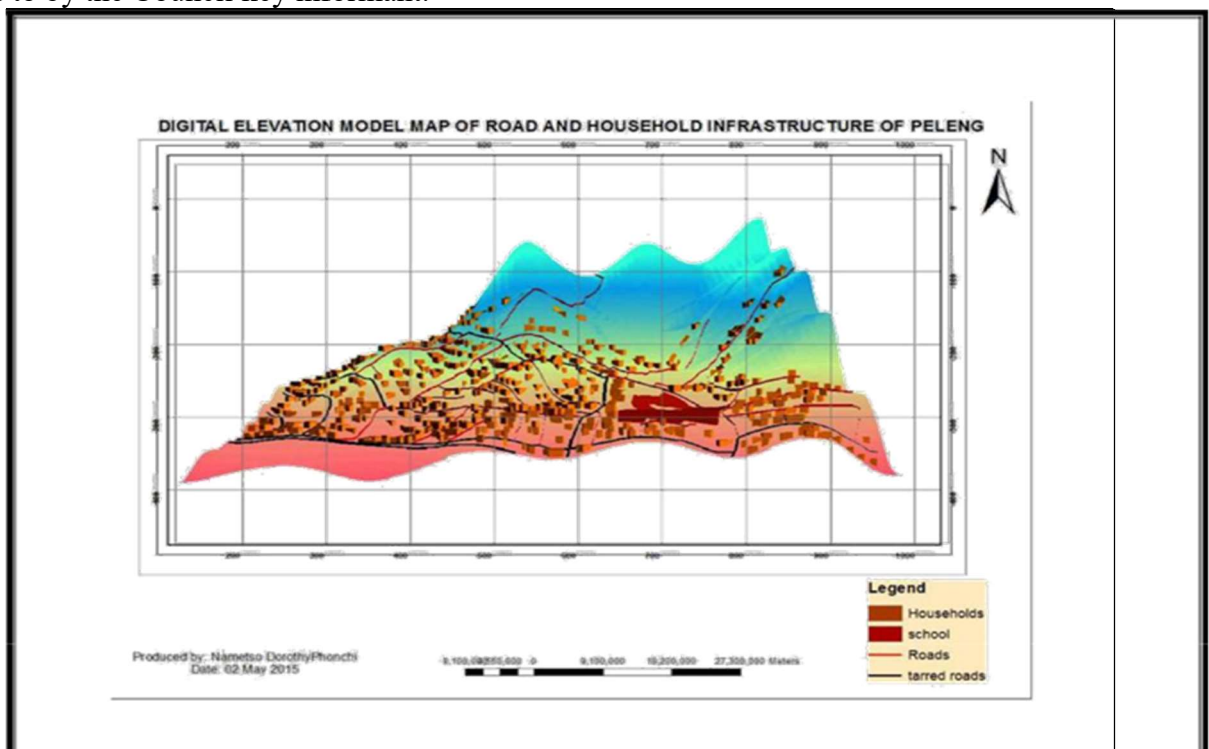


Figure 7.3: Digital Elevation Model of road and household infrastructure in Peleng ward

About 95% of households reported insufficient, inconsistent and delayed solid waste collection, which 27% described as sometimes taking up to a month, or no collection at all at some households, since waste collection compactors utilise main accessible roads for collection. It has been argued that such problems as insufficient solid waste collection, inconsistencies and delays of solid waste collection often hinder successful waste management (GOB, 1998) and deteriorate environmental quality in Botswana (Kgathi & Bolaane, 2001). Some of the Lobatse Town Council officials interviewed in this study indicated that due to financial constraints and frequent breakdowns of the fleet of waste collection vehicles, solid waste is collected once in two weeks, sometimes once a month. They reported that the Council has inadequate finances, and limited resource capacity to repair, service and buy compactors and equipment required for solid waste collection. It was stated that even though the standard frequency of solid waste collection at residential areas in Botswana towns is every 3.5 days per week, collection in Lobatse depends on availability of compactor vehicles. Previous studies have noted that the wealth of a city and responsiveness of local governments to the needs of urban groups are noted as some of the main factors that influence the provision of environmental infrastructure (Nunan & Satterthwaite, 2001).

Peleng township is the most populated area in Lobatse, and pollution in this area is reported by key informants to be the worst in the town. Key informants also reported a mishandling of solid waste at households as a result of a lack of segregation of waste prior to collection, and mismanagement of storage bins given freely to households. All households however, demonstrated an awareness of the impacts of solid waste on their health and environment. About 85% of the household respondents in this area belong to community solid waste management programmes such as litter picking campaigns, cluster groups, ('*environmental watchdogs*'). Most households (53%) located at the hilltop reported that they mostly opt for littering, burying, burning and illegal dumping of solid waste in the streets or in the forests nearby as cheap and available alternatives for disposing of solid waste.

The participation of residents in solid waste management is indispensable (Nunan & Satterthwaite, 2001); however, the spatial nature and environmental properties of Lobatse, the inaccessibility of many households (Areola *et al.* 2014; Kwailane *et al.* 2015) and its lack of adequate infrastructure hinder both efforts of households and government to effectively manage their solid waste. The relationship of road accessibility and household access helps to detect impacts of this setting on waste management and pollution associated with this locality. This study reveals that there has been a failure to incorporate future infrastructural adjustments in urban planning for the provision of solid waste management services. It is argued that sometimes political factors and governance on solid waste management in informal settlements impede residents' efforts of waste management in informal settlements (Nunan & Satterthwaite, 2001), as there is slight connection between the policies and priorities of government structures and the most pressing daily needs of most of the population.

References

- Areola, A., Gwebu, T. & Sebego, R. 2014. A spatio-temporal analysis of peri-urbanisation in sub-Saharan Africa; A case study from Lobatse, Botswana. *Africa Geographical Review*, 174-201.
- Asnani, P. U. 2006. *Solid Waste Management*. India Infrastructure Report.
- Benna, U. & Benna, I. 2017. *Urbanization and Its Impact on Socio-Economic Growth in Developing Regions*. IGI Global.
- Besen, G. R. & Fracalanza, A. P. 2016. Challenges for the sustainable management of municipal solid waste in Brazil. *disP – The Planning Review*, 45-52.

- CSO. 2011. *Population and Housing Census*. Gaborone: Government Printer.
- GOB. 1998. *Botswana's Strategy for Waste Management*. Gaborone: Government Printers.
- Gutberlet, J., Kain, J. H., Nyakinya, B., Oloko, M., Zapata, P. & Campos, M. J. 2017. Bridging weak links of solid waste management in informal settlements. *Journal of Environment & Development Policy Review*, 106-131.
- Hagos, D., Mekonnen, A. & Gebreegziabher, Z. 2012. Households' Willingness to Pay for Improved Urban Waste Management in Mekelle City, Ethiopia. *Environment for Development*, 1-29.
- Kgathi, D. & Bolaane, B. 2001. Instruments for Sustainable Solid Waste Management In Botswana. *Waste Management & Research*, 342-353.
- Kgosiesele, E. & Zhaohui, L. 2010. An Evaluation of waste management in Botswana: Achievements and Challenges. *Journal of American Science*, 144-150.
- Kwailane, T. T., Gwebu, T. D. & Hambira, W. L. 2016. Challenges of domestic solid waste management: a case study of Lobatse Botswana. *African Geographical Review*, 117-133.
- Kwete, S., Samuel, J. C. & Wilhemina, A. 2014. Household Demand and Willingness to Pay for Solid Waste Management Service in Tuobodom in the Techiman-North District, Ghana. *American Journal of Environmental Protection*, 74-78.
- Manaf, L. A., Samah, M. A. & Ilya, N. 2009. Municipal solid waste management in Malaysia: Practices and challenges. *Waste Management*, 2902-2906.
- Mmereki, D. 2018. Current status of waste management in Botswana. *Waste Management & Research*, 555-576.
- Nunan, F. & Satterthwaite, D. 2001. The Influence of Governance on the Provision of Urban Environmental Infrastructure and Services for Low- Income Groups. *International Planning Studies*, 409-426.
- Schubeler, P., Wehrle, K. & Christen, J. 1996. *Conceptual Framework for Municipal Solid Waste in Low Income Countries*. St.Gallen: Swiss Centre for Development Cooperation in Technology and Management.
- Shahid, Y., Kaoru, N. & Wei, H. 2007. *What Makes Cities Healthy?* World Bank Publications- Casual Employment.
- Sharholly, M., Ahmad, K., Vaishya, R. C. & Gupta, R. D. 2007. Municipal solid waste characteristics and management in Allahabad, India. *Waste Management*, 490-496.
- Subbhash, A. (2010). *Solid Waste Management*. New Delhi: Khrishan Mittal.
- Subhan, M., Ghani, A. B. & Joarder, M. H. 2014. Urban Community Willingness to Pay for Improved Solid Waste Management in Malaysian Municipality: A Choice Modeling. *Asian Social Science*, 122-136.
- Thomas-Hope, E. M. 1998. *Solid Waste Management: Critical Issues for Developing Countries*. Kingston: Canoe Press University of West Indies.
- Zapata Campos, M. J. & Zapata, P. 2013. Switching Managua on! Connecting Informal Settlements to the Formal City through Household Waste Collection. *Environment and Urbanization*, 1-23.

Chapter 8: Exploitation et gestion durable des ressources halieutiques en Lagune Aby (Côte d'Ivoire)

Koulai-Djedje Edith

Université Félix Houphouët-Boigny-Abidjan, Côte d'Ivoire.
koulaidjedje@gmail.com

Resume

L'exploitation des ressources halieutiques en lagune Aby est une activité importante au plan économique, social, et nutritionnel pour les populations riveraines. Cependant, l'apparition d'un phénomène de surexploitation dans les années 1980-1981 et encore actuel, constitue une menace pour la pêche durable. En effet, cette situation a été le fait d'une intense activité de pêche due à la pression démographique et au perfectionnement des engins de capture en lagune, ce qui lui a valu l'effondrement de son stock principal « Ethmalosa fimbriata ». La tendance actuelle est de réunir des stratégies pour la restauration des stocks et l'instauration d'une pêche durable. L'objectif de cette étude est d'analyser les conditions de l'instauration d'une pêche durable en lagune Aby face à un phénomène de surexploitation persistant. La méthodologie adoptée s'appuie sur les approches qualitatives (entretiens et observation de l'état des lieux) et quantitatives (questionnaires à tous les acteurs concernés). Les résultats obtenus montrent que les conditions de l'instauration d'une pêche durable en lagune Aby, relèvent de la prise de conscience, de la mobilisation et de l'implication des professionnels de la pêche aux décisions les concernant. En outre, les autorités administratives doivent mettre en place des dispositifs efficaces de régulation des systèmes de pêche.

Mots clés: Exploitation, Surexploitation, Gestion durable, Lagune Aby

Abstract

The exploitation of halieutic resources in Aby lagoon is an important economic, social and nutritional activity for local populations. However, the appearance of a phenomenon of over-exploitation in the years 1980-1981 and still currently as well, constitutes a threat to the sustainability. Indeed, this situation was the result of fishing activity due to the demographic pressure and the improvement of fishing gear in the lagoon, which led to the collapse of its main stocks « Ethmalosa fimbriata ». The current need is to combine strategies for restoring stocks and establishing sustainable fisheries. The objective of this study is to analyse the conditions of the introduction of sustainable fishing in Aby lagoon faced with a phenomenon of persistent overexploitation.

The methodology adopted is based on qualitative (interviews and observations of the state of the premises) and quantitative (questions to all relevant stakeholders) approaches. The results obtained show that the conditions for the establishment of a sustainable fishery in the Aby lagoon are part of awareness, mobilisation and involvement of fishing professionals in decisions concerning them. In addition, the administrative authorities must put in place effective systems for regulating fishing systems.

Keywords: exploitation, overexploitation, sustainable, Aby lagoon

Introduction

La pêche est la principale activité dans la région du Sud-Est et le poisson constitue l'essentiel de la consommation en protéines des populations. En effet, de toutes les régions de Côte d'Ivoire, le Sud-Est par sa situation géographique notamment sa position dans le proche hinterland du port d'Abidjan occupe une place de choix dans le développement économique lié à l'activité de pêche (Essan, 1986). Il s'agit en effet d'une région depuis longtemps soumise à des études scientifiques (Weigel, (1989), Verdeaux (1988 ; 1989), Perrot (1989), Berron (1973 ; 1979), Ngoran (1994), Charles-Dominique (1993), Anoh (2007) etc.) en raison de l'intensité de l'activité de pêche qui s'y déroule et de l'affluence des populations étrangères qui s'y installent. C'est cette région qui abrite la lagune Aby, objet de notre étude. (Figure 8.1)



Figure 8.1: Le système lagunaire Aby-Tendo-Ehy

En effet, la lagune Aby est un complexe lagunaire de trois lagunes dont la lagune Aby la plus grande (305 km²) qui a donné son nom à l'ensemble. Ensuite la lagune Tendo qui correspond à la médiane, est plus étirée d'Est en Ouest (75 km²) et enfin la lagune Ehy plus à l'extrême Est (45 km²) et qui se partage entre la Côte d'Ivoire et le Ghana (Figure 8.1). Cependant, avec son écosystème productif ce complexe lagunaire est utilisé de manière intensive pour la pêche (Kponhansia, 1994). Il offre à l'action des pêcheurs de vastes espaces où ils peuvent exercer leurs activités (Berron, 1973). Dans ces conditions, la lagune connaîtra une forte croissance démographique et par conséquent une intense activité de pêche.

Par ailleurs, cette intense activité de pêche due à la pression démographique, à l'accroissement des populations des pêcheurs et au perfectionnement des engins de capture, a conduit selon les chercheurs (Hié-Daré, 1989 ; Charles-Dominique, 1993), à une situation de surexploitation des ressources de la lagune. Ce phénomène de surexploitation qui est apparu

brutalement et qui a causé l'effondrement du stock principal « *Ethmalosa Fimbriata* » et par ricochet la baisse de la production persiste encore aujourd'hui plus de 30 ans après. Les études scientifiques montrent que tous les projets et programmes d'aménagement et de suivi mis en œuvre pour restaurer les ressources et préserver la lagune sont confrontés à des pratiques compromettantes. Alors, quel système de gestion pour une pêche durable en lagune Aby ?

Methodes et materiels

La méthodologie adoptée s'appuie sur la recherche documentaire, l'observation directe sur le terrain et sur les entretiens avec les acteurs de la pêche et les autorités coutumières et administratives en charge de la gestion de la lagune. Relativement à la recherche documentaire, les ouvrages consultés portent sur les activités de pêche en lagune Aby, sur les pratiques anciennes et actuelles d'exploitation et le mode de gestion de la lagune. Certes de longue date mais ces documents relatent les causes, les manifestations et les conséquences de ce phénomène de surexploitation qui a surgi dans les années 1980-1981. Les textes réglementaires et institutionnels liés à l'activité de pêche en générale et particulièrement à la situation de la lagune Aby nous ont également intéressé.

En ce qui concerne l'observation directe sur le terrain, elle s'est déroulée en deux temps. La première phase a eu lieu le 05 mars 2019, c'était une prise de contact avec tous les acteurs concernés, pour leur expliquer le but de notre visite et l'objectif de l'étude que nous menons. La deuxième s'est déroulée du 12 au 26 mars 2019. Il était question d'observer les pratiques actuelles de pêche après l'épisode d'un effondrement brutal des stocks, les engins utilisés, si conformes aux normes prescrites par les différents textes réglementaires, et les systèmes de gestion mis en place qui relève d'une volonté manifeste des populations riveraines à œuvrer pour l'instauration d'un développement durable des pêcheries.

Pour ce qui est des entretiens avec les acteurs concernés nous avons eu recours à des focus groupes. Ce choix a été fait parce qu'il permet d'évaluer des besoins, des attentes d'un groupe homogène. Ou de mieux comprendre des motivations, des opinions des sensibilités ou des comportements face à une situation donnée. Des groupes de 5 à 10 personnes ont été constitués en fonction du type d'activité. En ce qui concerne les autorités administratives et coutumières des entretiens singuliers ont eu lieu. Au cours de ces entretiens, ont été abordées les questions relatives à la gestion du plan d'eau après crise, aux pratiques actuelles d'exploitation, aux systèmes de gestion en vigueur, à l'application des textes réglementaires.

Les informations recueillies à partir des entretiens, associés à celles issues de la recherche documentaire et l'observation directe ont permis de faire une analyse de contenu de la situation qui prévaut actuellement en lagune Aby. Les cartes ont été réalisées à partir du logiciel Adobe Illustrator. Les prises de vue ont été possible grâce à des appareils photo de dernière génération. A l'issue de ce processus les résultats obtenus ont été organisés comme suit :

1. Les pratiques actuelles de pêche en lagune Aby
2. Un système de gestion dualiste du plan d'eau lagunaire
3. Les conditions de l'instauration d'une pêche durable en lagune Aby

Resultats et discussion

I/ LES PRATIQUES ACTUELLES DE PÊCHE EN LAGUNE ABY

Un système d'exploitation épuisant pour les ressources halieutiques

L'une des difficultés importantes des pêches en Côte d'Ivoire en générale et particulièrement

en lagune Aby, demeure le déficit de prise de conscience de la limitation et du plafonnement de la ressource. Cela devrait pourtant conduire à un minimum de précaution dans le prélèvement et à une gestion responsable et durable. Les systèmes de production dans la pêche artisanale sont de type traditionnel et régis par les lois et coutumes des riverains en collaboration avec l'administration, tout en laissant paraître une prédominance du droit coutumier. Ces derniers développent des pratiques d'exploitation qui n'aboutissent pas certainement à une protection véritable de la ressource et qui très souvent compromettent la mise en œuvre de la réglementation instituée. Nous citons en exemple la pêche aux produits toxiques et la pêche clandestine effectuée durant la période de fermeture destinée au repos biologique.

En effet, d'un point de vue général il serait bien de noter qu'il a un déséquilibre entre les moyens techniques mis en œuvre pour la production halieutique et les ressources exploitables disponibles (Charles-Dominique, 1993). Une distinction entre un secteur artisanal marqué par des pratiques traditionnelles mais souvent efficaces et un secteur moderne qui nécessite le plus souvent des investissements importants et des moyens de production modernes pose également problème (Anoh, 2007). La pêche est également confrontée à la vétusté des engins de pêche, à la non maîtrise des débarquements, ce qui rend pour la plupart les statistiques indisponibles et même quand elles le sont, elles restent peu fiables. Des pertes énormes de produits après capture sont également constatées (Anoh, 2007 ; Koulai, 2012). Les mauvaises pratiques de pêches et le non-respect des mesures liées à l'activité de pêche se résument par, Un rythme de pêche intense, le non-respect du repos biologique (pêche en plein temps), L'augmentation et la performance des engins de pêche, la pratique de la pêche illicite par l'utilisation de produits toxiques. Les figures 2 et 3 ci-dessous sont les conséquences de ces pratiques, capture des espèces de petites tailles et d'espèces en état de ponte qui sont censées assurer la reproduction des stocks.

Figure I 1 : des espèces de petites tailles



Sources : koulai 2012

figure I 2 : Des crevettes en état de ponte



Sources: koulai 2012

Figure 8.2: Des espèces de petites tailles

Figure 8.3: Une espèce en état de ponte

Tout ceci traduit toute l'urgence et la nécessité d'instaurer une pêche responsable et durable en lagune Aby, dont l'objectif principal serait la protection de la ressource et un développement économique et social équitable des professionnels.

II/ UN SYSTEME DE GESTION DUALISTE DU PLAN D'EAU LAGUNAIRE

En lagune Aby, on parle de co-gestion du plan d'eau. Deux systèmes de gestion sont

actuellement en vigueur. Le système traditionnel qui repose sur des interdits religieux et l'autre administratif et moderne. Les deux systèmes se complètent mais sont loin d'être parfaits. La réglementation moderne initiée par l'administration des pêches après les crises qui se sont succédées, s'inspire du droit coutumier en vigueur dans l'espace Aby depuis l'anthropisation du milieu lagunaire.

Le droit coutumier, une gestion fortement influencée par les prescriptions des divinités locales

En Afrique de l'ouest, les travaux de Pliya au Bénin (1985), de Verdeaux en Côte d'Ivoire (1986) et de Fay au Mali (1989) témoignent de l'ancienneté et de la diversité des formes d'appropriation des espaces aquatiques. De leur dynamique mais également des rapports de force qu'elles engendrent entre autorité locale coutumière et autorité nationale, et entre usagers (Cormier-Salem, 2000). Ainsi, l'importance de la communauté rurale villageoise avec le conseil des sages se révèle comme le garant du respect de la coutume et du contrôle des droits d'usage sur l'espace aquatique. Le contenu de ses droits varie entre et au sein des communautés littorales, allant de l'appropriation du plan d'eau, de l'usage exclusif de certains engins, de l'accès prioritaire aux débarcadères et aux marchés, de la rétention du savoir et de l'information.

En lagune Aby, les rapports privilégiés des Ehotilés avec les génies de l'eau en ont fait les médiateurs obligés pour l'accès au milieu lagunaire. En 1989, Perrot faisait observer que jusqu'en 1985, le calendrier religieux distribuait l'année en deux saisons. En mai, les prêtres et les chefs de lignage fermaient, solennellement, par d'ultimes sacrifices « la porte des génies », et en octobre ils « ouvraient leur porte », inaugurant le cycle des célébrations et des sacrifices qui se succédaient en ordre serré sur les rives, dans les lieux écartés et majestueux élus par les génies, ou au village. En 1992, Verdeaux relève qu'un rite d'ouverture est organisé pour l'ensemble de la lagune. L'ouverture était faite par le prêtre du génie Assouhou. Le droit coutumier contrôle toutes les activités effectuées sur le plan d'eau, et s'étend à toutes les pratiques susceptibles de compromettre la durabilité des pêches. Dans la coutume des Ehotilés, populations autochtones de la région, le mercredi est un jour de sacrifice consacré à l'adoration du génie protecteur. De ce fait toute activité est suspendue sur la lagune du mardi 18 heures au mercredi 15 heures. Aussi, le dimanche représente un jour de repos et de culte pour les populations de confession chrétienne (Anoh, 2007). D'une manière générale, l'accès à l'eau se fait sur la base de ces principes divins et d'un commun accord entre les villages riverains. Sur l'espace Aby, il est interdit aux pêcheurs étrangers d'être propriétaire d'engins de pêche, seuls les autochtones en ont le droit. Tous les conflits sont réglés sur la base des prescriptions divines.

Un cadre réglementaire mis en place pour préserver la pêche durable

À un niveau local, la pêche dans le complexe lagunaire Aby est régie depuis le 2 juillet 2001 par deux arrêtés préfectoraux (arrêté n°16/P.AD/CAB, portant institution de saisons de pêche (ouverture et fermeture) en lagunes Aby, Tendo, Éhy et dans le canal d'Assinie), (arrêté n°17/P.AD/CAB, portant réglementation des mailles pour certains engins de pêche en lagunes Aby, Tendo, Éhy et canal d'Assinie). Ces textes ont été pris à la suite des recommandations du rapport final du séminaire sur l'aménagement des pêches en lagune Aby, Tendo et Éhy tenu les 19, 20 et 21 juillet 1995 à Grand-Bassam. Ces textes reposent sur les grands principes de l'exploitation des eaux définis dans le Code de la marine marchande issu de la loi n°61-349 du 9 novembre 1961. L'arrêté n°16 institue une saison de pêche sur le complexe lagunaire Aby-Tendo-Ehy et dans le canal d'Assinie pour les sennes de plage et pour les sennes syndicats. La

pêche est fermée du 15 Juin au 31 Octobre de chaque année soit 4 mois et 15 jours. L'ouverture se fait du 1^{er} Novembre au 14 Juin. L'arrêté n°17 règlemente la maille minimale et la longueur maximale des filets. Les points remarquables de cette réglementation sont : L'institution du repos biologique par la fermeture la pêche pour permettre le renouvellement de la ressource, la lutte contre les pratiques illicites de pêche, la réduction du maillage des filets, les limitations des captures et de l'effort de pêche, définition des zones ou périodes de pêche.

L'administration a aussi en charge de veiller sur les zones protégées (baies) depuis 1995 date officielle de régime particulier de l'exploitation d'une baie après le séminaire de Grand-Bassam. Ainsi, naissent les premières baies cogérées par l'administration des pêches et les communautés villageoises. En 2005, Le nombre de baies protégées évolue très rapidement et atteint 13. L'arrêté N° 20/P.ADIK / CAB du 31 Mai 2017 porte également création de nouvelles baies au large des villages riverains de la lagune augmentant le nombre à 17 (figure 8.4).

Figure II 1 : Localisation des réserves Créées sur le complexe lagunaire en vue d'assurer le repos biologique des ressources halieutiques



Figure 8.4: Localisation des baies

Par ailleurs, toutes ces mesures qui devraient contribuer à une meilleure gestion du plan d'eau, sont compromises par la mainmise des populations autochtones sur le plan d'eau. La logique patrimoniale de l'espace empêche une quelconque application de la réglementation

II/ LES CONDITIONS DE L'INSTAURATION D'UNE PÊCHE DURABLE EN LAGUNE ABY

Les concepts généraux du développement durable

Le développement durable, est défini comme « un développement économiquement efficace, écologiquement prudent et socialement équitable » Zuideau (2000). De façon générale, le développement durable se construit donc autour des trois domaines combinés que sont l'économie, l'environnement et la société. Le développement durable peut ainsi s'appliquer à tous les secteurs d'activité et à tous les régimes économiques et politiques. C'est un

développement qui prend en compte les besoins des générations présentes sans compromettre ceux des générations futures. Les fondements du développement durable des pêches découlent alors des principes généraux du développement durable que sont l'irréversibilité, l'incertitude et la précaution.

Dans le cadre de la pêche, le développement durable peut être assimilé à une pêche qui intègre aux impératifs économiques de production à la fois des mesures de protection de la nature et de contrôle des ressources exploitées et des objectifs de bien-être social pour les populations. Dans le secteur de la pêche également, un Code de Conduite pour une Pêche Responsable (CCPR) a été élaboré par la FAO en 1995. Ce Code constitue un cadre de référence pour une exploitation durable des ressources aquatiques. Les grands principes et les objectifs du Code s'articulent autour de quelques idées fortes en rapport avec l'économie, l'environnement et la société. En juin 1992, un plan d'action appelé Agenda 21 pour le XXI^{ème} siècle a été adopté par 120 Etats lors du sommet de la terre à Rio de Janeiro. Il concerne les collectivités territoriales. Celles-ci sont appelées dans le chapitre 28 de ce programme à mettre en place un programme d'Agenda 21 à leur échelle intégrant les principes du développement durable à partir d'un mécanisme de consultation de la population. Ainsi, Selon l'agenda 21, pour qu'il ait pêche durable il faut qu'il y ait pêche concertée. L'idée serait de réunir autour d'une plateforme de discussion tous les acteurs de la pêche pour prendre part aux décisions les concernant.

Au regard de tous ces préceptes comment peut-on instituer une pêche durable en lagune Aby.

L'implication des populations riveraines

En lagune Aby, les conditions naturelles et humaines sont favorables à l'instauration d'une pêche durable. Des ajustements restent à faire bien sûr mais, dans l'ensemble, le droit coutumier et la réglementation moderne en vigueur adoptaient déjà des mesures de protection et de surveillance de l'environnement du plan d'eau. Les populations riveraines n'ont pas attendu l'arrivée du Code de Conduite pour une Pêche Responsable (CCPR) pour instituer le repos biologique marqué par la réglementation de l'accès à l'eau. Cependant, Les populations doivent veiller à ce que le repos biologique et la délimitation des aires protégées déjà instaurées soit scrupuleusement respectées. Des mesures complémentaires devront également être prises pour réaliser pleinement l'avènement de la pêche responsable. En lagune Aby, il est souhaitable de parvenir à une gestion participative de la ressource par une plus grande association des structures traditionnelles existantes à la réglementation de l'accès à l'eau (Anoh, 2007). Ce qui renvoie au regroupement des pêcheurs en coopérative. Nous avons l'exemple de la coopérative ANOENZE des pêcheurs collectifs (fil.y).

Figure III 1 : Siège de la coopérative des pêcheurs collectifs d'Eplemlan (Adiaké), un exemple de réunification des pêcheurs



Figure 8.5: Siège de la coopérative des pêcheurs collectifs d'Eplemlan (Adiaké)

Pour qu'il y ait pêche durable il serait alors nécessaire qu'il y ait pêche concertée. L'idée serait de bâtir des contrats de confiance avec des pêcheurs réunis en unités de gestion (Agenda 21). Le regroupement des pêcheurs en unité de gestion est donc une des solutions fortes pour une gestion durable des pêches en lagune Aby. La nécessité d'une prise de conscience des collectivités locales passe également par la réorganisation des pratiques de pêche en faveur de la réglementation liée à la pêche (Condition d'accès aux ressources, mailles autorisées pour les captures, zones protégées, repos biologique, pour permettre la reproduction des ressources). La préservation du plan d'eau est un défi pour l'instauration d'une pêche durable.

3/ Les résolutions des autorités administratives et politiques

Le rôle des autorités administratives et politiques s'observe à différents niveaux. Certes les problèmes liés à la durabilité des pêches artisanales en Côte d'Ivoire sont énormes (La non maîtrise des débarcadères, des statistiques difficiles d'accès, un secteur mal organisé, la vétusté du matériel de pêche, etc.), mais avec la volonté manifeste des pêcheurs à valoriser leur activité, les actions des autorités pourraient être facilitées (Koulai, 2012). Celles-ci peuvent se résumer en ces points suivants:

Ouvrir l'embouchure de la passe d'Assinie pour garantir les échanges mer-lagune. Toutefois, la fermeture des passes de la Bia et d'Assinie en lagune Aby est un sujet de préoccupation pour les pêcheurs. Ils estiment que cette situation est la cause de la réduction du volume des captures et, sont conscients que la réouverture des embouchures favoriserait la capture des espèces dites amphidromiques (dont le cycle se partage entre les eaux salées de la mer et l'eau saumâtre de la lagune) autrefois abondantes dans les eaux lagunaires.

Pour réaliser une exploitation durable des ressources en lagune Aby, nous recommandons la prise en charge des acteurs de la pêche par une formation adéquate. Les autorités doivent assurer l'éducation et la formation des professionnels de la pêche. Dans les communautés de pêcheurs, la perception et la compréhension du mot développement apparaissent comme le principal handicap pour la réalisation d'un développement durable. Dans les pratiques de pêche en vigueur, les principes et les règles de gestion qui présentent une conformité avec les normes du développement durable le sont par pur coïncidence. Les mesures

de protection de la ressource et de l'environnement des plans d'eau ne reposent sur aucune réalité scientifique. Cette situation pose toute la problématique de la compréhension du concept de développement durable et montre l'intérêt de l'introduction de la formation et de l'éducation chez les professionnels de la pêche. (Anoh, 2007).

L'harmonisation des règles de gestion traditionnelles et modernes et leur extension à l'ensemble du plan d'eau ainsi que l'amélioration de l'environnement social par la lutte contre les conflits de pêche est l'un des défis des autorités. La pêche durable est une activité responsable avec des acteurs conscients du danger qu'ils courent dans le cas d'une politique approximative d'aménagement et de gestion de la ressource.

Octroyer des fonds d'aide aux pêcheurs réunis en unité de gestion comme le stipule l'agenda 21. Les autorités gouvernementales à travers leurs institutions financières doivent également participer à la réhabilitation de la pêche en lagune Aby. Comme cela avait été le cas dans les années 1980-1981 avec la BNDA (Banque Nationale de Développement Agricole) qui avait été installée à Aboisso et à Adiaké, après l'effondrement brutal qu'a connu la lagune. Le PMDEP a octroyé des prêts aux jeunes pêcheurs de crabes. Ce projet avait pour but d'aider ces pêcheurs à investir leurs revenus. Cela leur permettra de réorganiser leurs activités, par exemple de renouveler et de moderniser leurs engins de pêche et même d'améliorer leurs revenus (Angaman, Touré, 2004). Une sensibilisation rigoureuse doit être menée auprès des populations pour faciliter l'action de ces institutions. Le regroupement des pêcheurs en coopérative serait aussi nécessaire pour la bonne marche de cette initiative.

Promouvoir des sources alternantes de revenus pour les pêcheurs, voilà une solution qui n'a pas véritablement été pensée dans le secteur de la pêche. Pourtant, créer de nouvelles activités en période de fermeture de la pêche reviendrait à inciter les professionnels de la pêche et les jeunes à s'intéresser à d'autres activités pendant la fermeture de la pêche au profit du repos des ressources halieutiques. L'aquaculture peut être également solution à la question d'aménagement des pêcheries. Lors du repos biologique des ressources, les pêcheurs peuvent se donner à cette autre activité. La FAO dans l'élaboration du Code de conduite pour une pêche responsable a défini à son article 9, les mesures à prendre pour un développement responsable de l'aquaculture. Il faut noter également que certains pêcheurs sont agriculteurs à la base. Ils peuvent donc retourner aux travaux champêtres pendant la fermeture de la pêche.

Conclusion

S'inscrire dans une logique de développement durable, c'est finalement tenter de mettre en œuvre de nouvelles démarches, de nouvelles méthodes au service d'un projet, dont le contenu doit être défini par chacun et mis en œuvre par tous. Toutefois les questions qui restent posées sont celles de savoir:

Comment en effet, appliquer des mesures de développement durable et d'exploitation responsable à des populations qui ont un besoin vital des produits aquatiques et dont la conception de la vie rend difficile la compréhension mais surtout l'appropriation des notions comme la limitation de la ressource qui induit un minimum de précaution dans son exploitation? Comment concilier le court terme c'est-à-dire le besoin de vivre pour une population pauvre et le long terme à travers la gestion durable? La formation et l'éducation sont-elles en mesure de rendre ces concepts accessibles et de corriger les insuffisances dans la perception actuelle du développement durable? Voici autant de questionnement qui nécessite d'être résolu ou éclaircis pour l'instauration véritable d'une pêche durable en lagune Aby tout en tenant compte des réalités des populations riveraines, mais sûrement dans toute la pêche artisanale.

Même si à quelques niveaux l'on aperçoit des efforts des autorités villageoises d'abord et ensuite de l'administration pour s'accommoder aux contraintes spécifiques liées à l'exploitation des ressources halieutiques en lagune Aby, les résultats restent insuffisants. Car, l'objectif d'un accroissement de la production fondé sur une maîtrise des stocks et une gestion durable semble être loin d'être atteint. En réalité, les communautés de pêcheurs ne perçoivent pas toujours l'intérêt à respecter les normes de gestion en vigueur, vu que l'activité de pêche est leur seule source de revenus. En dehors des interdits religieux qu'elles respectent par crainte de sanctions infligées par les divinités, elles trouvent les autres mesures contraignantes et sont prêtes à les enfreindre à la moindre occasion pour survivre.

References bibliographiques

- Angaman (K), TOURE (M) 2004 : Sur la lagune Aby (Côte d'Ivoire), la vie des pêcheurs de crabes s'améliore Bulletin de liaison du PMEDP, document n°16, juin 2004, 34 p
- Anoh (K P), 2007 : Pêche aquaculture et développement en Côte d'Ivoire, thèse, université de Nantes, 334 p
- Berron (H), 1973 : Les principaux marchés de gros des produits de la pêche de la lagune Aby, Annales de l'Université d'Abidjan, série G (Géographie), Tome V 329 p.
- Charles (D), 1984 : « La pêche artisanale en lagune Aby (Côte d'Ivoire) », analyse des prises et de l'effort de pêche, 1980-1981, document scientifique, CRO, Abidjan, ORSTOM, 1 (1-2) : 19-53 p.
- Chaussade (J), 1999 : De la gestion intégrée au développement durable : point de vue, Bulletin de l'AGF, Paris, 1999-2, p. 151-157
- Cormier-Slem (M. C), 2000 : Appropriation des ressources, enjeu foncier et espace halieutique sur le littoral ouest-africain. J-P. CHAUVEAU, E. JUL-LARSEN et C. CHABOUD (éds), Les pêches piroguières en Afrique de l'Ouest : Pouvoirs, Mobilités, Marchés CMI, IRD, Karthala, Paris, p. 205-229
- Essan (K), 1986 : Activité économique et structuration de l'espace dans les sous-préfectures d'Aboisso et Adiaké, thèse de 3^e cycle, IGT, juin 1986, 436 P.
- Fay Cl. 1989 : Systèmes halieutiques et espaces de pouvoirs : transformation des droits et des pratiques de pêche dans le delta central du Niger (Mali) 1920 – 1980. La pêche enjeux de développement et objet de recherche, Cahiers des Sciences Humaines, vol. 25 n°1-2, 1989, p. 215-236.
- FAO, 1995 : Code de conduite pour une pêche responsable, Rome, FAO, 1995, 46 p.
- Hatem F. 1990 : Le concept de développement soutenable, CEPPII, Économie prospective internationale, La Documentation Française, n° 44, 4^e trimestre p. 101-117
- Hie-Dare J-P, 1992. Étude sur l'aménagement des pêches sur la lagune Tagba (Côte d'Ivoire). Abidjan, Cent. Recher. Océanol. 23 p.
- Kponhassia (G), 1994 : « la dynamique sur le complexe lagunaire Aby-Tendo-Ehy » Amélioration du cadre juridique pour la coopération, l'aménagement et le développement halieutique des pays côtiers d'Afrique de l'Ouest 38 p, document n°8.
- Koulai (E), 2012 : Exploitation des eaux et développement durable des pêches en lagune Aby, Thèse unique de doctorat, université Felix Houphouët-Boigny Abidjan (Côte d'Ivoire) 301 p
- Koulai-Djedje (E), 2014 : situation actuelle de la pêche en lagune Aby 30 ans après l'effondrement des stocks EN 1980-1981 (Côte d'Ivoire) In revue de Géographie Tropicale et d'Environnement (GEOTROPE) EDUCI, ISSN : 1817-5589 n°1-2014 pp 75-82
- Koulai-Djedje (E), 2015 : La gestion des ressources halieutiques en lagune Aby In AHOHO,

- revue de Géographie du LARDYMES Université de Lomé (Togo), ISSN : 1993-3134, pp 159-166, 2015
- N'Goran (Y) 1994 : « élaboration d'un plan d'aménagement des pêches artisanales en lagune Aby », FAO, 41 p, document 9
- Perrot (C H), 1989 : le système de gestion de la pêche en lagune Aby au XIX siècle (Côte d'Ivoire), cahier des sciences humaines, Orstom, 1989, P, 159-176.
- Pliya (J.), 1985 : Protection du milieu et législation traditionnelle de protection en Afrique de l'Ouest, Communication au colloque de Cotonou, 10 pages multigr.
- QUATRIEMES RENCONTRES HALIEUTIQUES DE RENNES, 1997 : Activités halieutiques et développement durable, Actes du colloque, École Nationale Supérieure Agronomique de Rennes, 14-15 mars, Fiches techniques n° 1 à 4
- Sankare (Y), Kaba (N), Etien (N). 1994. La pêche par empoisonnement dans les eaux saumâtres tropicales (lagunes ivoiriennes) : effets sur l'environnement, Agronomie Africaine, vol. VI (2), p. 151-162.
- Zuindeau B. 2000. Développement durable et territoire, Villeneuve d'Ascq, Presses Univ. du Septentrion, coll. Sc. Sociales, 289.

Chapter 9: Modelisation prospective de l'occupation du sol d'une zone a forte pression anthropique: Cas du site Ramsar de Grand-Bassam, (Sud-Est de la Cote d'Ivoire)

Akadje Léocadie Marie-Claude^{1*}, Kangah Armand², Boussougou Boussougou Guy³,
Hauhouot Asseyo Célestin⁴, Brou Yao Téléphore⁵

^{1*} Assistante, Institut de Géographie Tropical (IGT), Université Felix Houphouët Boigny d'Abidjan, Côte d'Ivoire (*maclaude35@yahoo.fr*)

² Maître-assistant, Institut de Géographie Tropical (IGT), Université Felix Houphouët Boigny d'Abidjan, Côte d'Ivoire (*a_kangah@yahoo.fr*)

³ Assistant, Département de Géographie, UMR ESPACE DEV. Université de la Réunion (*guyboussougou@yahoo.fr*)

⁴ Professeur Titulaire, Institut de Géographie Tropical (IGT), Université Felix Houphouët Boigny d'Abidjan, Côte d'Ivoire (*c_hauhouot@yahoo.fr*)

⁵ Professeur Titulaire, Département de Géographie, UMR ESPACE DEV. Université de la Réunion (*telesphore.brou@univ-reunion.fr*)

Resume

Les pressions anthropiques sont à la base de la disparition des forêts, en Côte d'Ivoire. Les zones humides ivoiriennes subissent de plus en plus de pressions suites aux prélèvements des nombreuses ressources qu'elles abritent ou pour la recherche de terres arables ou pour la construction. Cette déforestation présente de nombreuses conséquences dont la perte de la biodiversité et des mutations dans le milieu. Afin d'avoir une idée des pressions futures sur le milieu et anticiper sur les décisions de gestion durable des ressources, cette étude se propose d'évaluer les pressions qui s'exerceront à long terme, en tenant compte des données d'occupation du sol de 1986 et 2000 et 2013 de la zone de Ramsar de Grand-Bassam et ses environs. Le travail a porté sur la simulation de l'occupation du sol en 2030 à l'aide du module Land Change modeler, à partir de l'analyse des changements entre des cartes d'occupation du sol de 1986 et 2000, établies par classification supervisées d'images satellites Landsat. La modélisation des changements d'occupation du sol a révélé une extension future des cultures pérennes et de l'habitat au détriment des forêts de la zone humide. Celles-ci seront en forte croissance respectivement à 42,11% et 14,74% en 2030.

Mots clés : Pressions anthropiques, occupation du sol, mutations, modélisation, zone humide ramsar.

Abstract

Anthropogenic pressures are the basis of the disappearance of forests, in Ivory Coast. Ivorian Wetlands are subjected to increasing pressure, due to the exploitation of many resources or research of arable land or building. This deforestation has many consequences, including loss of biodiversity and changes in the environment. To get an idea of future pressures on the environment and anticipate the sustainable management of resources decision, this study aims

to assess the pressures that will be in the long run, taking into account the land use data 1986 and 2000 and 2013 of the Ramsar area of Grand-Bassam and its surroundings.

The work has focused on the simulation of land use in 2030 using Land Change modeler module and analysis of changes in land cover maps produced by supervised classification of satellite images Landsat, between 1986 and 2000, Modeling of land use changes revealed a future extension of perennial crops and the habitat at the expense of forests. These will be high growth to 42.11% and 14.74% respectively.

Keywords: Anthropogenic pressures, land use, mutations, modeling, wetland ramsar.

Introduction

L'utilisation du sol, à l'échelle mondiale, constitue l'un des principaux facteurs à l'origine de la déforestation et des changements climatiques (Theriault *et al.* 2011). En Côte d'Ivoire, l'utilisation du sol pour l'agriculture, constitue le principal facteur de la déforestation. En effet, le choix économique de la Côte d'Ivoire, basé sur l'agriculture a favorisé la création et l'extension d'importantes superficies agricoles au détriment des formations forestières. Ainsi, de 14 millions Ha à l'indépendance (1960), le couvert forestier a été estimé à environ 2 millions Ha seulement en 1990 (Oswald, 2005, Atta, 2009; Sako, 2011). Par ailleurs, la conquête de nouvelles terres cultivables, a accentuée au cours des années le phénomène de déforestation. Il a atteint progressivement de nombreuses forêts classées qui ont été remplacées partiellement ou dans leur totalité par des plantations de café et de cacao (Dibi, 2008 ; Kangah, 2015 etc). Aujourd'hui, fort est de constater que le phénomène de la déforestation a également atteint les zones humides, notamment les sites Ramsar. En effet, la Côte d'Ivoire compte six sites Ramsar qui couvrent une superficie de plus de 122 000 Ha. Ces zones humides d'importance internationale demeurent, parmi les écosystèmes, les plus diversifiés et les plus productifs. Elles offrent non seulement, un cadre propice de conservation et de développement à de nombreuses espèces animales en danger mais constituent par ailleurs, pour de nombreuses espèces animales un site de reproduction, de repos ou d'alimentation. Cependant, ces zones humides, déjà très fragiles, restent fortement perturbées par diverses activités humaines. En effet, comme le signifie Koffi (2012), les zones humides subissent actuellement, d'importantes et diverses mutations (recompositions spatiales, pertes de surface initiale) occasionnées par d'innombrables activités anthropiques. et Elles sont sujettes à la déforestation (Brou *et al.* 1998). Le site Ramsar de Grand-Bassam, objet de cette étude constitue une preuve remarquable de cette déforestation constatée.

En effet, de nombreuses études réalisées dans le Sud-est ivoirien où est localisé la zone Ramsar de Grand-Bassam (Kangah, 2008 ; Hauhouot *et al.* 2011 ; Akadjé *et al.* 2014) montrent effectivement que cette zone subit une forte pression anthropique due à l'extension et à la diversification des cultures de rente (café, cacao, hévéa, palmiers à huile). Ces dernières ont impacté fortement le site Ramsar et menacent son existence, si aucune mesure n'est prise pour protéger ce site d'intérêt écologique international. La présente étude se propose à partir des données existantes de faire une simulation à long terme de l'occupation du sol du site Ramsar de Grand-Bassam, grâce à la modélisation prédictive ; et ce, afin d'attirer l'attention des décideurs sur les menaces que courent le site si aucune mesure de gestion n'est prise.

Le site d'étude

Le site Ramsar de Grand-Bassam est localisé dans le sud-est de la Côte d'Ivoire, à environ 15

Km de la ville d'Abidjan (Figure 9.1). Cet espace très complexe et fragile, est alimenté par un système fluvio-lagunaire très dense formant le plus vaste estuaire du littoral Ivoirien. Les sols dans la partie nord, sont formés d'accumulations de sables argileux, fortement dessaturés et riches en matières organiques (Koli bi, 2009). Ils sont bien drainés et très propices à l'agriculture de rente. Plus au sud, le cordon littoral quaternaire est formé d'accumulations de sable marins. Des vases de marécages permanents, faiblement étendus sont localement observés le long de la grande dépression du fleuve Comoé. Ces formations fluvio-lagunaires favorisent en surface, le développement de sols hydromorphes favorables aux cultures maraichères.

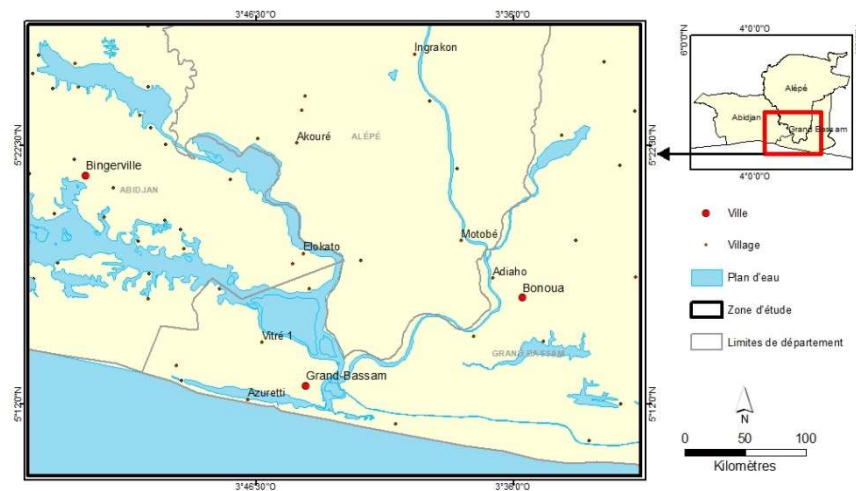


Figure 9.1: Localisation de la zone RAMSAR de Grand-Bassam et ses environs

Au plan écologique, le secteur d'étude appartient au grand domaine phytogéographique guinéen caractérisé, par divers types de formations végétales. On y rencontre des forêts sur terre ferme, des forêts marécageuses, des mangroves représentées par les palétuviers *Rhizophora Racemosa* (Palétuvier rouge) et *Avicennia Germinans* (Palétuvier blanc), des prairies marécageuses, des prairies à inondation temporaire ou permanente et des savanes côtières. Cette flore constitue non seulement un habitat, mais également un lieu de reproduction et de refuge pour de nombreuses espèces en voie de disparition. La population riveraine y pratique trois types d'activités: la pêche, l'agriculture et l'artisanat. La pêche est généralement de type artisanal. Les sont importantes avec la présence de plantations villageoises et industrielles de palmier à huile, d'hévéa, de cocotier, d'ananas, mais également de maraichers, de vivriers. S'agissant de l'artisanat, elle demeure une particularité de la zone d'étude à cause de sa richesse en flore qui constitue la matière première des artisans. Le bambou et le raphia à cause de cette activité sont en voie de disparition.

Donnees et methodes

Les données de l'étude

Plusieurs données numériques ont servi à la simulation de l'occupation du sol. Ce sont :

- Trois (3) cartes d'occupation du sol de la zone d'étude aux dates de 1986, 2000 et 2013. Ces dernières élaborées à partir d'images satellites en 2014 par Akadjé *et al.* ont été utilisées pour analyser les dynamiques et transformations spatiales de la zone d'étude.
- un (1) fichier des pentes, générées par un Modèle Numérique de Terrain lui-même créé par des courbes de niveaux (équidistance de 10 m),

- un (1) fichier du réseau hydrographique relatif aux cours d'eau et plans d'eau,
- un (1) fichier du réseau routier datant de 2005,
- un (1) fichier des zones habitées, datant de 2010.

Démarche de simulation de l'occupation du sol

Une démarche spécifique de prédiction de l'occupation du sol a été adoptée dans cette étude. Elle permet, par une analyse des dynamiques passées et actuelles, d'avoir une vision des changements futurs, grâce à la modélisation. Plusieurs modèles de prédiction existent ; mais pour ces travaux, le choix a porté sur le *Land Change Modeler* du logiciel IDRISI. Ce modèle utilise les réseaux neuronaux artificiels pour modéliser des systèmes écologiques complexes. Le Perceptron Multi-couche (ou multi-layer feed-forward - MLP), l'une des architectures neuronales les plus utilisées dans les études de dynamiques d'occupations et d'utilisations du sol (Mas *et al.* 2004 ; Paegelow *et al.* 2004), a servi dans la modélisation. En effet, le MLP permet d'examiner et de modéliser les relations complexes entre plusieurs variables. Sa capacité à appréhender des relations non-linéaires fait de lui, un outil puissant d'analyse des processus écologiques (Eastman, 2006 ; Maestriperie, 2013). La démarche est la suivante :

Calibration du modèle

Analyse des changements dans le milieu

Avant, l'utilisation d'un modèle il est nécessaire de le valider à l'aide de données connues. C'est la phase de calibration du modèle. A cet effet, une première estimation des changements sur la période de 1986 à 2000, (pertes, gains et superficies stables) a été réalisée, à partir des cartes d'occupation du sol existantes de 1986 et 2000. Cette estimation est représentée sous forme de graphique et de carte des changements.

Analyse de la relation entre les variables explicatives et la carte des changements

L'analyse des changements a permis d'établir les sous-modèles de transitions potentielles observées, de 1986 et 2000, entre les différents types d'occupation du sol. Ils représentent le passage d'un type d'occupation du sol à un autre (par exemple de forêt dégradée à Sol nu)Ainsi, les catégories de changements observés ont été regroupées en une dynamique majeure ou sous-modèle nommé PRESSION (Tableau 9.1).

Transition	Processus de changement (Sous modèle)	Explication
Foret -> Autre	PRESSION	Conversion de la forêt en un autre type d'occupation du sol
Sol -> Autre		Conversion des sols en plantations exotiques ou à l'urbanisation
Culture -> Autre		Conversion des zones de cultures à l'urbanisation ou entre cultures

Source: AKADJE, 2014

La simulation de changements futurs nécessite une intégration de variables qui expliqueraient

ces changements. Une grande quantité de variables jouent un rôle important dans les changements d'occupation du sol et dans la déforestation. Il est primordial pour le modèle, de ne prendre en compte, que des variables qui ont une influence sur le paysage, bien que certains soient non quantifiables ou indisponibles. Pour ce faire, avant leur intégration dans les sous-modèles, les variables sont au préalable évaluées avec le coefficient V de Cramer, afin de connaître leur pouvoir explicatif dans le processus de mutation. En effet, le coefficient V de Cramer calcule la corrélation entre des variables. Il varie de 0 et 1 (figure 9.2). Globalement, le coefficient est de 0,5145. Plus la corrélation est forte, plus le coefficient se rapprochera de 1 et vice versa. Selon Eastman J. R. (2004), la variable est acceptable, si son coefficient de Cramer est égal ou supérieur à 0,4 ; mais devra être rejetée au cas où il est inférieur à 0,15.

Cover Class :	Cramer's V :	P Value :
Overall V	0.5145	0.0000
Habitat	0.8980	0.0000
Culture de rente	0.5926	0.0000
Forêt dégradée	0.5748	0.0000
Formation marécag	0.4800	0.0000
Forêt dense sempe	0.4783	0.0000
Culture vivrière	0.4137	0.0000

Figure 9.2: Coefficient de Cramer pour chaque variable

Les variables retenues dans la conception du modèle sont :

- Les données de l'occupation du sol (1986, 2000 et 2013) ;
- Les variables socio-économiques (variables anthropiques qui ont une influence directe sur la déforestation et les transformations spatiales, la distance aux localités et aux axes routiers) ;
- les variables environnementales (l'altitude, distance aux plans d'eau et aux cours d'eau) (figure 9.3). Les données hydrographiques ont été scindées en deux (2) types car elles ont un impact différent et entraînent des comportements anthropiques différents sur le milieu selon qu'on soit en présence de l'un ou de l'autre. D'une part les fleuves et de lagunes qui sont très étendues, et d'autre part les rivières qui sont non seulement peu étalées, mais plus encore, certaines sont intermittentes.

La, met en évidence l'importance des relations entre les variables et les mutations qui s'opèrent dans l'espace.

- *La variable pente*

En exploitant le diagramme représentant les changements observés par rapport à cette variable, il s'avère que plus de 90 % des changements d'occupation du sol se situent à basse altitude.

- *Les variables « proximité aux routes » et « proximité aux cours d'eau »*

La variable « proximité aux cours d'eau » apparaît comme l'une des variables déterminantes de la déforestation entre 1986 et 2000. La relation existant entre les changements d'état des sols et les cours d'eau s'établit de la façon suivante : au fur et à mesure qu'on s'éloigne des berges, le taux de changement d'occupation du sol diminue.

Le graphe représentant la variable « Proximité aux routes » en fonction des changements se présente de la même manière que celui de la variable « proximité aux cours d'eau ». Plus l'on est proche des routes, plus les changements d'occupation du sol sont intenses.

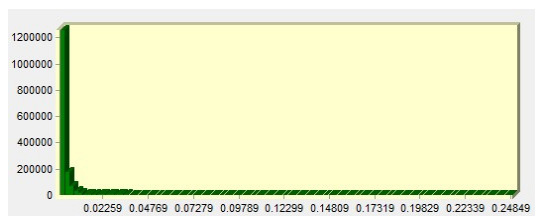
- *La variable « proximité aux plans d'eau »*

Cette variable est plus ou moins significative dans le processus de dynamique d'occupation du

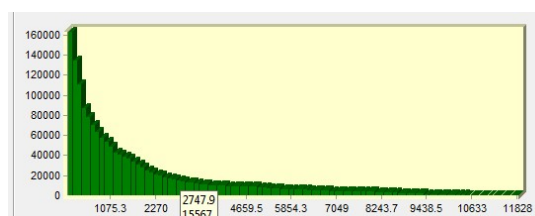
sol. En effet, plus l'on s'éloigne des grands plans d'eau de la zone, moins on a de changements.

- La variable « Proximité aux Localités »

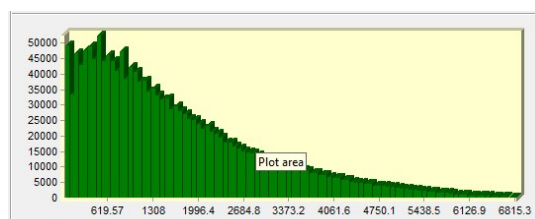
La relation entre la variable « Proximité aux localités » et changement d'état des sols diffère des autres relations. A proximité des localités, c'est-à-dire entre 0 et 619 m de distance aux localités, les taux de changements tout aussi élevés augmentent crescendo, au fur et à mesure que l'on s'éloigne des localités. Ensuite après les 700 m, le taux se remet à baisser jusqu'à ce qu'il atteigne 0 changement à 6815 m de distance.



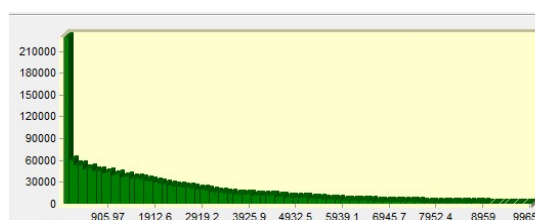
a) La variable courbe de niveau



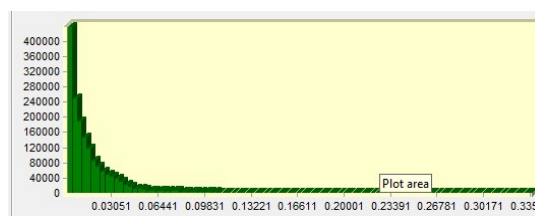
b) La variable Distance au cours d'eau



c) La variable Distance aux localités



d) La variable Distance aux plans d'eau



e) La variable Distance aux routes

Figure 9.3: Représentation des relations entre les changements d'occupation du sol et les variables explicatives en mètre par hectare

La phase d'élaboration des cartes de probabilité de transitions.

Cette phase consiste à construire des sous-modèles de transitions potentielles entre plusieurs catégories d'occupation du sol, tout en tenant compte des variables statiques ou dynamiques. Elle permet de générer des cartes de probabilité de transition par réseau neuronal, en combinant une carte de transition (1986-2000) aux variables expliquant ces changements. Les transitions utiles sont spécifiées lors de la génération des changements probables. Il est important d'atteindre un taux de réussite de 70 % pour espérer avoir des sous-modèles tendant vers la réalité.

Des hypothèses à la projection

L'année de simulation de l'occupation du sol choisie pour la calibration du modèle est 2013. Il est donc plus facile de comparer et de valider le modèle de l'occupation du sol simulée en 2013 à partir de la carte d'occupation du sol existante de 2013. Les Chaines de Markov ont été utilisées pour la simulation. Les résultats de cette simulation sont une carte de vulnérabilité de la zone et une carte de projection de l'occupation du sol en 2013.

Validation et évaluation du modèle

La validation du modèle s'est faite, d'une part, par la comparaison visuelle de la carte d'occupation du sol simulée en 2013 avec la situation réelle de 2013 (carte d'OCS 2013). Et d'autre part, une analyse statistique des données pixels dans un SIG a été utilisée pour quantifier le taux d'erreur de la simulation.

Simulation de l'occupation du sol en 2030

Après validation de la modélisation de l'occupation du sol en 2013, les données d'occupation du sol de 1986 et 2013, ont servies comme base de données, pour simuler l'occupation du sol en 2030. Les étapes précédentes, allant de l'analyse des changements entre les deux dates jusqu'à la projection de l'occupation du sol, ont été reprises pour obtenir l'occupation du sol simulée en 2030.

Resultats

Les cartes de probabilité de transition (2000-2013)

Les cartes résultantes correspondent à chacune des transitions susmentionnées, en exprimant, pour chaque pixel, leur probabilité graduelle d'occurrence, sur une échelle continue de 0 à 1. Ce sont des cartes de risques qui mettent en exergue les zones potentiellement soumises à des changements en 2013.

Ainsi, le risque potentiel pour les sols, les forêts et les zones de culture de changer pour un autre type d'OCS est fort dans les zones rouges (figure 4). Le risque des sols de la zone de devenir des habitats est élevé dans le sud-Ouest vers Port-Bouet et dans les environs de Grand-Bassam. Le risque est tout aussi fort dans les alentours de la forêt d'Abatta et dans la zone de Lamé au Sud-est de la zone de travail, où les sols nus deviendraient des zones de culture de rente, de culture vivrière ou de jachère. La carte de vulnérabilité (figure 9.4) présente toutes les zones de changements possibles, allant des zones les moins vulnérables à celles qui le sont le plus, entre 2000 et 2013. Les zones les plus vulnérables se localisent comme suit :

- Dans le centre: c'est une zone de forêts dégradées en proie à la pression humaine
- La zone sud : C'est une zone constituée de sols nus et d'anciennes plantations. Elle est proche de la plus grande métropole du pays (Abidjan) et se situe dans les villes de Grand-

Bassam et Bingerville (Abatta) et dans la zone de Bonoua. Ce sont toutes des zones en pleine mutation.

- Les alentours des forêts denses sont aussi d'une grande vulnérabilité.

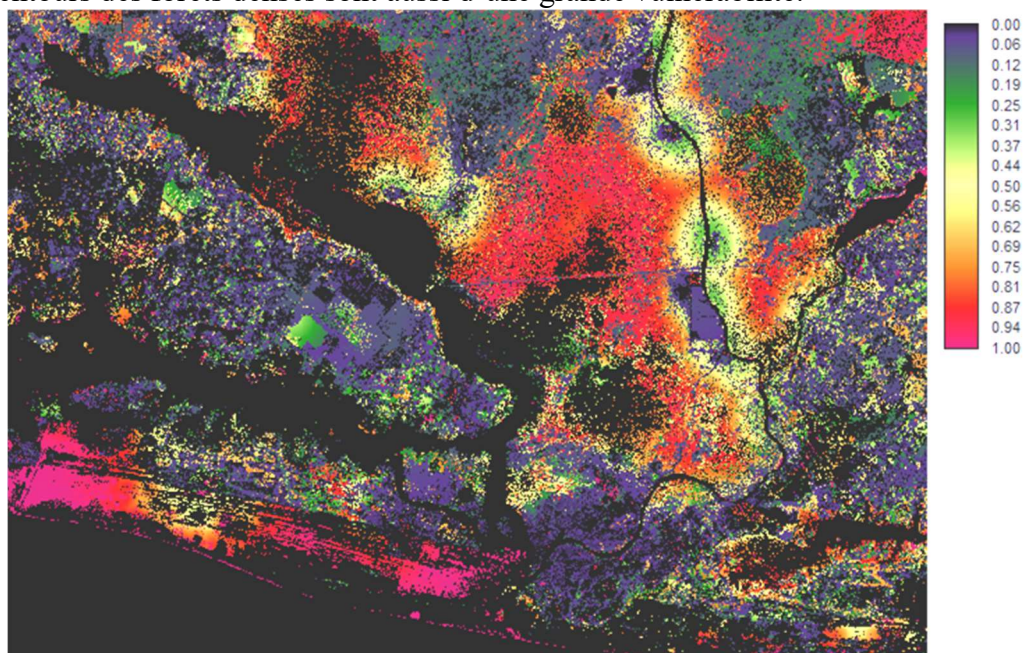


Figure 9.4: Carte de vulnérabilité des types d'occupation du sol simulée en 2013

Occupation du sol simulée en 2013

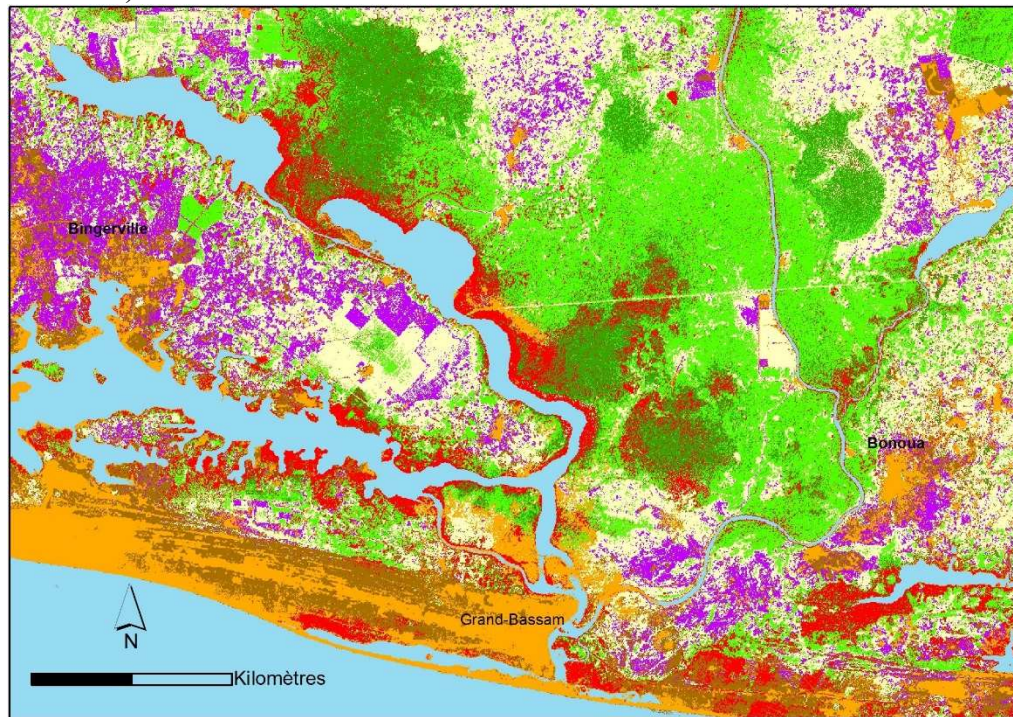
En s'appuyant sur les variables explicatives des changements dans le milieu et les sept cartes de probabilités de transitions, le modèle attribue la distribution idéale pour chaque type d'occupation du sol. Il prend en compte les dynamiques passées et les probabilités de transitions entre chaque type d'occupation du sol.

La matrice de Markov entre 2000 et 2013 (tableau 9.2) indique la probabilité dont dispose chaque catégorie d'occupation du sol, en 2000, de changer pour une autre catégorie, ou de rester stable en 2013.

	Eau	Habitat	Sol nu	Formation marécageuse	Forêt dense	Forêt dégradée	Culture de rente	Culture vivrière
Eau	0,9682	0,0047	0	0,0219	0,0003	0,0013	0,0029	0,0006
Habitat	0,0287	0,6109	0,2306	0,0464	0,0016	0,0131	0,0343	0,0343
Sol nu	0,0022	0,4335	0,1834	0,0619	0,0034	0,0349	0,1401	0,1407
Formation marécageuse	0,0541	0,0678	0,0043	0,4166	0,098	0,1905	0,1373	0,0315
Forêt dense	0	0	0	0,1801	0,5108	0,2521	0,057	0
Forêt dégradée	0	0,0012	0,0002	0,0452	0,089	0,566	0,2645	0,0339

Culture de rente	0,0011	0,0836	0,0107	0,0802	0,0173	0,1654	0,4269	0,2148
Culture vivrière	0,0051	0,0403	0,0056	0,0363	0,0157	0,1539	0,5821	0,1609

Le taux de précision de la simulation est de 80,39%. L'examen visuel donne une estimation de la qualité de la prédiction en comparant la carte réelle de 2013 et celle de la simulation en 2013 (Figure 9.5a et 9.5b).

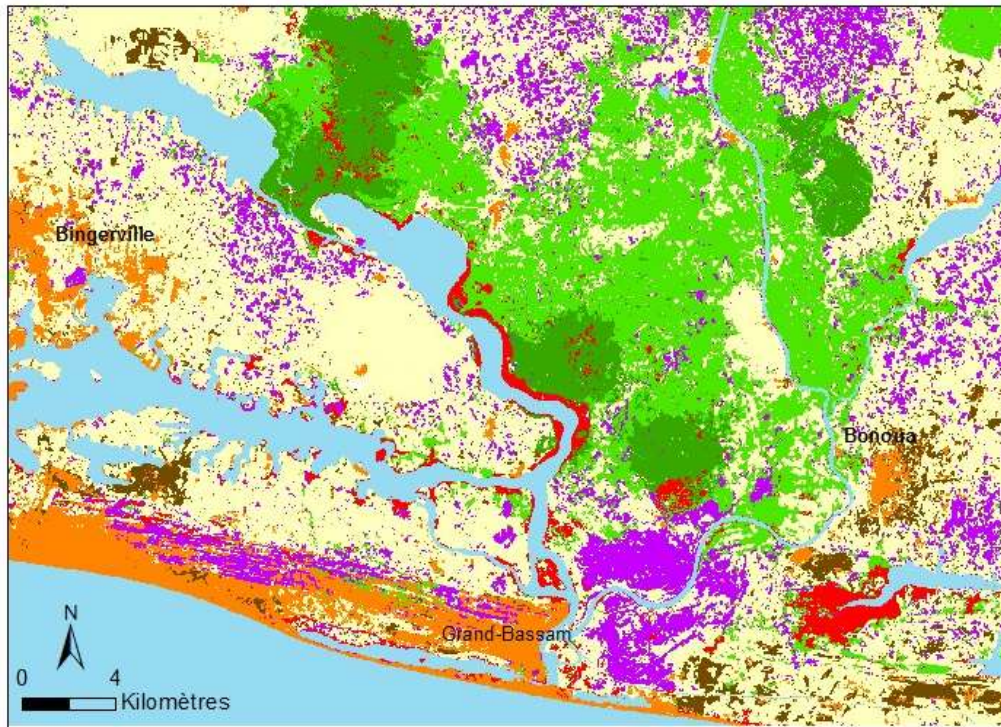


Source: Nos travaux, 2015

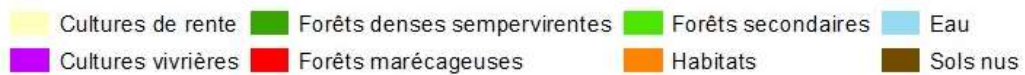
Conception et réalisation: AKADJE Marie-Claude, CURAT

Figure 9.5a

a) Occupation du sol simulée en 2013



Source: AKADJE Marie-Claude, CURAT, 2015



Occupation du sol réelle en 2013

Figure 9.5b: Comparaison de l'occupation du sol (réelle et simulée) en 2013

Les données statistiques permettent une meilleure explication de l'évolution (Tableau 9.3). La carte simulée présente une évolution des forêts dégradées, presque identique à l'évolution du sol réel, en 2013. Il s'agit de 25829,7 hectares de forêts dégradées simulées, contre 24014,79 hectares de forêts dégradées existantes. Les forêts denses et formations marécageuses sont quant à elles presque intactes.

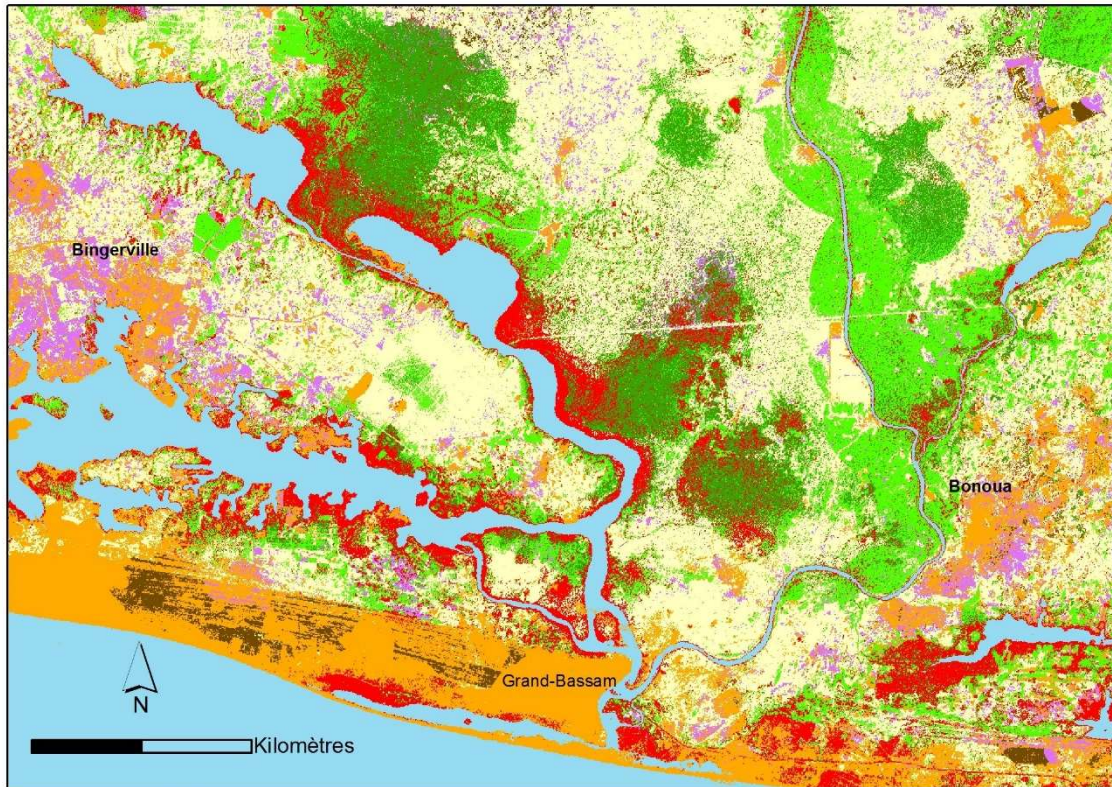
Les zones urbanisées simulées en 2013 sont relativement plus nombreuses que celles qui ont existé en 2013. Il s'agit de 11928,9 hectares habités et 8866,9 hectares de sols nus simulés contre respectivement 7927,84 hectares habités et 4411,03 hectares de sols nus réels. La majeure partie des différences est constatée au Sud-Est de la zone d'étude, où beaucoup plus de zones urbanisées ont été créées par le modèle, ainsi que de nombreux sols nus dans le Sud. Les erreurs les plus importantes commises par le modèle ont été observées sur la classe « cultures vivrières ». En effet, dans le nord-Ouest, la simulation a surévalué les quantités de ce type d'occupation du sol qui est passé de 14081,69 hectares réels à 24 311,6 hectares simulés en 2013.

Tableau 9.3: Superficies des types d'occupation du sol simulés en 2013 et 2030

	ocs réelle 2013	ocs simulée 2013 (en ha)	ocs simulée en 2013 (en%)	ocs simulée 2030 (en ha)	ocs simulée en 2030 (en%)
Eau	22 753,53	22 890,00	16,48	22 950,00	16,52
Habitat	7 927,84	11 928,90	8,59	20 474,40	14,74
Sol nu	4 411,03	8 866,90	6,38	1 968,70	1,42
Formation marécageuse	3 928,34	5 725,53	4,12	5 317,10	3,83
Forêt dense	8 286,97	9 544,40	6,87	8 982,50	6,47
Forêt dégradée	24 014,79	25 829,70	18,60	12 392,80	8,92
Culture rente	53 498,78	29 803,80	21,46	58 495,70	42,11
Culture vivrière	14 081,69	24 311,60	17,50	8 321,40	5,99
TOTAL	138 902,97	138 900,83	100,00	138 902,60	100,00

Simulation prédictive en 2030

L'évolution des types d'occupation du sol dans le temps et dans l'espace est projetée à l'horizon 2030, sur la base des changements actuels et des probabilités déterminées. L'analyse de cette projection révèle, qu'à l'horizon 2030 (figure 9.6), pendant que les agglomérations ainsi que les plantations et jachères augmenteront, les forêts dégradées connaîtront une forte régression (12 392,80 hectares). Les surfaces habitées doubleront, selon la simulation et atteindront 20474,40 hectares. En effet, les prochains changements continueront de se faire, au dépends des espaces forestiers et au profit des espaces agricoles et des agglomérations.



Source: Nos travaux, 2015

Conception et réalisation: AKADJE Marie-Claude, CURAT

Type d'occupation du sol



Figure 9.6: Simulation de l'occupation du sol en 2030

Discussion

Les résultats des simulations de 2013 et 2030 montrent les mêmes tendances dans l'évolution de l'occupation du sol. Les zones de culture de rente et d'habitation ont augmenté considérablement, au détriment des forêts dégradées.

Avant de simuler l'occupation du sol en 2030, la précision de la simulation a été testée en comparant la carte d'occupation du sol simulée de l'année 2013 à celle de la carte de "référence" de la même date, par interprétation visuelle puis par analyse de l'indice de Kappa. L'indice de réussite de la simulation est de 0,80. Selon Pontius (2000), les valeurs de Kappa supérieures à 0,50 indiquent un bon accord entre le «réel» et la carte simulée ; les résultats sont bons et exploitables. Sur la base de ce critère d'accord, il y a une divergence entre les cartes d'occupation du sol "réelle" et simulée. Les raisons de ces écarts pourraient être attribuées au nombre restreint de facteurs utilisés pour modéliser le phénomène (carte d'aptitude) et aux erreurs de classification des classes entre les images de 1986 et 2000. L'utilisation des cartes d'aptitude dans la simulation a une grande influence sur le résultat de la prédiction (Behera *et al.* 2012). Par ailleurs, Kouassi K. (2014), soutient que la complexité du système forestier rural ivoirien ne peut effectivement pas se résumer à un nombre restreint de facteurs. Aussi, certains auteurs ont montré que l'ajout de données explicatives supplémentaires pouvait être limité par leur nature non quantifiable et leur indisponibilité en

format digital (Maestriperi et Paegelow, 2013). C'est en effet, le cas de précipitations, ou encore d'exploitations forestières recueillies sur la zone, pour cette étude. Leur non-quantification dans l'espace ne permet pas leur utilisation dans le modèle alors qu'elles jouent un rôle important dans la dégradation du milieu.

L'occupation du sol simulée de 2030 indique une tendance d'augmentation des surfaces agricoles et urbanisées et une diminution de surfaces forestières. Cela induit une augmentation des terres agricoles et une perte de végétation naturelle. Cette tendance serait due aux pressions anthropiques et l'augmentation de la population. Dans les régions à forte densité de population (généralement autour des villes), tout l'espace disponible sera converti à l'agriculture dans un futur proche. Les conversions ultérieures de l'utilisation des sols sont rencontrées le long des routes proches des forêts, aux endroits où la probabilité d'activité agricole est élevée. Cela aboutira à un fort taux de déforestation, surtout dans ces régions. Si les limites des forêts protégées (propriétés publiques) ne sont pas contrôlées, les petites forêts seront certainement converties en terres agricoles.

C'est donc dans le but de prévenir cette déforestation, que le Plan National de Développement 2012-2015 adopté par le Gouvernement, visant à faire de la Côte d'Ivoire un pays émergent à l'horizon 2020, s'est fixé comme objectifs: d'améliorer la compétitivité, notamment par l'accroissement de la productivité, d'aider à atteindre l'autosuffisance et la sécurité alimentaire. Malheureusement, compte tenu du faible taux de rendement en milieu paysan et des techniques culturales non encore améliorées, l'atteinte de ces objectifs passe nécessairement par une augmentation des superficies cultivées. Cette augmentation de superficie se fait au détriment des forêts qui connaîtront une réduction plus prononcée à l'horizon 2030. C'est le cas de l'hévéaculture avec une prévision de production estimée à 600 000 tonnes de caoutchouc pour une superficie de 300 000 ha (Minagri, 2013). Si les tendances évolutives constatées sont maintenues, les prévisions faites dans le cadre des études de perspectives à long terme seront affectées.

Conclusion

Une simulation à long terme des pressions anthropiques dans la zone RAMSAR de Grand-Bassam et ses environs, a mis en exergue les différentes tendances d'évolution du milieu. Elle s'est basée sur des critères qui ont été définis après une analyse des changements d'occupation du sol de la zone, à plusieurs périodes. Ainsi, elle présente des tendances à la déforestation, à l'urbanisation et à la mise en culture des sols ; tendances qui seraient une continuité des mutations actuelles.

La modélisation spatiale prédictive montre son plein potentiel afin d'identifier les zones à enjeux socio-environnemental. Sa capacité à quantifier et localiser les changements futurs d'occupation du sol constitue une base plus ou moins solide dans le processus décisionnel, dans la mesure où elle permettra de calculer les impacts des processus environnementaux. La simulation des changements d'occupation des sols dans cette zone de grande importance écologique, donne aux décideurs une vision simplifiée d'un système complexe du futur qui pourrait les aider pour leurs prises de décisions, pour une gestion efficace des ressources naturelles.

References

Akadje L., Hauhouot A.C. 2014. « Analyse par télédétection des dégradations environnementales de 2000 à 2013 dans la zone Ramsar de Grand-Bassam (Sud de la Côte d'Ivoire) », in *Revue Scientifique Internationale de Géomatique*, Vol. 1, N° 0001 p. 33-40

- Atta K.J. M. 2009. Contribution de la Télédétection et des SIG pour une approche modélisatrice de la déforestation en vue d'une gestion durable des forêts tropicales : cas des Forêts classées de Béki et de Bossématié dans l'Est de la Côte d'Ivoire, Doctorat de géographie, Université de Nantes, 370p.
- Behera M. D., Borate S. N., Panda S.N., Behera P.R., Roy P. S. 2012. «Modelling and analyzing the watershed dynamics using Cellular Automata (CA) - Markov model: A geo-information based approach», in Revue *Earth System Sciences*, 121 (4) : p. 1011-1024
- Bonn et Rochon. 1992. *Précis de télédétection*, Volume 1, Principes et méthodes. Presses de l'Université du Québec, AUPELF, 486 p.
- Chen H., Pontius J.R. 2010. «Diagnostic tools to evaluate a spatial land change projection along a gradient of an explanatory variable», in Revue *Landscape Ecology*, vol. 25, p. 1319-1331.
- Eastman J.R. 2009. *The Land Change Modeler for Ecological Sustainability IDRISI Andes. Guide to GIS and Image Processing*, Worcester, 234-256.
- Hauhout A. C. 2004. « Les pressions anthropiques sur les milieux naturels du sud-est ivoirien », in Revue *Géo-Eco-Trop*, p. 69-82.
- Hauhout A. C., Pottier P., Bamba Y. 2011. « Recul des formations forestières dans la zone humide du littoral de grand-Bassam, Côte d'Ivoire » in Revue, *Revue internationale de la géomatique*. Volume 21 n°3. P. 327-339.
- Kangah A. 2015. « Pression humaine sur les massifs forestiers en côte d'Ivoire : cas de la forêt classée de Niégré, Sud-Est Ivoirien », in *Revue des sciences sociales PSS-PASRES*, n 7 pp 30-46.
- Kangah A. 2008. « Intégration des données de télédétection dans un SIG, pour l'évaluation et le suivi de mutations spatiales dans une ancienne zone d'économie de plantation : le cas de Bonoua en Côte d'Ivoire », in Aloko N. (dir) *Systèmes spatiaux et structures régionales en Afrique*, France, Edition la Nouvelle Imprimerie Laballery, Clamecy. pp155-171.
- Koli bi Z. 2009. « Dynamique de l'occupation du sol et des mutations socio-spatiales en pays Ehotilé d'Assinie sur le littoral Est de la Côte d'Ivoire », in Revue *Géotrope*, p. 3-19.
- Koffi, K. E. 2012. Mutation des paysages de zone humide et enjeux environnementaux et socioéconomiques dans le sud-est de la cote d'ivoire : cas du territoire des sous-préfectures de Dabou, Azaguié et du District d'Abidjan, Thèse unique, Université Félix Houphouët Boigny d'Abidjan, 237p.
- Maestriperi N. M., Paegelow. 2013. « Validation spatiale de deux modèles de simulation : l'exemple des plantations industrielles au Chili », in Revue *Cybergeo : European Journal of Geography, Systèmes, Modélisation, Géostatistiques*. 653, 30 p.
- Mas J.F., Puig H., Palacio J.L., Sosa-lópez A. 2004. « Modelling deforestation using GIS and artificial neural networks», in Revue *Environmental Modelling & Software*, vol. 19, p. 461-471.
- Oszwald J. 2005. Dynamique des formations agroforestières en Côte d'Ivoire (des années 1980 aux années 2000) : Suivi par télédétection et développement d'une approche cartographique, Université des Sciences et Technologies de Lille, UFR de Géographie et d'aménagement, Laboratoire de Géographie des Milieux Anthropisés (UMR CNRS 8141), Thèse de doctorat, 304p.
- Paegelow M., Villa N., Cornez L., Ferraty F., Ferre L., Sarda P. 2004. « Modélisations prospectives de l'occupation du sol. Le cas d'une montagne méditerranéenne », in

- revue *Cybergeo : European Journal of Geography*, Systèmes, Modélisation, Géostatistiques, <http://cybergeo.revues.org/2811>, No.295, 6 décembre 2004, 18 p.
- Pontius R.G., Huffaker D., Denman K. 2004. « Useful techniques of validation for spatially explicit land-change models », *Ecological Modelling*, vol. 179, p. 445-461.
- Pontis R. G. 2000. Quantification error versus location in comparison of categorical maps. *Photogrammetric Engineering and Remote Sensing*, 66 (8): 1011-1016.
- N'da D.H., N'guessan K.E., Wadja E. M. 2008. « Apport de la télédétection au suivi de la déforestation dans le Parc National de la Marahoué (Côte d'Ivoire) », in *revue de télédétection*, vol. 6, n°3, pp 17 – 34
- Sako N. 2011. Dynamique paysagère et biodiversité des aires protégées du littoral ivoirien : exemple des Parcs Nationaux du Banco et des Îles Ehotilé (sud-est de la Côte d'Ivoire), Thèse de doctorat en Géographie-Environnement, Université Paris Diderot, 290p.
- Theriault, M., Sparfel L., Gourmelon F., Le Berre I. 2011. « Modélisation des changements d'occupation et d'utilisation du sol. Cadres formels et exemple d'application », in *Revue Internationale de Géomatique* vol. 21 n°3.

Section C: Environmental conservation, natural resource use and governance

Chapter 10: Community opinions on land use practices and activities in relation to natural resource conservation at the Amboseli ecosystem, Kenya

Tom W. Okello^{1,2}

¹Department of Geography, QwaQwa Campus, University of the Free State, PO Box X13, Phuthaditjhaba 9866, Republic of South Africa

²The School for Field Studies, Center for Wildlife Management Studies, P.O. Box 27743 – 00506, Nairobi, Kenya.
okellotw@ufs.ac.za; weremaali@gmail.com

Abstract

Conflicting land use options often arise in areas where natural resource conservation and human development are both dominant land use practices. This scenario has been unraveling over the past few decades in the Amboseli region of southern Kenya. Using a cross sectional survey design, this study assessed the community opinions of their land use practices and activities on natural resource conservation and preservation initiatives. Household surveys were conducted in nine villages of two group ranches (Kimana and Imbirikani). Agro-pastoralism was stated by respondents as the dominant land use practice in the area, suggesting the gradual change in economic activities of the rural Maasai community from solely pastoralism to sedentary crop cultivation. Although many respondents suffered economic loss from crop raiding by wildlife, most of these individuals still considered natural resource conservation important and were willing to relinquish part of their land for conservation efforts. Along with sustainable natural conservation strategies to limit human-wildlife conflicts, other forms of livelihood should be introduced into the area to check the current land use practices and foster positive attitudes towards natural resource conservation.

Keywords: community, land-use, natural resource conservation, Amboseli, Kenya

Introduction

Increased human population accompanied by land use-land cover changes in Kenya has rapidly led to insularisation of most of her protected areas (Okello & Kiringe, 2004). This insularisation may have challenges for biodiversity conservation (Burkey, 1994). Common factors for the insularisation of protected areas are expansion of human activities and structures (Mwale, 2000), tourism activities inside protected areas (Johnson, 2000), and degradation of wildlife dispersal areas (Lamprey & Reid, 2004). To circumvent these, wildlife dispersal areas and migration corridors need to be maintained and kept open to allow wildlife for feeding and breeding grounds, other populations to supplant resident populations, encourage genetic diversity, and allow locally extinct species to restock former ranging areas, and hence reduce potential genetic drift and local extinctions (Newmark, 1993).

The Amboseli area of Southern Kenya comprises extensive areas of land, whose bulk is legally registered as group ranches owned by individuals mostly from the Maasai community (Altmann, Alberts, Altmann, Roy, 2002). This area is characterised by diversity of landscapes of wildlife and livestock habitats from Amboseli and Chyulu Hills/Tsavo West national parks

(Okello, Buthmann, Mapinu & Kahi, 2011). The area forms a corridor and dispersal zone between these protected areas. Anthropomorphically, the region has undergone a steady shift in land use practices from purely pastoral to mixed agro-pastoral systems driven by a variety of socio-economic, cultural and geopolitical factors (Berger, 2003). These changes may have largely been influenced by changes in land tenure systems within the area and the steady switch from communal group ranches to individual parcels of land.

Group ranches emerged in 1968 under the Group (Land Representatives) Act (BurnSilver, 2007); however, the group ranch system gradually dissolved decades after its inception. Individual ownership of parcels of land granted people alternative forms of income by either leasing, cultivating, or selling part of their land (Mwangi, 2005). Productive, commercialised agricultural activity within the arid regions of some group ranches heightened fear among the community that they would lose their grazing land to non-natives practising agriculture, hastening the subdivision of group ranches (Mwangi, 2006). At the same time, increased food scarcity, poverty, population growth, and water shortage in the region has spurred the conversion of traditional pastoral lands to agricultural fields for personal economic benefits (Western, Groom, Worden, 2009). The group ranch concept was not short of challenges. Communal governance of the group ranches required active management and enforcement costs to eliminate overgrazing and regulate livestock herd size quotas (Mwangi, 2005). Resource scarcity remains an inevitable outcome of group ranch subdivision. Population pressures and migration into the area for land led to increased valuation of land as a limiting resource (Mwangi, 2005). In this post-subdivision environment, some community members have since established collective access rights to resources, pursuing joint pasture and herd management systems (Mwangi, 2006). Further, the privatisation and subdivision of land hinders livestock movement and communal grazing among pastoralists, leading to the crop cultivation in the Amboseli region (Okello and D'Amour, 2008). Of all herders in the Amboseli region, an estimated 71% have attempted some form of agricultural work (Okello, 2005). Crop cultivation is easily practised in the subdivided group ranches, generating income for locals who sell their crops to the local markets of Kimana and Oloitokitok (Okello and D'Amour, 2008).

One of the leading threats to natural resources conservation is degradation and diminished habitats within the Amboseli Ecosystem. Natural resources are available in finite quantities and considered common pool resources that are easily excludable (Pearce, 1993). As such, the sustainability of current community land use practices is constrained. Prior to the migration of non-native residents in recent years, the natives were able to conserve natural resources and avoid resource exploitation by denying outsiders access to critical pastures and bodies of water, especially during the dry season (Blewett, 1995). In the recent past, overexploitation of natural resources in the Amboseli region has resulted from population increase and the lack of economic opportunities (Okello and Kioko, 2011). Localised vegetation resources are steadily dwindling as more people migrate to the Amboseli region to practise agriculture. Cooking, fencing, and building household structures require natural vegetation, leading to the steady overutilisation of these plant resources (Okello and Kioko, 2011). These changes in socio-economic practices of the native Maasai community are ultimately limited by resource availability. As such, without other viable forms of land use practices and socio-economic activities to support their livelihoods, natural resource conservation would remain futile.

This study sought to assess community opinions on land use practices and activities in relation to natural resource conservation at the Amboseli Ecosystem, Kenya. The specific objectives were to:

- Establish local opinions and views concerning environment and natural resources and implications of this on wildlife dispersal and local livelihoods in Amboseli Ecosystem
- Assess Community opinions on land use practices and effect on the local well-being in Amboseli Ecosystem
- Assess Community Attitudes towards the Environment and their effect on natural resources conservation in Amboseli Ecosystem
- Make appropriate recommendations on the way forward.

The study area

The study area was the Amboseli ecosystem in Southern Kenya. The area comprises of Amboseli National Park, surrounding group ranches, and community wildlife sanctuaries (Okello, Manka, D'Amour, 2008). This wildlife rich area is located in Kajiado County bordering Tanzania around the Mt. Kilimanjaro area. Protected areas in the region are not large enough to support most wildlife without accompanying dispersal areas (Okello & Kiringe, 2004). Kimana and Imbirikani Group Ranches, which are key communal lands and dispersal areas for the protected area in the wet season, have community-based wildlife sanctuaries that also serve as important dry season wildlife concentration areas (Lichtenfeld, 1998) for Amboseli. The group ranches are relatively small, with an area of 251 km² (Figure 10.1). The area is semi-arid rangeland with a bimodal rainfall pattern (Ntiati, 2002) with long rains (65%) occurring from March to early June, while the short rains occur in October and November (35%). The amount of rainfall (250mm) received is influenced by Mt. Kilimanjaro, which casts a rain shadow on the area. These rainfall characteristics are typical of semi-arid areas, also characterised by low and erratic rainfall and high temperatures.

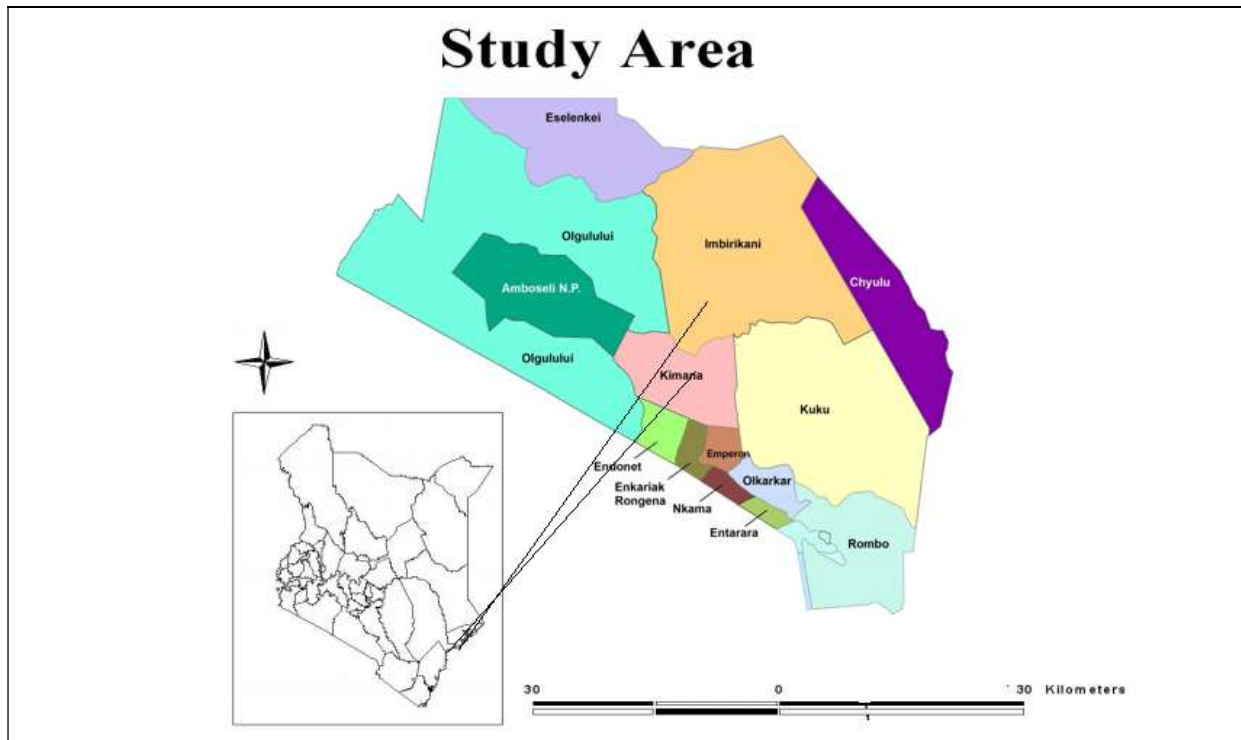


Figure 10.1: The group ranches between Amboseli National Park and Tsavo / Chyulu Parks in southern Kenya. Inset is the map of Kenya with region demarcations.

The vegetation is dominated by grasses, shrubs, and Acacia species that are adapted to long periods of drought. The study area rangeland consists of a variety of habitats, including dense and open shrub land, bush land, and woodland. The dominant vegetation in the riverine habitat is *Acacia xanthophloea*, but *Acacia tortillis* and *Acacia mellifera* in drier areas (Irigia, 1995). Dominant perennial grass species such as *Cenchrus ciliaris* and *Chloris roxburghiana* are common in the area (Gichohi, 1996). Soils in this region are volcanic, and generally highly saline and alkaline. The soils are also less well developed, shallow and generally unproductive, but can be very productive near water sources (Katampoi, *et al.* 1990).

Irrigation agriculture is practised in the study area (Okello, 2005; Okello & D'amour, 2008) except in areas near Kilimanjaro where rain-fed agriculture is possible due to relatively higher rainfall of over 1,000 mm annually (Katampoi, *et al.* 1990; Campbell, Gichohi, Mwangi, & Chege, 2000). Group ranches in the Tsavo- Amboseli ecosystem support and provide wildlife corridors and dispersal areas that link protected areas in the ecosystem (Amboseli, Tsavo West and Chyulu Hills) and community conservation areas allowing them to support large populations of seasonally migratory mammals (Western, Groom, Worden, 2009). The group ranches on their own also support populations of wild large mammals in an open landscape (Sindiga, 1995) with 70% of wildlife living outside the protected areas (Wishitemi & Okello, 2003).

Methods

Both land owners and land users (those who rent land for agricultural activities) from Kimana and Imbirikani Group ranches were accessed. This was done by use of semi- structured questionnaires, a strata of land uses (farmer or pastoralism strata), clusters of human settlement (homesteads) design units (Okello, 2005), across land use transect (Campbell, Gichohi, Mwangi, & Chege, 2000; Campbell, Lusch, Smucker, Wangui, 2003). A land use owner or

lease of an agricultural land was the sampling unit for agricultural farms. This was necessary because the range of issues investigated concerned both land users and owners, particularly in fenced areas within the group ranches (Okello & D'amour, 2008) where sub-division was into individual ownership. The sampling design therefore considered views of both cultivators (in irrigation schemes inside the electric fences) and the mainly pastoralist Maasai community living in open range where they keep livestock. The dominant Maasai community lives in family clusters of settlements (related or sometimes not related) called *bomas* especially along rivers, roads and water points. To examine local community opinions, interviews were done using semi-structured questionnaires and discussions with key informants and stakeholders in both group ranches. To obtain wider and representative information, both the Maasai and non-Maasai cultivators were interviewed in the first stratum using a simple random sampling approach for farm plots (owners) (Ratti, & Garton, 1994). The second stratum was mostly Maasai pastoralists living in an open range (outside agriculture clusters confined in electric fences) where all homesteads were known.

Due to their clustered settlements in homesteads (*bomas*), a two-stage sampling approach was used in which all clusters of settlements were located and included in sampling whereby individual *bomas* were randomly selected in each cluster. Once *bomas* were selected, all households within each *boma* were included in the interview (Ratti, & Garton, 1994). At least a sampling effort of over 40% of the homesteads (*bomas*) was maintained in each cluster. The sampling unit for the pastoralism interviews was a household (Zar, 1999) within a homestead (*boma*). The location and number of community clusters and homestead settlements (*bomas*) outside the fences (*bomas*) and other settlement clusters were mapped in a previous preliminary study, and so it was possible to know the sampling effort and households from *bomas* (a *boma* comprises typically between one and five families) to be included in a random sample.

Only an adult family head (man or woman) was interviewed from each household to ensure the independence of the data collected, as well as getting the most representative views possible. The interview and discussion with each interviewee was done separately from anyone else. To further ensure robustness of tests, reliability of inference and conclusions, an effort was made to interview equal numbers of men and women (even though most Maasai women will not agree to give interviews when their husbands are present), while also ensuring a good sample size of households interviewed in each strata. Interviews were done between July and September 2017. The local guides and interpreters were trained and used for exact translation into Maasai language from English. To ensure that the information asked was accurate, consistently phrased and presented in the same way from one interviewee to another, a discussion guided by a semi-structured questionnaire with local interpreters was done question by question to ascertain the meaning, wording and expected responses from the interviewees. These "trained" local translators and interpreters (good in both Swahili and Maasai, the commonly spoken languages in the area) were retained throughout the study.

Before conducting the questionnaire interviews, the introduction of the interviewers and the general purpose of the interview were done. Questions focused on land use practices, resource use, forms of livelihoods, wildlife relationships, and group ranch communal management. After the interview, the interviewees were allowed to ask questions that they had for the researchers and make further comments about questions asked to enhance participatory discussions for further insights (Drijver, 1994; Kumar, 2002). Later, results of the work were presented in a joint presentation in which local community members, group ranch officials and other stakeholders were invited for discussions and further clarification of issues. Excel

Spreadsheet for windows (Microsoft Corporation 2010) was used to tally and synthesise all study issues raised in the questionnaire. Frequencies of interviewed household heads giving a particular response as well as differences in frequencies of particular responses of an issue were summarised and equality of frequencies tested using chi-square goodness of fit (Zar, 1999). A chi – square cross tabulations analysis was employed using SPSS Version 9.0 for Windows (SPSS Inc. 2015) to establish factors influencing certain responses and particular relationships with specific attributes, Statistical tests were considered significant with p – values equal to or less than 0.05 [38]. For goodness of fit, if the p-value was equal or less than 0.05, then the frequencies were significantly different (and similar if p-value was greater than 0.05). For chi – square cross tabulations, if p-value was equal to or less than 0.05, then a response was dependent on an attribute, and independent of the attribute if p – value was greater than 0.05.

Results

Table 10.1: Demographics of respondents			
Respondent demographics (N=224)			
Gender		Reading ability	
Male	65 (29%)	Easily	65 (29%)
Female	159 (71%)	With difficulty	36 (16%)
		Not at all	125 (56%)
Age		Years of residence in the study area	
16-25	49 (22%)	0-5	83 (37%)
26-30	40 (18%)	6-10	45 (20%)
31-35	25(11%)	11-15	20 (9%)
36-40	16 (7%)	15+	76 (34%)
41+	45 (20%)		
Unknown	49 (22%)		
Ethnicity		Religion	
Maasai	199 (89%)	Christian	215 (96%)
Kikuyu	11 (5%)	Traditionalist	2 (1%)
Kamba	7 (3%)	Other	7 (3%)
Other	7 (3%)		
Education Level			
Pre-primary	2 (1%)		
Lower primary	47 (21%)		
Upper primary	36 (16%)		
Tertiary college	4 (2%)		
University	4 (2%)		
None	132 (59%)		
Other	1 (0.4%)		

The majority of individuals interviewed in both group ranches were female (71%). The respondents were fairly distributed across the age groups, except the 36-40 group (7%). The Masaai was the dominant (89%) ethnic group among respondents. The majority (59%) of respondents had no formal education, while lower primary (21%) was the highest level of education for the respondents. Slightly over half of the respondents (56%) had no reading ability. However, 29% of respondents could easily read any form of literature. Most of the respondents had lived in the area for less than five years (37%) or more than fifteen years (34%). Christianity (96%) was the dominant religion among the respondents.

Local opinions on the status of the land use practices

Agro-pastoralism (40%) was stated as the dominant land use practice followed by Pastoralism (30%) and Agriculture (27%) respectively (Table 10.2). All forms of major land use practices within the group ranches had increased over the last five years, as follows: Agriculture (73%), Agro-pastoralism (64%), and Wildlife conservation (64%) (Table 10.2). The amount of land for wildlife habitats had increased (48%) over the past five years. Based on the results (Table 10.2), there appears to be an increase in land use practices within the Amboseli region.

Agro-pastoralism was stated to be the dominant land use practice between both group ranches, indicating a gradual land use practice caused primarily by the need of land for agricultural purposes. Agriculture was suggested to have increased over the past few years. An explanation for this observation could be a lack of understanding among the respondents and their inability to assess land use changes and practices.

Dominant land use changes			
Pastoralism	67 (30%)		
Agriculture	60 (27%)		
Agro-pastoralism	90 (40%)		
Wildlife conservation	2 (0.9%)		
Forestry	1(0.4%)		
None	3 (1.3%)		
Changes in land use practices	Increase (%)	Decrease (%)	No Change (%)
Pastoralism	130 (58%)	69 (31%)	25 (11%)
Agriculture	164 (73%)	27 (12%)	34 (15%)
Agro-pastoralism	143 (64%)	29 (13%)	52 (23%)
Wildlife conservation	143 (64%)	41 (19%)	38 (17%)
Forestry	92(41%)	72 (32%)	63 (28%)
Changes in size of land for wildlife habitats	Increase (%)	Decrease (%)	No Change (%)
	108 (48%)	83 (37%)	34 (15%)

Community opinions on land ownership, economic loss and compensation

Land ownership

In both Kimana (82%) and Imbirikani (72 %) group ranches the majority of respondents owned the land upon which they resided (Table 10.3). The majority (74%) of the respondents from Kimana group ranch owned between 0-5 acres (77%) of land for Agriculture compared to those who did not own land (12%). The majority of respondents (51%) from the Imbirikani group ranch owned the land upon which they resided compared to those (47%) who did not. The majority (73%) of respondents from the Imbirikani owned land for agriculture between 0-5 acres (92%) (Table 10.3).

According to the chi-square contingency test, the percentage of respondents that observed a change in the amount of land for wildlife habitats in the past five years was dependent on the system of land ownership for respondents ($f = 16.536$, $df = 4$, $p\text{-value} = 0.002$). Of the respondents who owned land upon which they resided, 52% observed an increase in the size of land for wildlife habitats, while 38% observed a decrease in the size of land for wildlife habitats. Of the respondents who rented the land upon which they resided, 37% observed an increase in the size of land for wildlife habitats, while 58% observed a decrease of

land for wildlife habitats. Of the respondents who neither owned nor rented the land upon which they resided, 40% observed an increase in the amount of land for wildlife habitats; however, 30% observed a decrease while the remaining 30% observed no change in wildlife habitats over the past five years .

Table 10.3: Community opinions of land ownership, economic loss and compensation			
General land ownership	Kimana	Imbirikani	Chi Square Goodness of fit; df; P-Value
Own land	184 (82%)	114 (51%)	No analysis necessary
Rent land	38 (17%)	7 (3%)	
Other	2 (1%)	105 (47%)	
Agricultural land ownership	Kimana	Imbirikani	
Yes	166 (74%)	58 (26%)	f = 16.536, df = 4, p-value = 0.002
No	164 (73%)	60 (27%)	
Size of Agricultural land owned (Hectares)	Kimana	Imbirikani	
0-5	172 (77%)	206 (92%)	
6-10	13 (6%)	4 (2%)	
11-15	4 (2%)	2 (1%)	
16-20	9 (4%)	2 (1%)	
Unknown	27 (12%)	9 (4%)	
Economic losses and compensation	Kimana	Imbirikani	
USD \$(0 – 1099)	101 (45%)		f = 11.047, df = 4, p-value = 0.026
USD \$(1100 - 2747)	25 (11%)		
USD \$(2748– 5495)	8 (3.4%)		
Above –USD \$(5295)	16 (7%)		

Economic losses and compensation

Respondents (45%) estimated the seasonal economic loss due to crop raiding from wildlife between USD \$(0 – 1099); while 35% were unsure ; however, 4% estimated the loss between USD \$(2748– 5495) (Table 10.3). Of the individuals who stated that crop raiding occurred, 98% asserted that they were never compensated for economic losses caused by crop raiding. Only 2.1% of respondents who stated that crop raiding occurred in the area indicated that they were compensated for economic losses. According to the chi-square contingency test, the respondents' preference for conserving natural resources was dependent on the estimated seasonal economic loss due to crop raiding of agricultural fields by wildlife (f = 11.047, df = 4, p-value = 0.026). 100% of respondents who stated that they lost above USD \$(0 – 1099) per growing season due to crop raiding considered natural resource conservation important, while 65% of respondents who were unsure of the seasonal economic loss due to crop raiding considered natural resource conservation important. Of the respondents who were unsure of the seasonal economic loss due to crop raiding, 35% considered natural resource conservation unimportant.

Community attitudes towards the environment

The proportion of respondents willing to give up their land for conservation initiatives was dependent on their preference for conserving natural resources (Table 10.4). With regard to

willingness to give up land for conservation initiatives, the majority (55.6%) would give up their land for conservation. Of the respondents who considered natural resource conservation important, only 68% would give up their land for conservation while the majority (84.4%) did not consider natural resource conservation important and would not give up their land for conservation. The proportion of the respondents willing to give up their land for conservation initiatives was dependent on the proportion of those who noticed the presence of environmental organisations in the community. Of the respondents who were aware of environmental organisations in the community, 66.2% were willing to give up their land for conservation, while 21.6% were not willing to do so. Of the respondents who were not aware of environmental organisations in the community, 50.3% were willing to give up their land for conservation, while 41.6% were not willing to give up their land for conservation.

Attributes	Willingness to give land for conservation		
Conserving natural resources is important	Yes	124 (55.6 %)	f = 63.749, df = 3, p-value < 0.001
	No	78 (35%)	
	Maybe	10 (4.5 %)	
	I don't know	11 (4.9%)	
Presence of environmental organisations in the community	Yes	124 (55.6 %)	f = 8.847, df = 3, p-value = 0.031
	No	78 (35%)	
	Maybe	10 (4.5 %)	
	I don't know	11 (4.9%)	
Conservation areas and protected areas were beneficiary to the community	Source of employment	107 (47.7%)	f = 38.917, df = 4, p-value < 0.001 124 (55.6 %)
	Provide services	24 (10.6%)	
	Tourism	15 (6.9%)	
	Protect wildlife	3 (1.4%)	
	Protect wilder	15 (6.5%)	
	No benefits	50 (22.2%)	
	Other	Community main beneficiary of conservation areas	
	Household & community	78 (35%)	
	Community only	10 (4.5 %)	
	Neither household nor community	11 (4.9%)	
	I don't know	124 (55.6 %)	

Employment was the most frequently cited benefit of conservation areas among respondents (Table 10.4). 47.7% of respondents stated that employment was the dominant benefit of conservation areas, while 22.2% of respondents stated that the conservation areas provided no form of benefit to the community. Protecting animals was the least frequently stated benefit of conservation areas, at 1.4%. According to the chi-square contingency test, the percentage of respondents who considered natural resource conservation important was dependent on the respondents' perception of the main beneficiary of conservation areas ($f = 38.917$, $df = 4$, p -

value < 0.001). 93.7% of respondents who stated that conservation areas benefited the household and community considered natural resource conservation important. Of the respondents who indicated that conservation areas benefited neither the household nor the community, 51.4% considered natural resource conservation not important. 78.6% of respondents who stated that conservation areas benefited only the community considered natural resource conservation important, whereas 63.6% of respondents who stated that conservation areas benefited only the household considered natural resource conservation important.

With regard to respondents' willingness to give up their land for conservation initiatives, the proportion of respondents willing to give up their land was dependent on the respondents' view of the main beneficiary of conservation areas ($f = 77.662$, $df = 12$, $p\text{-value} < 0.001$). Of the respondents who stated that only the household benefited from conservation areas, 72.7% were not willing to give up part of their land for conservation; however, 83.8% of respondents who stated that neither the household nor the community benefited from conservation areas were not willing to give up part of their land for conservation. 74.8% of respondents who stated that both the household and community benefited from conservation areas were willing to give up part of their land for conservation. According to the chi-square contingency test, the percentage of respondents who considered natural resource conservation important was not dependent ($f = 0.520$, $df = 1$, $p\text{-value} > 0.05$) on percentage of respondents owning agricultural land.

Discussion

Based on the results there is an increase in size of land suitable for wildlife dispersal as indicated that the amount of land for wildlife habitats has increased over the past five years. This could be caused by a decline in forestry and timber cultivation practices, providing greater natural vegetation and habitat availability for wildlife. Another explanation could be that with increased land subdivision and encroachment on common wildlife dispersal areas for agricultural purposes, individuals would have greater interactions with wildlife, leading to the perception that the amount of wildlife habitat land has increased. The majority of individuals with agricultural land believed that the amount of land for wildlife habitats has increased over the past five years.

Comparing the two group ranches, owning land upon which one resides was much more common in the Kimana Group Ranch than in Imbirikani Group Ranch. Within Imbirikani Group Ranch, individuals rarely owned or rented the land because communal ownership of the land negates the need or concern for land security, titles, and deeds. This may suggest that individuals within Kimana Group Ranch are more likely to own their land, altering their view of changes in the size of land for wildlife habitats. Although an increase in wildlife habitats was the most frequently stated change among people who neither owned nor rented their land, roughly a third of individuals who neither owned nor rented their land stated no change in wildlife habitat. This could suggest that the inability to own or rent land in Imbirikani group Ranch would lead to greater movement within the group ranch to find suitable land for economic activities. In turn, these individuals may encounter wildlife more frequently, leading to their belief that wildlife habitats have been increasing over the past few years.

In terms of the economic losses incurred from crop raiding, the majority of respondents estimated that they either lose USD \$(0 – 1099) per growing season or they were unsure of the monetary amount. Variations in crop type produced, the number of acres owned, and the education level of the respondent could explain the variation in the estimated economic loss from crop raiding. Compensation for crop raiding was uncommon among farmers because

compensation initiatives by the national government and Kenyan Wildlife Service are non-existent (Okello, Buthmann, Mapinu & Kahi, 2011). Although economic losses from crop raiding remain consistent and farmers lack any forms of compensation, individuals continue agricultural work and crop production. With few other types of economic activities in the region, agriculture and pastoralism remain the only viable economic activities for the Maasai. While the respondents' preference for conserving natural resources is dependent on the economic loss from crop raiding, the variables lack a clear correlation. Within all estimated economic loss ranges, the majority of individuals stated that they considered natural resource conservation important. This suggests that the community attitude toward conservation is not directly affected by the amount of money lost due to crop raiding. However, individuals that were unsure of the exact amount of money lost to crop raiding had the highest percentage of those that considered natural resource conservation unimportant. This could be the result of low levels of education and the lack of awareness of conservation initiatives rather than the economic loss due to crop raiding.

The majority of respondents had a positive attitude towards natural resource conservation and protected areas. Specifically, over half of the respondents were willing to give part of their land for conservation initiatives. This variable was dependent on respondents' preference for natural resource conservation and their interaction with environmental organizations. While an overwhelming majority of individuals who believed natural resource conservation was unimportant were unwilling to give part of their land for conservation, a small percent of respondents who did not approve of natural resource conservation were willing to give part of their land for conservation. A similar trend was present when examining the impact of environmental organisation presence on an individual's willingness to give part of their land for conservation. A larger proportion of individuals who had been exposed to environmental organisations in the area were willing to give part of their land to conservation compared to individuals who had not encountered environmental organisations in the area. This suggests that organisations, which directly interact with the community, alter their perception of natural resource conservation.

As for conservation areas and protected areas, the majority of respondents believed they provided some form of benefit to various groups of people. Employment was the dominant benefit, followed by no benefits, and services. This suggests that direct economic benefits are more significant to the Maasai than intrinsic and indirect benefits, such as increased tourism and wildlife protection. The respondents' perception towards conserving natural resources and their willingness to give up land for conservation were both dependent on the main beneficiary of conservation areas. Benefits to both the household and the community were stated most often among individuals that answered positively towards conservation initiatives, while benefits to neither the household nor the community were stated most often among individuals that answered negatively towards conservation initiatives. This suggests that the community views conservation efforts in a positive manner when these initiatives economically benefit both the community and household and therefore the community is more willing to participate in these efforts when more people are involved. Conservation areas that only benefit a small sect of individuals are less effective at altering the communities' perception towards these natural resource conservation efforts and wildlife preservation.

Conclusions and recommendations

The community attitude towards the environment and conservation efforts depends upon individual ownership of land and personal economic livelihoods. Since agro-pastoralism and agriculture are the dominant land use practices in the area, crop raiding occurs frequently,

causing some individuals to perceive conservation efforts and wildlife preservation negatively. These negative attitudes would continue to undermine holistic conservation efforts unless the economic loss to crop raiding is reduced and individuals are compensated for their losses caused by wildlife (Okello and Kioko, 2011). Although the proportion of individuals who own agricultural land is dependent on the economic loss incurred from crop raiding, the estimated amount lost does not correlate to agricultural land ownership, suggesting that animal conflicts do not deter agricultural practices.

Conversely, economic losses due to wildlife have been shown to influence transaction costs for creating, maintaining, and implementing arrangements for protected areas (Mburu *et al.* 2002). In turn, the increased frequency of wildlife damage to the economic activities of the Community will deter their willingness to maintain the infrastructure for proposed conservation initiatives. At the same time, the community views the benefits of conservation areas in a positive manner if they provide direct economic benefits, such as employment and services, to households and the community.

As the group ranches in the Amboseli region undergo subdivision, fragmentation and land degradation will persist. Increased community land use practices, especially agriculture and agro-pastoralism, limit the natural vegetation and dispersal areas for wildlife. Although the community are aware of the benefits provided by the environment and natural resources, these benefits are examined in terms of their direct economic benefit and therefore the resources and ecosystem services in the region run the risk of severe overexploitation within the next few decades. Conflicts with wildlife do not deter the community from practising agricultural work, but rather heighten the tension between these two groups. Without other forms of employment readily available in the region, the community will continue to rely on agriculture as their sole form of livelihood, conflicting with efforts to preserve the wildlife and natural resources of the Amboseli ecosystem (Okello and Kioko, 2011).

These findings reiterate the common view that direct benefits from conservation, such as employment and services, are regarded most highly among the community. As a result, conservation initiatives must provide some form of immediate and direct benefit to locals in order for them to consider it a worthwhile cause; however, crop cultivation will persist unless other forms of employment are established in the community. Sustainable economic activities should be introduced in the Amboseli region by the national government to lessen the intensive land-use labour associated with this area and limit the occurrence of human-wildlife interactions.

Many respondents suggested the creation of electric fences around their farms. However, prior studies have shown that poor management and financing of fences in the area make such a solution impractical (Okello and D'Amour, 2008). Creating natural barriers composed of crops that deter wildlife is a wildlife-friendly technique that requires less upfront costs and less maintenance than an electric fence. Compensation schemes should be implemented in instances when wildlife destroys agricultural fields and predators attack livestock. A lottery system should be developed to allocate the remaining un-subdivided land within group ranches in order to mitigate the continued alteration of common wildlife dispersal areas into agricultural plots. Regular meetings should be held in town centres to promote environmental awareness. To further mitigate natural resource degradation, other sustainable economic activities and forms of livelihood should be introduced into the area such as a regulated ecofriendly charcoal industry.

Acknowledgements

I would like to thank the School for Field Studies and its Centre for Wildlife Management

Studies for financial and logistical support for this work. I also would like to thank my field guide, Joshua Leyian, for assisting me during the data collection process. I also thank our facility assistant and driver, Sipaya and Martin, for field support and logistics.

References

- Altmann, J., Alberts, S.C., Altmann, S.A., and Roy, S.B. 2002. Dramatic change in local climate patterns in the Amboseli basin, Kenya. *African Journal of Ecology* 40, 248-251.
- Berger, D.J. 1993. *Wildlife extension: participatory conservation by the Maasai of Kenya*. African Centre for Technology Studies (ACTS) & Initiative Publishers: Nairobi, Kenya.
- Blewett, R.A. 2013. Property rights as a cause of the tragedy of the commons: institutional change and the pastoral Maasai of Kenya. *Eastern Economic Journal* 21, 477-490.
- Burkey, T. Faunal collapse in East African game reserves revisited. *Biol Conserv* 1994; 7(1): 107-10.
- BurnSilver, S., and Mwangi, E. 2007. *Beyond group ranch subdivision: collective action for livestock mobility, ecological viability, and livelihoods*. CGIAR Systemwide Program on Collective Action and Property Rights (CAPRI): Washington, D.C.
- Campbell, D., Lusch, D., Smucker, T., Wangui, E. *Root Causes of Land Use Changes in the Loitokitok Area, Kajiado District, Kenya*. Land Use Change Impacts and Dynamics (LUCID) Project Working Paper 19. International Livestock Research Institute. Nairobi, Kenya, 2003.
- Campbell, D.J., Gichohi, H., Mwangi, A., Chege, L. Land use conflict in Kajiado District, Kenya. *Land Use Policy* 2000; 17: 337-48.
- Drijver, C. Participatory Rural Appraisal (PRA): a challenge for people and protected areas. *Parks* 1994; 4(1): 35-40.
- Gichohi, H., Mwangi, E., Gakahu, C. *Savanna ecosystems. In East African ecosystems and their conservation*. McClanahan T R, Young T P. Eds. Oxford University Press, New York, New York, USA. 1996; pp 273-98.
- Johnstone, R. Talking ecotourism. *Swara*. 2000; 22(4): 5- 9.
- Katampoi, K., Genga, G., Mwangi, M., Kipkan, J., Seitah, J., Van Klinken, M. & Mwangi, SM. *Kajiado District Atlas. ASAL Programme Kajiado*. Kajiado, 1990.
- Kumar, S. *Methods for community participation: a complete guide for practitioners*. ITTG Publishing, London, 2002.
- Lamprey, R.H., Reid, R.S. Expansion of human settlement in Kenya's Maasai Mara: what future for pastoralism and wildlife? *J Biogeogr* 2004; 31: 997-1032.
- Lichtenfeld, L.L. *Local Participation and Conservation in Kenya: A Case Study of the Kimana Community Wildlife Sanctuary*. Yale University, School for Forestry and Environmental Studies, New Haven, Connecticut, USA. The 12th Annual Meeting of the Society of Conservation Biology. July 13-16, 1998.
- Mburu, J., Birner, R. & Zeller, M. 2003. Relative importance and determinants of landowners' transaction costs in collaborative wildlife management in Kenya: an empirical analysis. *Ecological Economics* 45, 59-73.
- Mwale, S. Changing Relationships. *Swara* 2000; 22(4): 11-7.
- Mwangi, E. 2005. *The transformation of property rights in Kenya's Maasailand: triggers and motivations*. CGIAR Systemwide Program on Collective Action and Property Rights (CAPRI): Washington, D.C.
- Mwangi, E. 2006. *Subdividing the commons: the politics of property rights transformation in*

- Kenya's Maasailand*. CGIAR Systemwide Program on Collective Action and Property Rights (CAPRI): Washington, D.C.
- Newmark, W.D. The role and design of wildlife corridors with examples from Tanzania. *Ambio* 1993; 22: 500-4.
- Ntiati, P. Ranches subdivision study in Loitokitok division of Kajiado district, Kenya. Land Use Change Impacts and Dynamics (LUCID), International Livestock Research Institute, Nairobi, Kenya, Working Paper 7. 2002.
- Okello, M.M. & D'amour, D.E. Agricultural expansion within Kimana electric fences and implications for natural resource conservation around Amboseli National Park, Kenya. *J Arid Environ* 2008; 72: 2179-92
- Okello, M.M. & Kiringe, J.W. Threats to biodiversity and the implications in protected and adjacent dispersal areas of Kenya. *J Sustain Tour* 2004; 12(1): 55-69.
- Okello, M.M., Manka, S.G. & D'Amour, D.E. The Relative Importance of Large Mammal Species for Tourism in Amboseli National Park, Kenya. *Tour Manage* 2008; 29(4): 751-60.
- Okello, M.M. Land use changes and human - wildlife conflicts in the Amboseli area, Kenya. *Hum Dimens Wildl* 2005; 10(1): 19-28.
- Okello, M.M., Buthmann, E., Mapinu, B. & Kahi, H.C. (2). (n.d.). Community opinions on wildlife, resource use and livelihood competition in Kimana group ranch near Amboseli, Kenya. *Open Conservation Biology Journal*, 5(1), 1-12.
- Okello, M.M. & D'Amour, D.E., 2008. Agricultural expansion within Kimana electric fences and implications for natural resource conservation around Amboseli National Park, Kenya. *Journal of Arid Environments* 72, 2179-2192.
- Okello, M.M. & Kioko, J.M., 2011. A field study in the status and threats of cultivation in Kimana and Ilchalai swamps in Amboseli dispersal area, Kenya. *Natural Resources* 2, 197-211.
- Pearce, D. 1993. *Economic values and the natural world*. Earthscan Publications Limited: London, England.
- Ratti, J.T. & Garton, E.O. *Research and experimental design*. In *Research and management techniques for wildlife and habitats*. Bookhout T, Ed. The Wildlife Society, USA, 1994, pp 1-23.
- Sindiga, I. Wildlife-based tourism in Kenya: land use conflicts and government compensation policies over protected areas. *J Tour Stud* 1995; 6(2): 45-55.
- Western, D., Groom, R., Worden, J. 2009. The impact of subdivision and sedentarization of pastoral lands on wildlife in an African savanna ecosystem. *Biological Conservation* 142, 2538-2546.
- Wishitemi, B.E.L., & Okello, M.M. Application of the protected landscape model in southern Kenya. *Parks* 2003; 13(2): 12-21.
- Zar, J.H. *Biostatistical Analysis*. 4th. ed. Prentice-Hall, Inc., Upper Saddle River, New Jersey, USA, 1999.

Chapter 11: Natural resource governance and protected areas: On the co-management of the Okhahlamba-Drakensberg National Park, KwaZulu-Natal, South Africa

Hlengiwe M.S. Cele and Innocent Moyo

¹Department of Geography and Environmental Studies,
University of Zululand, Kwa-Dlangezwa, 3886, South Africa

*Corresponding author: hmscelle@gmail.com

Abstract

Throughout the 20th century, natural resource governance was controlled by the colonial government, which introduced exclusionary policies, resulting in the creation of Protected Areas (PAs). After the dawn of democracy, the government introduced a co-management model to govern PAs. Theoretically, this is a pluralist tactic which seeks to achieve conservation objectives such as the sustainable use of natural resources, equivalent distribution of benefits as well as responsibilities. This means that co-management should be influenced by indigenous communities' desire for the acknowledgement, inclusion and integration of their Indigenous Knowledge (IK) as existing practices in natural resource management. This paper therefore evaluated the practical implementation and effectiveness of the co-management plan, in the Okhahlamba-Drakensberg National Park in KwaZulu-Natal, South Africa. The study deployed a qualitative approach comprising in-depth interviews with open and closed-ended questions with the community leaders (traditional authority) and PA authorities. The analysis of the study points to the fact that indigenous communities have definitely no acquaintance of what the co-management strategy, who it implicates and how they are supposed to be benefitting from this strategy. There exists unending miscommunication and a plethora of conflicts amongst protected areas and communities as well as within community configurations as a whole. Most notably, the study highlights that a new policy should be established or amendments made to the existing co-management plan, allowing and involving local communities in the decision-making processes, the management of the protected area and distinct reflection of the benefits of local communities involved.

Keywords: Co-management, natural resource governance, Okhahlamba-Drakensberg, Protected Areas, Indigenous Knowledge

Introduction

In order to link the co-management model with Indigenous Knowledge Systems (IKS), the background to the establishment of the model as well as that of indigenous people and their IKS will be briefly outlined in this section of the paper. In Africa as well as other parts of the world, protected areas were established without including local people (Maluleke, 2018). These protected areas adopted Western exclusionary approaches that, in due course, were not sufficient in curbing natural resource depletion and/or environmental degradation in protected areas (Martín-López and Montes, 2015). According to Shafer (2015) and Cundill *et al.* (2013), it was thereafter that the co-management model was implemented so as to remedy the

adversities of exclusionary policies that disregarded indigenous communities. Maluleke (2018) wrote that the co-management model has been an instrument widely utilised for decision making for environmental management. This participatory approach was also designed to include indigenous peoples in the governance of protected areas (Hill *et al.* 2012). Essentially, co-management is the sharing of authority (Gilmour, 2013); the model suggests that there be mutual governance between indigenous communities and the protected areas (Moller *et al.* 2004). Kohler and Brondizio (2017) assert that the principal roles of this model are shared authority, to increase the involvement of local people in environmental conservation and also to widen the likelihood of benefiting local people. The management of natural resources has thus been essential for protected area management. Likewise, the recognition and acknowledgement of their Indigenous Knowledge (IK) for conservation management (Ross *et al.* 2016). Frameworks within the co-management approach are envisioned as facilitators of equitable distribution of power amongst the state and indigenous communities whilst sustaining natural resources (Diver, 2016). The success of co-management is dependent on the relationship established between the state, resource users and other stakeholders involved (Dube 2018). It is anticipated that co-management, should yield enhanced outcomes for all participants involved assuming their full participation in adopting this approach (Dube 2018). In the South African context, co-management is seen as an approach that perceives the distribution of power and enhanced natural resources management as the key fulfilment of post-apartheid policies (Dabo, 2017) in formerly controlled areas (Thondhlana *et al.* 2015). As a result, this paper seeks to evaluate the effectiveness of the co-management of a protected area (PA) namely the Okhahlamba Drakensburg, with specific focus on the access to and consumption of resources as well as the process of beneficiation.

Background and context

Generally, indigenous communities have been managing and conserving their surrounding natural environments (Fabricius *et al.* 2013). Traditionally, sacred areas were designated with controlled access and the consumption of ecosystems services were controlled by community leaders and royal decrees (Boucher *et al.* 2013, Soliku and Schraml, 2018). Sacred areas were demarcated to avert the misuse and mismanagement of resources as well as the prohibited consumption and hunting of sacred animals (Fabricius *et al.* 2013). This paper maintains that the aforementioned was a tradition that succeeded for many centuries (Hummel *et al.* 2019). This situation obtained until the introduction of exclusionary policies and/or the adoption of the western methods of environmental conservation, alternatively called top-down approaches (Putzel *et al.* 2015), and the development of the fortress conservation model that focused on excluding indigenous communities (Maluleke, 2018).

Fortress conservation is evident in the Mkomazi National Park in Tanzania (Noe and Kangalawe, 2015) and the Kruger National Park in South Africa (Büscher, 2016). Tomasini and Theilade (2019) argue that the implementation of the latter was due to the belief that, indigenous communities and their traditional knowledge were impractical when compared with western knowledge. So far, this has been the key process that has debilitated IKS practices, compromised livelihoods of secluded indigenous communities (Mehta, 2017), restrictions of indigenous habitual proprietorship and practices (Brockhaus and Angelsen, 2012) and social injustices (Cleaver, 2017). In addition, Segage (2015) argued that the implementation of exclusionary policies meant that people were to be evicted from the fertile land and in this process not provided with any kind of support and/or recompense which often left local communities in destitution.

Furthermore, these exclusionary policies have been disputed taking into account their inadequacies (Reid *et al.* 2004) and incompetency (Segage, 2015). Therefore, it is within this context that the inclusion and/or integration of indigenous communities in natural resource governance within protected areas is encouraged. Mostly grounded on natural resources, governance of these areas has revealed the lack of accomplishment when indigenous communities are disregarded along with the conditions that shape their livelihoods (Kohler and Brondizio, 2017).

1.1 The co-management approach

Co-management has been applied to involve indigenous communities in the decision-making processes of natural resource governance, the devolution of authority, resolving multifaceted ecological disputes as well as the agreements with regards to the distribution of benefits (Seid-Green, 2014). According to Moller *et al.* (2004), co-management called for the cooperative relations and ecological obligations between local communities and the state. However, Ross *et al.* (2016) have argued that co-management has failed in addressing the latter and former seeing that it has situated the state as the leading manager in natural resources governance.

Mutekwa and Gambiza (2017) have contended that exclusion of local people from decision-making and management processes has led to the impoverishment of the communities, the violation of their rights and generated conflicts (Dutse *et al.* 2015). An additional initiative to co-management was to resolve conflicts; however, the model has had shortfalls (De Pourcq *et al.* 2015). Likewise, the marginalisation of indigenous communities and potential IKS for natural resources management has steered the ineffective conservation of protected areas (Joa *et al.* 2018). Notably, Tomasini and Theilade (2019) maintain that for ensured proprietorship of and support for conservation objectives from indigenous communities, they should be included in management strategies. According to Smith *et al.* (2017) there is a substantial role for indigenous communities in the management of ecological resources. Equally important, to maintain good relationships within co-management, indigenous communities, their IK and livelihood must be considered (Shafer, 2015).

Therefore, this paper seeks to investigate the integration of indigenous communities in the decision-making and management level in the co-management plan of the Okhahlamba-Drakensberg National Park. To achieve this, a qualitative research method was deployed by the study. This involved the in-depth interviews of community leaders from the AmaNkwane, AmaSwazi and AmaZizi traditional areas in Okhahlamba-Drakensberg as well as park representatives from the Okhahlamba-Drakensberg. These respondents were purposively sampled; in total five people were interviewed of which three were traditional leaders and two were Park managers. As earlier mentioned, in-depth interviews that encompassed open-ended and closed-ended questions were utilised to gain information from the participants. By means of content analysis, data was analysed, coded and divided into themes and subthemes.

1.1 The integration of IKS in the co-management plan

The community leaders of the AmaSwazi and AmaNkwane traditional areas asserted that, the community has no knowledge of what the co-management plan is, the roles and responsibilities of persons involved and how they can benefit from this plan. Conversely, in the AmaZizi tribal area, the community leader spoke of the existence of a conservation forum. This forum consisted of community members that used to be invited to meetings regarding the co-management plan and other conservation related meetings on a monthly basis, but this does not happen anymore. There have never been any reasons given to them as to why they are not involved in these meetings anymore, if they still continue or take place. Currently, their

conservation forum is responsible for safeguarding their natural environment, with some help from government institutions.

In addition, the park representatives mentioned that certain parts of the national park are undergoing a land claim process where it has been discussed that there is a possibility that land ownership will revert back to the respective communities which will allow for further implementations of co-management given that land-use in this conservation area will not in any way be altered. Park representatives speak of public participation and consultation (especially with community leaders) and various stakeholders (United Nations Educational, Scientific and Cultural Organization (UNESCO), the Department of Environmental Affairs (DEA), the Department of Economic Development Tourism and Environmental Affairs (EDTEA), Amafa AkaKwaZulu-Natal, District and Local Municipalities) (Figure 11.1 below) during the process of creating and implementing policies and plans.

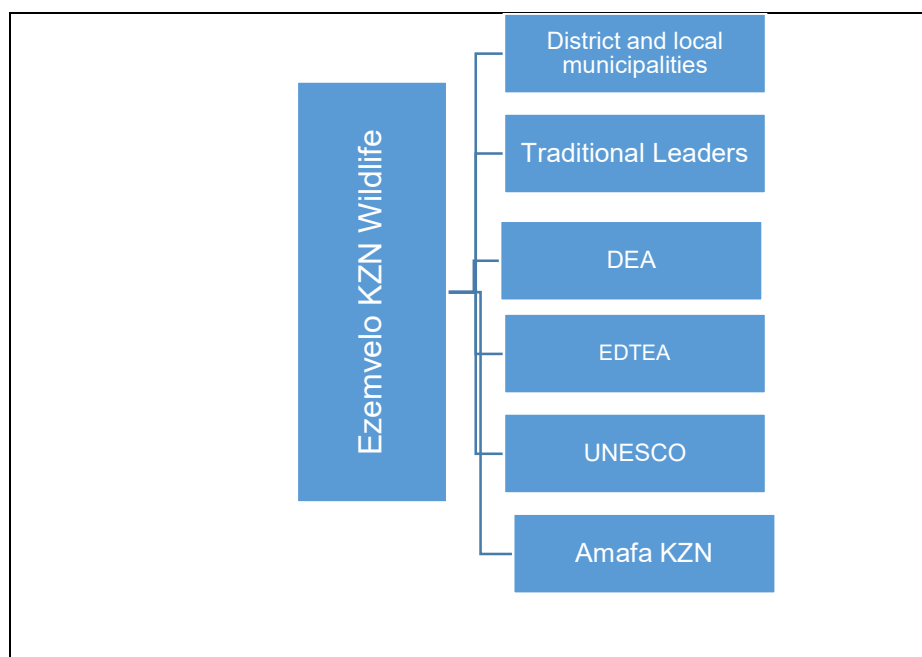


Figure 11.1: Ezemvelo KZN and stakeholders involved in the co-management plan

However, the park representatives mentioned that even though community leaders are a part of this process, they are just present there and cannot comprehend the essence of topics and issues being discussed, therefore do not see any direct benefits. Regarding the perceptions of the existing co-management plan, the park representatives say that these are well-structured. Also, according to the park representatives, IKS and the local communities are included in the co-management plan of the park. Community leaders disagree with the latter, therefore conflicts exist amid community members and how parks implement these, as well as the fact that various miscommunications between these two parties as well as in community structures exist (see Figure 11.2 below).

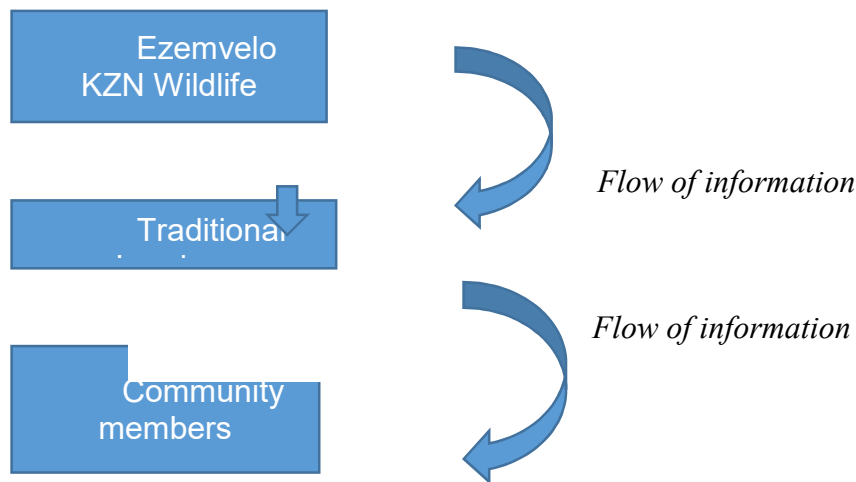


Figure 11.2: Illustration of the flow of information between parties

Park representatives maintain that there are educational programmes provided (within a 10km radius) by the park for raising awareness and enlightening people of the significance of safeguarding the resources inside the park as well as in the surrounding community. One of the park representatives spoke of the “Sifundimvelo Programme” which is in line with the primary school level curriculum, youth engagements that are endorsed by the Department of Education; there is also an Environmental Awareness Plan (from the IMP) created by Universal Uniqueness. An alternative approach of raising awareness is in the form of forums and/or gatherings with the communities. Unfortunately, there are not sufficient resources and these programmes are inclined to become dogmatic initiatives and in most cases the park has to outsource resources in order to implement these programmes (eg. Sports Day event supported by Richards Bay Minerals). On the other hand, the community leaders say that these programmes are not sufficient and target only a certain group of individuals and not everyone in the community is included. The AmaZizi leader mentioned that these programmes focus mostly on school children and then only to a certain degree, given that they have knowledge of a learning centre inside the protected area. However, even the school children have no access to this area and therefore they ask, “Who is it for?”

Park representatives have stated that the co-management plan does offer benefits to the communities. However, as earlier mentioned, the AmaNgwane and AmaSwazi traditional leaders do not know of the co-management plan and therefore are not aware of any benefits rendered by this plan. All three community leaders assert that there is a lack of, or no access to resources that they utilise, one typical example would be that of access to grasslands for their cows to graze due to strict regulations enacted by the park. Employment opportunities that they are promised are not delivered to them as they should be. The leaders are not sure if that is due to the co-management plan that they are not even familiar with or other reasons such as miscommunication or no communication at all that hinders this process, given that the park mainly employs people that are not from these areas (AmaNgwane, AmaSwazi and AmaZizi). They usually say that local people are not skilled for the employment opportunities that are advertised by the park. Even so, employment advertisements only reach the community level on the day of the deadline or do not at all. The latter has contributed to many conflicts and animosity against the park. According to the park representatives and the traditional community leaders, there is a lack of effective communication.

Conclusion

As mentioned above, the results of the study have shown a distinctive absence of effective communication between the people and the park. The uKhahlamba Drakensberg Park Integrated Managed Plan (IMP) revised in 2019 stated that the IMP was developed and assumed a collaborative method that involved various stakeholders and indigenous and/or local community members. However, findings show otherwise. Consequently, the findings of this study show that the guiding principles of the benefits of the co-management plan as written in the uKhahlamba Drakensberg Park Integrated Managed Plan as revised in 2019 (pages 71-73) have not been a success. This is because of various reasons, which include, among others, that there are marginal efforts made to ensure that the community is aware of the park's commitments. Stakeholder engagements are very low; communities do not have any sense of ownership of resources and there is no common understanding on the issues that exist between the park and the local communities given the unending conflicts and lack of cooperation. The communities are still complaining regarding available employment opportunities and the processes deployed for employing local people, how their livelihoods are impacted as well as the levels of poverty in the areas. Further, one out of the three communities have knowledge of the community levy trust, three communities stated that the park does not provide any training of community members. To these can be added that the park does not have any public support regarding the efforts of the park.

Based on the results of this study, co-management has been confronted by various inadequacies. Against this, the study recommends that firstly, the park should ensure that in all three traditional communities, all community members should know about the co-management plan, what it entails, how it works, who it involves in the processes of management and decision-making, as well as the benefits that are due to the community. Secondly, there should be an increase in the creation of awareness and educational programmes provided by the park, not just for school children in the areas but everyone in the community as well as measures to promote public participation in these programmes and the implementation of the co-management strategies and future strategic developments. The former and latter should be prepared and/or conducted considering that most terms in the co-management plan are not understood by community members.

Acknowledgements

To the Ezemvelo KZN Wildlife park managers, the community leaders of AmaNcwane, AmaSwazi and AmaZizi, my team of hardworking individuals including my co-author and supervisor as well as my data collection team, I am forever grateful for the full participation I received for this paper.

References

- Boucher, T. M., Spalding, M. & Revenga, C. 2013. Role And Trends Of Protected Areas In Conservation. In: Levin, S. A. (Ed.) *Encyclopedia Of Biodiversity (Second Edition)*. Waltham: Academic Press.
- Brockhaus, M. & Angelsen, A. 2012. Seeing Redd+ Through 4is: A Political Economy Framework. *Analysing Redd+: Challenges And Choices*. Center For International Forestry Research, Bogor, Indonesia, 15-30.
- Büscher, B. 2016. Reassessing Fortress Conservation? New Media And The Politics Of Distinction In Kruger National Park. *Annals Of The American Association Of Geographers*, 106, 114-129.
- Cleaver, F. 2017. *Development Through Bricolage: Rethinking Institutions For Natural*

- Resource Management*, Routledge.town
- Cundill, G., Thondhlana, G., Sisitka, L., Shackleton, S. & Blore, M. 2013. Land Claims And The Pursuit Of Co-Management On Four Protected Areas In South Africa. *Land Use Policy*, 35, 171-178.
- Dabo, D. 2017. *Community-Based Natural Resource Management: The Case Of Community Forest Management Areas In Pete, Zanzibar*. University Of Cape Town. dissertation or thesis?
- De Pourcq, K., Thomas, E., Arts, B., Vranckx, A., Léon-Sicard, T. & Van Damme, P. 2015. Conflict In Protected Areas: Who Says Co-Management Does Not Work? *Plos One*, 10, page numbers
- Dutse, I. A., B Abdullah, R., Bin Bolong, J. & Asnarulkhadi, A. S. 2015. Indigenous Knowledge: As A Panacea For Environmental Management-Review.published town?
- Fabricius, C., Koch, E., Turner, S. & Magome, H. 2013. *Rights Resources and Rural Development: Community-Based Natural Resource Management In Southern Africa*, Routledge.town
- Gilmour, P. W. 2013. *Factors and Processes Affecting Co-Management Of Natural Resources*.
- Hummel, C., Poursanidis, D., Orenstein, D., Elliott, M., Adamescu, M. C., Cazacu, C., Ziv, G., Chrysoulakis, N., Van Der Meer, J. & Hummel, H. 2019. Protected Area Management: Fusion And Confusion With The Ecosystem Services Approach. *Science of the Total Environment*, 651, 2432-2443.
- Joa, B., Winkel, G. & Primmer, E. 2018. The Unknown Known – A Review Of Local Ecological Knowledge In Relation To Forest Biodiversity Conservation. *Land Use Policy*, 79, 520-530.
- Kohler, F. & Brondizio, E.S. 2017. Considering The Needs Of Indigenous And Local Populations In Conservation Programs. *Conservation Biology*, 31, 245-251.
- Maluleke, G. 2018. Rethinking Protected Area Co-Management In The Makuleke Region, South Africa (Sa). details?
- Martín-López, B. & Montes, C. 2015. Restoring The Human Capacity For Conserving Biodiversity: A Social–Ecological Approach. *Sustainability Science*, 10, 699-706.
- Mehta, S. 2017. Role Of Traditional Practices In Conserving Environment: A Case of Manesar Village, Gurgaon. *IOSR Journal of Humanities and Social Science (Iosr-Jhss)* 22, 10-16.
- Moller, H., Berkes, F., Lyver, P. O. B. & Kislalioglu, M. 2004. Combining Science And Traditional Ecological Knowledge: Monitoring Populations For Co-Management. *Ecology And Society*, 9.page numbers
- Mutekwa, V. T. & Gambiza, J. 2017. Forest Protected Areas Governance In Zimbabwe: Shift Needed Away From A Long History Of Local Community Exclusion. *Journal of Environmental Management*, 198, 330-339.
- Noe, C. & Kangelawe, R. Y. 2015. Wildlife Protection, Community Participation In Conservation, And (Dis) Empowerment In Southern Tanzania. *Conservation And Society*, 13, 244.
- Putzel, L., Kelly, A. B., Cerutti, P. O. & Artati, Y. 2015. Formalization As Development In Land And Natural Resource Policy. *Society & Natural Resources*, 28, 453-472.
- Reid, H., Fig, D., Magome, H. & Leader-Williams, N. 2004. Co-Management Of Contractual National Parks In South Africa: Lessons From Australia. *Conservation And Society*, 2, 377.

- Ross, A., Sherman, K. P., Snodgrass, J. G., Delcore, H. D. & Sherman, R. 2016. *Indigenous Peoples And The Collaborative Stewardship Of Nature: Knowledge Binds And Institutional Conflicts*, Routledge.twon
- Segage, M. 2015. *The Effects Of Nature Conservation On Local Economic Development In Timbavati, Mpumalanga Province*. University Of Limpopo.details
- Seid-Green, Y. 2014. *Defining Co-Management: Levels Of Collaboration In Fisheries Management.details?*
- Shafer, C. L. 2015. Cautionary Thoughts On Iucn Protected Area Management Categories V–Vi. *Global Ecology And Conservation*, 3, 331-348.
- Smith, B. M., Chakrabarti, P., Chatterjee, A., Chatterjee, S., Dey, U. K., Dicks, L. V., Giri, B., Laha, S., Majhi, R. K. & Basu, P. 2017. Collating and Validating Indigenous And Local Knowledge To Apply Multiple Knowledge Systems To An Environmental Challenge: A Case-Study Of Pollinators In India. *Biological Conservation*, 211, 20-28.
- Soliku, O. & Schraml, U. 2018. Making Sense Of Protected Area Conflicts And Management Approaches: A Review Of Causes, Contexts And Conflict Management Strategies. *Biological Conservation*, 222, 136-145.
- Thondhlana, G., Shackleton, S. & Blignaut, J. 2015. Local Institutions, Actors, And Natural Resource Governance In Kgalagadi Transfrontier Park And Surrounds, South Africa. *Land Use Policy*, 47, 121-129.
- Tomasini, S. & Theilade, I. 2019. Local Ecological Knowledge Indicators For Wild Plant Management: Autonomous Local Monitoring In Prespa, Albania. *Ecological Indicators*, 101, 1064-1076.

Chapter 12: The influence of donor funded community development on population growth in selected communities bordering the Phinda Private Game Reserve (South Africa)

Claire Louisa Fordred and Prof Kevin Mearns

University of South Africa, Department of Environmental Sciences
Private Bag X6, Florida 1710, South Africa
cfordred@gmail.com; mearnkf@unisa.ac.za

Abstract

Private game reserves contribute significantly to biodiversity conservation in South Africa. These private game reserves fund their operations predominantly through tourism activities. Private game reserves promote positive support from surrounding communities through various community development projects and benefit-sharing interventions. Rural development projects provide communities with opportunities that add value and quality to their everyday livelihoods. The development projects also bring improved infrastructure and service delivery to the local area and in some cases collaboration with other non-government and government institutes that further improves the living conditions of the community involved. In the development of Phinda Private Game Reserve in KwaZulu-Natal, South Africa, community development projects with the local communities have been implemented. In the past members of the community have been relocated in order to expand the game reserve. Community development projects have been implemented as a form of compensation and goodwill as part of these voluntary resettlements. However, it has been noticed that these development projects come with consequences affecting the community itself, the environment and the original stakeholders running the development projects. The increase in the population numbers in the area and the associated deterioration of the environment have resulted in a reduction in the availability of natural resources for communities to utilise. Rural communities adjacent to the protected areas have become overcrowded, resulting in negative social and health related issues. The original reason for the commencement of the community projects has become overwhelmed by increases in the size of and demands made by communities.

Keywords: Community; development projects; increased population; land cover

Protected areas

Africa has a large abundance and wide variety of natural landscapes and biodiversity. Because of this, the continent has many protected areas and often it is these protected areas that are found in remote natural areas. However, with the generally increasing population, these areas are becoming populated and are facing an increase in degradation (Furze *et al.* 1996). Because of this, environmental projects are now in place, including projects for the local communities, as there is a direct link between conservation and rural development. Furze *et al.*, (1996) further discuss how this link of protected areas provides development opportunities for communities as well as the protection of the environment. South Africa has a high biodiversity with several biomes filled with a variety of flora and fauna. It is this variety of biomes and climate that makes the country fortunate to be the home of a range of endemic environments and natural

resources. Challenges of a rising population include detrimental effects on the environment and the increased uptake of natural resources. Due to this, solutions to utilise natural resources wisely have been put forward and, in this case, protected biodiversity areas are now scattered across South Africa. It is within these government and private protected areas that the future of natural resource biodiversity survival exists.

According to the International Union for Conservation of Nature (IUCN), a protected area is a “clearly defined geographical space, recognised, dedicated and managed through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values” (IUCN, 2008:3). Private reserves, also known as protected areas, are a crucial instrument for conserving nature and a means for sustainability. Protected areas are also on the rise as they are sought-after destinations for tourism, generating income and increasing the country’s Gross Domestic Product (GDP). Challenges have developed concerning socio-economic gains and politics of various communities and organisations. It has been noted that the people in close proximity to protected areas have felt isolated and even excluded from the resources offered by these lands and that the conservation of these protected areas is only for the benefit of the wealthy people that visit them (Grossman & Holden, 2003; Snyman, 2012a). Burgoyne and Kelso (2014) also show a clear difference of perceptions among community members of a government-run protected area to a privately-run reserve.

Adjacent communities of protected areas

It has been an imperative of the World Conservation Strategy to include the local communities in the economic opportunities and benefits associated with the tourism industry in these protected areas. Over the years it has been learnt that a prerequisite for the sustainability of protected areas is to include all people neighbouring the area (Snyman, 2014). Including tourism, conservation industries and the local communities and thus revenue should be shared by the tourism industry with the surrounding communities (Snyman, 2014). The United Nation’s Convention on Biological Diversity of 1992 points out that fair income sharing is an important strategy for biodiversity conservation (Hall, 2010). The International Union for the conservation of nature’s (IUCN) 2014 World Parks Congress reported that sharing the benefits from tourism and protected areas ensures long-term support of communities. This has resulted in an increase in benefit-sharing schemes in Africa. With evidence from previous studies done in Africa, it is vital to include local populations in tourism and conservation for the long-term sustainability of protected areas (Hoon, 2004; Musumali *et al.* 2007).

Literature encourages us to use lessons learnt from past designs and the implementation of previously effective benefit-sharing schemes (Spenceley *et al.*, 2014). Currie (2001) and Snyman (2014) have done numerous studies of communities which have benefited from tourism in protected areas. These communities have more positive attitudes towards protected areas and tourism development in South Africa. Emptaz-Collomb (2009), Ahebwa, van der Duim and Sandbrook (2011) and Snyman (2014), conclude that benefiting communities are more inclined to view tourism and protected areas positively and to contribute to the conservation of natural resources. However, a study by Walpole *et al.* (2001) discusses how local populations that are not receiving direct benefits from tourism still have positive attitudes towards protected areas and tourism. Their perceptions and beliefs of receiving the benefits are motivating factors that instil these positive attitudes, especially based on seeing other communities receiving benefits (Walpole *et al.* 2001). It is this instilled positivism that creates advantages and disadvantages pros and cons to the protected area, the organisations involved in the protected areas and associated tourism ventures. The anticipation of communities

receiving benefits from the protected areas and tourism instils positive attitudes towards the involved stakeholders. However, it has been found that this initial anticipation creating enthusiasm in the communities diminishes over time if these expectations are not met by the tourism operations and protected area stakeholders, challenges arise (Alexander, 2000). Communities become dissatisfied and disillusioned, which may lead to an increase in tension between communities on the one hand versus the tourism stakeholders and the authority of protected areas on the other hand (Alexander, 2000).

Over the years there has been an increase in the population numbers adjacent to the protected areas, not only because of growing populations but as a result of perceived benefits leading to migration into the area (Joppa *et al.* 2010). Perceived benefits include potential employment either directly or indirectly through the protected area (Joppa *et al.* 2010). Other reasons include acquiring any of the remaining resources that are the very resources the protected area is protecting. It has been thought that with urbanisation on the increase, human populations would move to the cities for employment, with this trend benefiting biodiversity conservation in rural areas. Yet, case studies across Africa have found that protected areas benefit rural communities with opportunities, infrastructure and ecosystem services provided by the natural area are drawcards for rural populations (Joppa *et al.* 2009).

Developing countries with protected areas are nowadays also looking at biodiversity protection whilst contributing to poverty reduction and the economic development of the adjacent communities. Through the Durban Accord of 2003, the World Parks Congress specifically emphasised the role of protected areas as “...contributors to poverty reduction and the economic development and as creators and sustainers of livelihoods” (World Parks Congress, 2003: 2) and urged protected areas to continue to address commitments with neighbouring communities. Conservation policies are now shifting towards poverty alleviation which is causing debatable issues all round with traditional conservationists (Roe & Walpole, 2010). Creating the movement of community-based conservation, including conservation initiatives with socio-economic development goals (Berkes, 2007). In many African countries the adjacent rural communities of protected areas experience rates of poverty above those of the national average (Hulme & Murphree, 2001). In South Africa, the People and Parks Programme was implemented to address the socio-economic challenges associated with apartheid conservation rules with new policy frameworks (Pelser *et al.* 2013).

Today, South African conservation follows the People and Parks approach with an inherent philosophy of embracing a relationship between protected areas and neighbouring communities, linking biodiversity and socio-economic benefits for all through a variety of development projects. The People and Parks Programme’s philosophy is possible with the support of the National Environmental Management: Protected Areas Act (Act No. 57 of 2003 as amended in 2006) (Murambadoro, 2009). At the same time, South Africa’s Bill of Rights, Section 24 and NEMA (Act 107 of 1998) states that environmental management needs to focus on people and their needs: physically, psychologically, culturally, and their social interests must be included while managing the environment at the same time (Murambadoro, 2009). It has been noticed that the state focuses more on communities that were forcibly removed and now resettled through the land redistribution programme, especially those adjacent to ecotourism centres, private and national parks (Dudley *et al.* 2010). These communities receive more development programmes and benefits than other communities that have not been relocated (Dudley *et al.* 2010).

Research done by Burgoyne and Kelso (2014) in the Umhlabuyalingana and the Big Five municipalities of KwaZulu-Natal, South Africa looks at the communities mainly in the

Mkuze area of the under-resourced rural communities. The research further looks at the community livelihoods and land cover changes as well as the socio-economic benefits expected from living adjacent to protected areas. Within their qualitative results, they found that the communities adjacent to Mkuze Game Reserve felt left out with the lack of funding and development support. The Mkuze communities experienced “a contrast between this lack of benefit sharing and the successful benefit sharing experienced by a neighbouring community which borders a private reserve” (Burgoyne & Kelso, 2014:51). This private game reserve is Phinda (Figure 12.1).

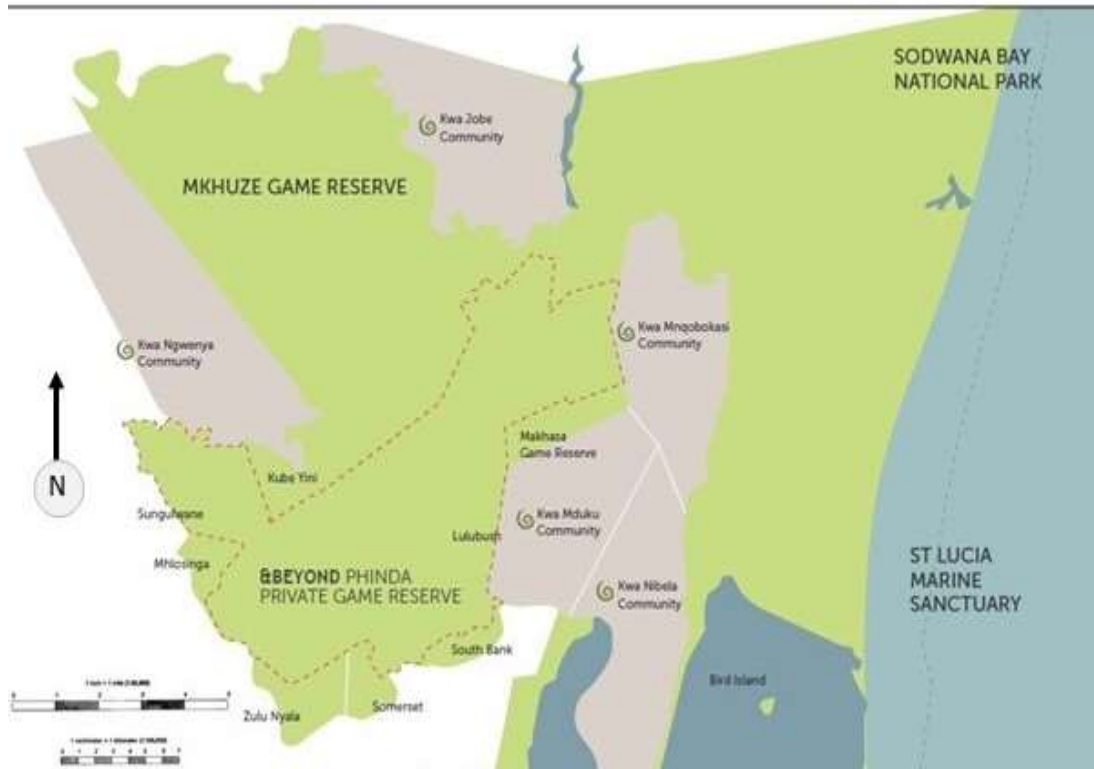


Figure 12.1 : The location of Phinda

Phinda Private Game Reserve is one of today’s luxury wildlife tourism companies. &Beyond was once known as the Conservation Corporation Africa, which has always had a business model that included the surrounding communities, which made their lodge operations so successful. Within South Africa, &Beyond has three protected reserve areas where &Beyond lodges and camps operate and where the Africa Foundation (an independent NPO working in partnership with &Beyond) is helping the many surrounding communities.

Phinda Private Game Reserve has abundant fauna and flora, diverse habitats and safari activities which makes it a very popular tourism destination. The reserve was established in 1991 on reclaimed farmland that had been used for farming cattle, pineapples, cotton and also for hunting. One hundred and twenty kilometres of fencing was erected, and thousands of animals reintroduced to the area. The name Phinda is most suitable; it is a Zulu word meaning “the return” (Africa Foundation, 2019).

Communities neighbouring Phinda Private Game Reserve

Phinda Private Game Reserve borders the Makhasa, Mngobokazi, KwaJobe and Nibela

communities with Zulu culture including strong beliefs in extended families. These beliefs and polygamy result in large families living off one breadwinner (Muzirambi, 2017). Many of the younger generation migrate to urban areas seeking employment, leaving the young and old in the communities. This social structure has created many orphaned vulnerable children (OVC) in the area. The Umkhanyakude region which includes these three mentioned communities has been reported to have the highest HIV/AIDS infection rates in South Africa – up to three times the national average (Big Five False Bay Municipality IDP, 2007/2008). The communities are electrified but many cannot afford the cost of electricity (and water) and rely on paraffin and firewood with little access to clean water. This is one of the area's major challenges. During the dry seasons, the communities rely on rainwater harvesting. The region has primary and secondary schools; however, the teacher-pupil ratio is more than 1:40 (Africa Foundation, 2019). Factors such as water shortage, lack of teachers and classrooms and poor sanitation impacts learners' attendance. Young mothers struggle because of the lack of infant and child care facilities in the area, resulting in their being deprived of the opportunity to further their education or seek employment.

Traditional leaders collaborate with the political leadership of the area; however, the alignment of individual, community and political agendas is needed to improve social development and livelihoods in the area. The Big Five False Bay Municipality IDP (2007), estimates the population of the three communities at around 33000 people, 45% being children under the age of 15 years old. Adult illiteracy is estimated at 75%, while unemployment is estimated at 75% for the region (Big Five False Bay Municipality IDP, 2007). With this background of the everyday challenges in the region, one can understand how policies have been implemented over time to include the communities in the socio-economic development of regions as well as the biodiversity of protected areas.

Benefiting-schemes through tourism

Tourism is one of the fastest growing industries in the world (UNWTO, 2016), therefore it is an excellent tool for development. Sustainable tourism is a constructive tool used to positively contribute to the preservation of the natural and cultural heritage, while promoting sustainable development (UNEP, 2002). It is important to envision the conservation of the land as well as the people, who live there and use it, as a mutual relationship that works towards sustainable tourism and development. According to Hall *et al.* (2006: 250-251), “[t]ourism needs to be appropriately embedded within the particular set of linkages and relationships which comprise the essence of rurality with tourism being recognised as but one component of the policy mix which government and the private sector formulate with respect to rural development”. This emphasises the purpose of seeing the environment and cultural heritage as one, including policies and government involvement.

Sustainable development is a feature of the economic sector, where it is compulsory to represent a company's effort and contribution to the conservation of the land and the people, while addressing the company's impacts, both environmentally and culturally. This is also known as Corporate Social Responsibility (CSR), which is a framework aiming to minimise an organisation's negative impacts, while enhancing the positive impacts, as well as to play a responsible role within society. To address rural community livelihood challenges CSR approaches have been implemented to share the benefits with the neighbouring populations in the same geographic proximity as protected areas (Fennell, 2003). Corporate Social Responsibility approaches are also known as benefitting-schemes, benefitting all parties involved. Businesses of all types use CSR as an approach to address environmental and social impacts of the company's activities. One must remember that CSR is a framework that looks

at an organisation's responsibility in society and assists organisations to attain the business's long-term viability (Werther & Chandler, 2011). The main methods that organisations use for achieving their CSR are sustainable livelihood approaches (SLAs). These approaches appeared in the literature in the mid-1980s to early 1990s when there was a movement away from food security to a more livelihood-based development perspective (Frankenberger, 2000).

Benefit-sharing from tourism is just one way in which communities can gain advantages from living in proximity to conservation areas. Other ways include access to ecosystem services through the protection of water sources, access to and use of natural resources such as firewood and medicinal plants, and cultural benefits such as access to traditional or cultural sites of significance (Lockwood *et al.* 2006).

Swemmer *et al.* (2015: 17) define benefit-sharing as "... the process of making informed and fair trade-offs between social, economic and ecological costs and benefits within and between stakeholder groups, and between stakeholders and the natural environment ...". What is important to note is what constitutes a benefit before the process begins. It needs to be well defined, clear and feasible with appropriate objective, qualitative and quantitative indicators defined by the stakeholders who are involved. Monitoring programmes should also be considered to evaluate the success of the benefit-sharing (Swemmer, 2015). Benefits can be tangible and non-tangible, as well as direct and non-direct. Examples of tangible benefits include direct employment, income and developed infrastructure. Intangible benefits include skills development, cultural benefits and capacity building, for examples. One also includes revenue-sharing, the revenue shared from the earnings from tourism, partnerships and concessions (Pelser, 2013). However, when communities are simply receiving payments it creates conflicts within the communities. Benefits need to be maximised with other forms of approaches and benefit-sharing such as capacity building, training and even access to natural resources. These collective benefits create positive community attitudes towards protected areas and tourism. Snyman (2012b) states that for revenue-sharing to gain from tourism enterprises, setting lease fee agreements that increase each year builds a level of community revenue growth with further potential. Revenue-sharing is a complex process, with benefits divided on a rotational basis between communities, meaning that the turnaround process until the next payment to communities can take very long, creating negative impacts on the communities' financial planning and also uneven distribution (Spenceley *et al.* 2017).

Phinda Private Game Reserve's corporate social responsibility scheme

Africa Foundation is an independent, tax-exempted non-profit organisation registered in South Africa, United Kingdom and the United States. The Foundation is &Beyond's community development partner, building relationships and partnerships with communities, facilitating the socio-economic development of communities in the surrounding rural regions of &Beyond private conservation areas. The foundation aims at empowering and uplifting rural communities near protected conservation areas, creating a long-term relationship whilst enabling conservation. Africa Foundation quotes "creating mutually beneficial relationships, it is critical that communities recognise the relevance of these conservation areas and in doing so, contribute to both their long-term sustainability" (Africa Foundation, 2016). All of this is possible through community participation which is driven by local leadership. The success of a community development project is based on the partnership with local stakeholders. This is Africa Foundation's core role, facilitating relationships between communities, local government and &Beyond. Africa Foundation has four main development areas (Africa Foundation, 2016):

- **Education:** is a solution to poverty alleviation. With Africa Foundation's support, improvement of educational development in rural communities is possible through building schools, renovations and the improvement of existing educational establishments. Scholarship programmes are also in place, as well as various vocational training and adult education.
- **Healthcare and clean water:** Accessible disease-free water and healthcare are vital for a community to thrive. Africa Foundation assists with upgrading and building clinics and medical staff accommodation whilst also creating awareness of HIV/AIDS. Water sources are made accessible through hippo rollers, water tanks and drilling boreholes for the communities.
- **Small business development:** Africa Foundation aims at providing communities with income opportunities, working together on agriculture projects, building skillscentres and markets where community members can sell their products. The organisation is also a link between facilitating small community businesses and local businesses that are adjacent to &Beyond lodges.
- **Environment and conservation:** Not only does Africa Foundation assist with programmes of land management and conservation to the community members, but it also focuses on wildlife conservation. Conservation lessons and visits are made in the &Beyond reserves, teaching environmental and wildlife conservation. Programmes include training on water usage, alien invasive plants and how tourism benefits the community as well as conservation at the same time.

AndBeyond's values and Africa Foundation's development goals, both care for the people, environment and wildlife. Africa Foundation's community development projects start with the community leaders who are elected by the community; then the community informs the leaders of community needs and possible project ideas. Africa Foundation's community manager discusses these community needs and possible projects together and start developing sustainable and long-lasting initiatives to help the communities. These projects are designed so that they can be handed over to the community, who take ownership of the project, creating leadership development. Community leaders and the communities are thereby equipped with the knowledge before projects are handed over to ensure long-term sustainability. Africa Foundation's philosophy is that communities need to be informed and actively involved in projects from start to finish. after which they are no longer actively involved. This is important as it has been seen that participatory and consultative approaches need to occur involving the local people in conservation and sustainable tourism decision-making for conservation to be successful (Stoll-Kleeman; 2005; Imran & Beaumont, 2014). Africa Foundation is the development implementer for &Beyond. Communities turn to &Beyond for job opportunities in the lodges and in conservation, while Africa Foundation supplies opportunities for the communities to work collaboratively to develop community development projects. It's this close-knit co-operation between organisations and communities which makes this programme so successful.

Africa Foundation and &Beyond have a mutually successful relationship. Africa Foundation needs &Beyond to help them promote and generate sponsorships and donations, while &Beyond relies on Africa Foundation to work within the communities and help meet the community needs and to build relationships as well as addressing CSR (Burns & Barrie, 2005). The foundation focuses on the partnership between the natural environment, wildlife and the people. Simpson (2009: 186) explains that one of the key challenges to sustainable tourism is that it needs to develop an economically viable enterprise that provides "livelihood benefits to

local communities while protecting indigenous cultures and environments”. Africa Foundation is an example of this, an organisation in partnership with a private protected area stakeholder creating economic enterprise opportunities whilst aiming at conserving the land and the wildlife. It has been found that areas with local community development initiatives, education and awareness for environmental conservation have greater success in changing people’s attitudes to conservation than communities without involvement (Waylen *et al.* 2010).

The influence of donor-funded community developments

Africa Foundation has been contributing positively to the development and empowerment of the neighbouring communities of the Phinda Private Game Reserve. The foundation has been liaising with the communities, investigating their needs, providing local skills, materials and labour. Relationships and collaboration with the local government as well as traditional leaders has led to the integration of the Mduku Clinic into a state primary healthcare plan for the uMkhanyakude Region (Africa Foundation, 2019). Modern clinics have been constructed in the area with boreholes and, rain tanks, all contributing to the improvement of sanitation and hygiene (Muzirambi, 2017). Medical services have improved in the area with the assistance of Africa Foundation’s collaboration with the local government, building additional clinic wings for voluntary counselling and a testing centre (Muzirambi, 2017). Accommodation for the nursing staff has also been built through the help of Africa Foundation. Various business enterprises have started in the area, through arts and craft centres and the local Mduku bakery. Africa Foundation runs active conservation programmes with schools, providing opportunities to learners to visit the Phinda Private Game Reserve. Education improvements in the area have been visible with schools being built, staff accommodation and bursary programmes with students graduating at university level now (Muzirambi, 2017). Skills development and capacity building has increased employment levels and opportunities in the area, bringing in more breadwinners for families within the communities.

Along with all these positive contributions to the livelihoods of the communities neighbouring Phinda Game Reserve there are also negative impacts. As already mentioned, the tensions caused by revenue-sharing and the resulting conflicts of this also feature a noticeable increase in the community population numbers. Staff of Africa Foundation that have been working in the area for several years have seen the increase in the demand for support and the implementation of more development projects in the area.

The last population census in South Africa was in 2016, with the total population indicating a total of 55.7 million people and with an estimated population of 57,73 million in 2018 (Stats SA, 2019). KwaZulu-Natal covers 92 100 square kilometres, which is 7.6 percent of South Africa’s land surface of 1 21909 square kilometres. In 2016, KwaZulu-Natal has a population of 11.1 million people, being 19.9% of South Africa’s population. That is the second most populated province after Gauteng which has 24, 1% (13,4 million people). Phinda Private Game Reserve is situated in KwaZulu-Natal and with these high population numbers the employment opportunities sadly decrease in the areas, creating further issues back at home and in the social structures of communities. South African rural challenges include inadequate access to socio-economic infrastructure and services, unsustainable use of natural resources, a lack of water for agricultural practices and households. Other challenges include a lack of skills development, low literacy rates, migratory urban and labour practices and unexploited opportunities in the economic sector (Van Schalkwyk, 2015). Fox and Van Rooyen (2004) discuss the fact that development projects in rural areas are generally unsuccessful because of inadequate participation by the community members, due to the lack of capacity to implement

them and keep them going. Past policies of creating high density ‘homelands’ in rural areas created dislocated communities living in poverty.

It has been found, in the work of Van Schalkwyk (2015), that communities try to meet their needs while making use of accessible resources, attaining social cohesion and increasing their economic prosperity. In the communities adjacent to Phinda Private Game Reserve, members are receiving support to sustain this livelihood through the community development project run by Africa Foundation. Because these communities have access to the support of Africa Foundation, it is attracting more people into the area, which can be seen in Burgoyne and Kelso (2014) with intensive research in the district which is discussed in the case study below.

Over the years Africa Foundation has also grown in staff capacity to handle the demand for support needed in the communities of eastern Africa, including the Phinda Private Game Reserve in South Africa. Africa Foundation originally only worked in the one community adjacent to the game reserve, while today they are working in four communities with over 12 000 community members in each (Africa Foundation, 2019), increasing the staff’s abilities, receiving donations and other income which contributes to the quality of the service and support the community is receiving from the stakeholders.

Case study review

Working towards the co-management of protected areas with the adjacent communities involves the communities’ readiness to buy into conservation objectives with positive perceptions of the benefits of the protection of biodiversity. Burgoyne and Kelso (2014) state that there has been an increase in the competition for land around protected areas. Their results include the areas of Mkuze, and Phinda along with the population density of the surrounding communities, representing a definite increase in population since 1991 to 2001 adjacent to protected areas. The three highest population densities of people per square kilometre are the communities on the borders of Phinda Private Game Reserve – Mngobokazi, KwaJobe and KwaNgwenya. Mngobokazi and KwaJobe had a 20% increase in population in the 1990s, which is the equivalent of 14 people/km². These results are linked to the increasing pressure on natural resources (Burgoyne & Kelso, 2014; Estes *et al.* 2012). A contributing factor to the high population numbers in these two communities is the available water resources in the vicinity - the Mkuze River and wetlands.

The use of remote sensing in Burgoyne and Kelso’s research (2014:57) detected the land cover changes from 1979 to 2008 with an average of 432km of natural land-cover being lost with major land degradation in densely populated areas in proximity to water sources too. Mngobokazi, KwaJobe and KwaNgwenya yet again showed the highest values of change, in this case in land-cover (Burgoyne & Kelso, 2014:58). Informal discussions were conducted as reported in Burgoyne and Kelso’s research (2014) in the communities surrounding Phinda Private Game Reserve and Mkuze Game Reserves. One of the local indunas (tribal leader) commented that the biggest change he had seen in the communities since his childhood was the increase in the homestead numbers and cattle and that the natural flora was cleared away in his community as a result (Burgoyne & Kelso, 2014:60).

Positive recurring answers from the local communities were that the communities were receiving education bursaries. Negative feedback was that community members were more interested in waiting for grants and pensions than working on the land for their livelihood (Burgoyne & Kelso, 2014). These results correlate with the donor-funded projects occurring in the communities where Africa Foundation is working, adjacent to Phinda Private Game Reserve. An increase in land competition was also reported in a respondent’s answer, related

in Burgoyne and Kelso's (2014) interview of a man discussing how competition is high for their families. Another result is that community members perceive and seek work in the neighbouring reserves and there is no understanding that there are limited employment opportunities within the protected areas to support the increasing population in the communities and country. This lack of communication and understanding causes people to move closer to the reserves before it is too late to obtain any form of job opportunity. Burgoyne and Kelso (2014:63) quote "one of the key findings resulting from our discussions with residents was that the benefits derived by those adjacent to the private reserves seem to be greater than those derived by communities adjacent to the public reserve". This statement ties in with the result of the highest populated communities being on the borders of Phinda Private Game Reserve, and that the Corporate Social Responsibility initiatives of &Beyond with Africa Foundation are attracting people into the area. Another correlating result is the statement by Burgoyne and Kelso (2014:63) that "the several projects being run by Phinda Game Reserve, is a significant multiplier of community development ability" implying that the projects also bring in rural and spatial developments. This is evidence that these projects are having impacts on the communities and are attracting people to the local communities adjacent to Phinda Private Game Reserve. A paper by Burgoyne *et al.* (2015) looks at the trends of increasing population in the vicinity of Phinda and Mkuze. According to the trends and calculations, there will be an increase in population and land cover with the advent of corporate sugar cane agriculture having the greatest increase of 26.4% land cover. By 2020, the trend represents a further increase of land degradation of bush by 43.7km², grassland by 25.1km² and wetland by 3km², with increase of population and resource use being the causes (Burgoyne *et al.* 2015:226). Included in these trends and forecasting is the fact that the most densely populated community is KwaJobe, especially because of the water sources found there (Burgoyne *et al.* 2015:226).

Conclusions

If tourism is used correctly, it is an important tool for conservation and rural development, especially rural development of community areas surrounding tourism establishments, bringing in more opportunities than communities without local development projects. It is by these community development projects that Africa Foundation is empowering community members and creating further attraction to the area. These communities with development projects have spatial development with roads and access to better infrastructure, including educational institutions. All contribute to population increase, the clearing of land cover for homesteads and their cattle. To ensure long-term planning of rural development, the factors of the impact of revenue-sharing must be understood as it is a complex process for each individual area. Impacts of donor-funded community projects are both negative and positive, receiving more positive credit only if the implemented community development projects are taken over and run successfully by the communities themselves in the end. This will then provide donors and stakeholders with opportunities to support additional communities and members. In this paper, one can clearly see that successful integrated donor projects administrated by privately run game reserves attract more people who seek to gain access to benefit from the CSR projects into an area. Inevitably, this CSR and job opportunity attraction increases the population, that has a ripple effect and increasing pressure on the use of natural resources and even the capacity of the stakeholders assisting the communities. Further research into future initiatives needs to be done to make a future difference.

References

- Africa Foundation. 2016: About Africa Foundation (Brochure). Johannesburg.
- Africa Foundation. 2019. About Africa Foundation, Available online: (<http://www.africafoundation.org.za>), Accessed on 27 April 2019.
- Ahebwa, W. M., van der Duim, R. & Sandbrook, C. 2011. Tourism revenue sharing policy at Bwindi Impenetrable National Park, Uganda: A policy arrangements approach. *Journal of Sustainable Tourism*, 20, 377–394.
- Alexander, S., 2000. Resident attitudes toward conservation and black howler monkeys in Belize: The community baboon sanctuary. *Environmental Conservation*, 27(4), 341–350.
- Berkes, F., 2007. Community-based conservation in a globalized world. *Proceedings of the National Academy of Sciences*, 104(39), 15188–15193.
- Big Five False Bay Municipality IDP (2007/2008). 2007. “KZN Top Business” [pdf], Available online: [kzntopbusiness.co.za/site/search/downloadencode/nNy8Z6SebNeqrYyx], Accessed on 15 April 2019.
- Burgoyne, C.N & Kelso, C.J. 2014. ‘The Mkuze River it has crossed the fence’ – communities on the boundary of the Mkuze protected area. In: Rogerson, C.M. and Szymańska, D. editors, *Bulletin of Geography*. Socio-economic Series, 26, 51–66.
- Burgoyne, C.N., Kelso, C. & Ahmed, F, 2016. Human activity and vegetation change around Mkuze Game Reserve, South Africa, *South African Geographical Journal*, 98(2), 217-234.
- Burns, P.M & Barrie, S. 2005. Race, space and our own piece of Africa: Doing Good in Luphisi Village? *Journal of Sustainable Tourism*, 13 (5): 468-485
- Currie, J. 2001. Towards sustainable conservation: Community perceptions of game reserves in the Maputaland region of South Africa: Comparative case studies of Phinda and Mkuze game reserves (Master’s thesis). Middlesex University, London.
- Dudley, N., Mansourian, S., Stolton, S. & Sukuwana, S. 2010. Do protected areas contribute to poverty reduction? *Biodiversity* 11, (3-4) 5-7.
- Emptaz-Collomb, J. 2009. Linking tourism, human wellbeing and conservation in the Caprivi Strip, Namibia. University of Florida, Florida, FL.
- Estes, A., Kuemmerle, T., Kushnir, H., Radeloff, V. & Shugart, H. 2012. Land-Cover Change and Human Population Trends in the Greater Serengeti Ecosystem from 1984 to 2003, *Biological Conservation*, 147 (1), 255-263.
- Fennell, D.A. 2003. *Ecotourism: an introduction*, (2nd edition), Routledge, London.
- Fox, W. & Van Rooyen, E. 2004. *The Quest for Sustainable Development*. Juta, Cape Town.
- Frankenberger, T. R. 2000. A brief overview of sustainable livelihoods approaches, in: Proceeding from the Forum on Operationalizing Sustainable Livelihoods Approaches, Pontignano (Siena).
- Furze, B., De Lacy, L. & Birkhead, J. 1996. *Culture Conservation and Biodiversity*. Wiley, West Sussex.
- Grossman, D. & Holden, P. 2003. Spreading the benefits of conservation: indigenous communities, equity and parks. In G.I Gowan, J Yawitch & M. Swift. (Eds). *Strategic innovations in biodiversity conservation: The South African experience*. Department of Environmental Affairs and Tourism, Pretoria.
- Hall, C.M. & Page, J.P. 2006. *The Geography of Tourism & Recreation, Environmental, Place and Space*. (3rd Edition), Routledge, London.

- Hall, C.M. 2010. Tourism and the implementation of the Convention on Biological Diversity, *Journal of Heritage Tourism*, 5(4), 267-284.
- Hoon, P. 2004. Impersonal markets and personal communities? Wildlife, conservation and development in Botswana. *Journal of International Wildlife Law & Policy*, 7(3), 143–160.
- Hulme, D. & Murphree, M. 2001. Community conservation as policy: Promise and performance. In D. Hulme & M. Murphree (Eds.), *African wildlife and livelihoods*, David Philip, Cape Town.
- Imran, S., Alam, K. & Beaumont, N. 2014. Environmental orientations and behaviour: Perceptions of protected area tourism stakeholders. *Tourism Management*. 40(4): 290-299.
- Muzirambi, J. M. 2017. Perceptions of local community participation in wildlife and tourism management: Phinda Private Game Reserve, UMkhanyakude district, Kwazulu-Natal, South Africa, PhD dissertation, University of South Africa, South Africa.
- Joppa, L.N, Loarie S.R., Pimm S.L. 2009. On Population Growth Near Protected Areas. *PLoS ONE*, 4(1), 1-5.
- Joppa, L. N., Loarie, S. R. & Nelson, A., 2010. Measuring population growth around tropical protected areas: current issues and solutions. *Tropical Conservation Science*, 3 (2), 117-121.
- Lockwood, M., Worboys, G. L., & Kothari, A., 2006. *Managing protected areas: A global guide*. IUCN, Earthscan, London.
- Murambadoro, M., 2009. *How the Sustainable Livelihoods Framework can contribute towards sustainable social development: Where are we going? Sustainable social ecological systems*, CSIR, Pretoria.
- Musumali, M., Larsen, T., & Kaltenborn, B., 2007. An impasse in community based natural resource management implementation: The case of Zambia and Botswana. *Oryx*, 41(3), 306–313.
- Pelser, A., Redelinghuys, N., & Velelo, N., 2013. *Protected areas as vehicles in population development: lessons from rural South Africa in Environment, Development and Sustainability – A multidisciplinary Approach to the theory and Practice of Sustainable Development*, Springer, town?.
- Roe, D. & Walpole, M. J., 2010. Whose value counts? Trade-offs between biodiversity conservation and poverty reduction. In Leader-Williams, N., Adams, W.M., & Smith, R.J (Eds.), *Trade-offs in conservation: Deciding what to save*, Blackwell, Oxford.
- Simpson, M.C., 2009. An integrated approach to assess the impacts of tourism on community development and sustainable livelihoods. *Community Development Journal*, (2), 186-208.
- Snyman, S., 2012a. The impact of Land Management systems on community attitudes towards tourism and conservation in six South African Countries. *Parks*, 18 (2) 20-31.
- Snyman, S., 2012b. Ecotourism joint ventures between the private sector and communities: An updated analysis of the Torra Conservancy and Damaraland Camp partnership, Namibia. *Tourism Management Perspectives*, 4, 127–135.
- Snyman, S., 2014. Assessment of the main factors impacting community members' attitudes towards tourism and protected areas in six southern African countries, *Koedoe*. 56 (2), 21–32.
- Spenceley, A., Hvenegaard, G., Mader, R., Snyman, S., Nikolaeva, E., Bushell, R. & 18 TAPAS Group Members, 2014: IUCN WCPA Annual report to the steering

- committee: Tourism and Protected Areas Specialist Group (TAPAS Group), Reporting period 1 January 2014–31 December 2014.
- Spenceley, A., Snyman, S. & Rylance, A. 2017. Revenue sharing from tourism in terrestrial African protected areas, *Journal of Sustainable Tourism*, 22 (8), 1-15.
- Statistics South Africa, 2019. www.statsa.gov.za, Accessed 20 April.
- Stoll-Kleeman, S. 2005. Voices for biodiversity management in the 21st century. *Environment: Science and Policy for Sustainable Development*, 47, 24-36.
- Swemmer, L., Grant, R., Annecke, W., & Frietag-Ronaldson, S. 2015. Toward more effective benefit-sharing in South African National parks. *Society and Natural Resources*, 28(1), 4–20.
- United Nations Environmental Programme (UNEP). 2002. *Global Environmental Outlook*, Nairobi, Kenya: United Nations Environment Programme
- UNWTO. 2016. Why tourism? <http://www2.unwto.org/content/why-tourism>. Accessed 24 November 2016.
- Van Schalkwyk, B. 2015. Challenges in Realising Sustainable Community Development in Rural South Africa. Agriculture, Forestry and Fisheries. Special Issue: *Planning for Sustainable Communities: Green-Spaces in Rural Areas*. 4(4-1)73-79.
- Walpole, M., Goodwin, H., & Ward, K. 2001. Pricing policy for tourism in protected areas: Lessons from Komodo National Park, Indonesia, *Conservation Biology*, 15, 218–227.
- Waylen, K.A., Fischer, A., McGowan, P.J.K., Thirgood, S.J. & Milner-Gulland, E.J. 2010. Effect of local cultural context on the success of community-based conservation interventions, *Conservation Biology*, 24 (4),1119-1129.
- Werther, Jr. W.B., & Chandler, D. 2011. *Strategic corporate social responsibility: Stakeholders in a global environment*. (2nd edition), Sage Publications, Los Angeles.
- World Parks Congress. 2003. The Durban Accord. <http://cmsdata.iucn.org/downloads/durbanaccorden.pdf>. Accessed March 11, 2019.

Chapter 13: Indigenous communities, hegemonic subjugation and environmental conservation: On protected areas in KwaZulu-Natal, South Africa

Hlengiwe Cele^{1*} and Inocent Moyo¹

¹Department of Geography and Environmental Studies, University of Zululand,
Kwa-Dlangezwa, 3886, South Africa

*Corresponding author: hmscelle@gmail.com

Abstract

Through hegemonic subjugation and the creation of Protected Areas (PAs), subsequent to colonial conquest, indigenous communities were displaced and marginalised to hinterlands, which restricted them from accessing and utilising resources within the PAs, all in the name of conservation. The colonists usurped land from indigenous communities, leaving them with infertile soils and without any land entitlements. Given the above, this study explores consequences of the displacement and/or marginalisation of indigenous communities from their aboriginal lands to give way to PAs, which brings to the fore social issues, such as class, race and inequality, which has implications for, inter alia, livelihoods. The study deployed a qualitative research approach involving in-depth interviews with the members of the traditional council of the respective area and PA authorities. Results of the study reveal that there have been unceasing augmented encounters amid indigenous communities and park authorities arising from dogmata that have undesirably impacted the livelihoods of indigenous communities. This study has therefore realised the need for an innovative multi-level approach, one that empowers indigenous communities to participate in the developments of and implementation of the new policy.

Keywords: Hegemonic subjugation, Protected Areas, Livelihoods

Introduction

Following the creation of the earliest protected area in 1872, the Yellowstone National Park (Robin, 2013, Machado *et al.*, 2017), the United States Yellowstone Model and/or Act (1872) ensued (Shafer, 2015). According to Shafer (2015), this model expounded the inordinate expulsion and dispossession of indigenous societies from their ancient territories to locations with infertile soils in the designation of protected areas. Generally, protected areas were well conceived, to be the fundamental practices for governing and managing biodiversity loss as well as preserving the natural environment (Stolton *et al.*, 2015). Thereafter, this example of exclusionary policies was assumed on a comprehensive scale in regions such as Asia (Heinen, 2012), Europe (Mose, 2016), Latin America (Larson and Dahal, 2012) and Africa (Andersson *et al.*, 2017). According to Noyoo (2015), in this era, South Africa experienced callous decrees and inequalities within the apartheid system. Apartheid structures beside imperialist approaches premeditated dogmata that permitted the dispossession of society away from their original lands to confined areas devoid of any property prerogatives (Chomba *et al.*, 2016), unproductive land with meagre supplies of natural resources that were significant to indigenous communities (Drewniak *et al.*, 2012; Noyoo, 2015) as well as the implementation of Western

epistemologies for the conservation and management of protected areas over Indigenous Knowledge Systems (IKS) that belonged to the dispossessed inhabitants (Maluleke, 2018, Thondhlana *et al.* 2016). These areas made it difficult for indigenous people and contributed to social issues of class, gender and ethnical variances and disparities in the right to the use of and distribution of natural resources, thus negatively affecting the livelihoods of the marginalised groups (Kull *et al.* 2015). These exclusionary policies and the displacement of people from their aboriginal land were policies influenced by colonial interests in the extraction of natural resources for fiscal profits (Winters, 2015) as much as they were conceived for conservation objectives (Stolton *et al.* 2015). As a consequence they led to extended environmental alteration as well as disputes over natural resources (Adger *et al.*, 2001). However, until recently, these policies have been studied, adjusted and new policies have been enacted (Gilmour, 2013). This indicates a need to question the innumerable perceptions of the marginalised groups regarding the new policies and the use and/or application of IKS in the conservation of protected areas. It is against this backdrop that this paper also investigates how their livelihoods have been impacted by policy modifications by the Okhahlamba-Drakensberg National Park in KwaZulu-Natal, South Africa.

PAs and land dispossession

In the subsequent sections in this paper, it will be argued that the exclusionary policies that came about as a result of the creation of protected areas furnished the upsurge of segregation and relegation of indigenous communities and their indigenous knowledge as well as the restrictions of access to these areas and natural resources (Stone and Nyaupane, 2016). This led to the social exclusions and negative effects on the livelihoods of indigenous communities (Kull *et al.* 2015). Further land restrictions were enacted using the creation of buffer zones (Shafer, 2015) that subjected indigenous people to areas beyond protected areas (Andersson *et al.* 2017). The debate regarding the implementation of protected areas so as to achieve conservation objectives (Stolton *et al.* 2015) has gained fresh prominence with many arguing that protected areas are merely a policy enacted to exercise strict control over the access and the utilisation of resources (Kitamura and Clapp, 2013). Many label this policy as a hegemonic mechanism example (Fuente-Carrasco *et al.* 2019) that makes the most of a top-down methodology that excludes local people (Wang, 2019) in the administration and safeguarding of natural resources which adversely controls the livelihoods of immediately situated indigenous communities (Soliku and Schraml, 2018).

Contrariwise, it is generally thought that protected areas are key implements for conserving natural resources (Machado *et al.* 2017). This view is supported by Watson *et al.*, (2014) who argue that protected areas were created and utilised to realise uncountable objectives for society. A broader perspective has been adopted by Mutekwa and Gambiza (2017) who argue that so far this method has burgeoned, with the exclusion of people from the right of entry to and the consumption of natural resources, violating their social rights to a point of underdevelopment and thus leading to conflict. Central to the entire discipline of environmental conservation, the concept of protected areas is seen as a threat to indigenous communities and their financial displacement, which refers to the constraints imposed by protected areas that create challenges for local people in pursuing their livelihoods (Brockington and Wilkie, 2015).

Questions have been raised about how these exclusionary policies impede the livelihood of marginalised indigenous communities, given that they have always depended on these resources (Kabra, 2018). It must also be noted that indigenous communities have always had a direct link with the natural environment (Martín-López and Montes, 2015). Additionally,

the conservation of natural resources is a process that has habitually been assumed by indigenous communities articulated through their cultural practices (Ayaa and Waswa, 201) as soon as they had come to appreciate the services provided by natural resources and acknowledged that they are limited, for example, the creation of sacred areas, demonstrating noble relations (Mehta, 2017). Consequently, the necessity to sustain them for impending consumption (Mehta, 2017). In the same way, Cruz and Abeledo (2015) emphasise that IKS has been thought of as a key factor in providing people with alternative solutions to adapting to dynamic environmental changes.

Mehta (2017) posits that policy-makers have disregarded the use of IK in conserving natural resources with the goal of accomplishing maximum fiscal advancement while depleting these resources and raising resource conflicts (Kohler and Brondizio, 2017). Overall, the significance of IKS in the conservation and environmental management is marginalised (Sandlos and Keeling, 2016). In this situation, the exclusion of people has led to unlawful actions such as the illegal cutting down of eucalyptus plantations in Brazil and illegal poaching of rhinos in South Africa (Kohler, Eduardo and Brondizio, 2017). Moreover, the latter identified issues are said to have been perpetuated by environmental dispossession in the process of implementing exclusionary policies against indigenous people (O'Brien *et al.* 2007).

Environmental conservation

According to Mtolo (2010) environmental conservation and policies mandated within the field ensued given the overutilisation of ecosystem resources, as a process that could be utilised to manage impacts on the environment (Mostert, 2015, Carelse, 2016) and govern man-nature relationships in conservation assuming their dependency on natural resources (Uitto, 2014). Boucher, Spalding and Revenga (2013) surmise that indigenous communities have always been effectively conserving and protecting their surrounding natural areas. Despite this, there is increasing concern that indigenous people and their IKS have been continuously disregarded and surpassed (Mehta, 2017) by western approaches to environmental conservation. Besides, protected areas were established using scientific data that prejudiced the selection of areas of conservation need, design of principles as well as administration diplomacies (Mehta, 2017).

Advocates of western epistemologies assert that protected areas are indispensable for environmental conservation (Brockington and Wilkie, 2015). However, the institution of this model suggested there be involuntary removal of people from resource rich areas to areas where their IK regarding environmental conservation could not be practical (Kitamura and Clapp, 2013). Similarly, the access to and consumption of natural resources by local people who depend on them would be considered illegal, thereby leading to the destruction of their livelihoods (Shafer, 2015).

There has been recent interest in integrating IK into Western utilitarian approaches for ecological protection and management (Ludwig, 2016). Therefore, this paper attempts to show that IKS has always contributed to conservational practices and has the potential to accomplish environmental conservation (Dutse *et al.* 2015). By integrating local people in environmental conservation practices, their marginalized IK can be utilised as new information in achieving conservation objectives (Ludwig, 2016). Ludwig (2016) writes that involving IK in the existing policies for environmental conservation does not simply mean developing probable approaches for conservation, but also the benefits of previously marginalised local communities. Correspondingly, Sutton and Anderson (2013) postulate that IK provides ways to monitor, adapt and/or overcome ecological issues. The marginalisation of IK can be a drawback in endeavours to modify conservation practices (Joa, Winkel and Primmer, 2018). Therefore, it is within this context that this paper seeks to investigate the impact of subjugation on

livelihoods and the integration of IKS in the conservation of protected areas. To achieve this, the qualitative research approach was deployed in addressing the issues of marginalised communities and their IK for environmental conservation. The target population of the study included community leaders from the AmaNgwane, AmaSwazi and AmaZizi traditional areas in Okhahlamba-Drakensberg as well as park representatives from the Okhahlamba-Drakensberg National Park. The total sample included three community leaders from the respective areas and three park managers. Data was collected through interviews that encompassed open-ended and closed-ended questions to establish variances as well as to gain valuable information regarding IK and the management of natural resources. Data was analysed using content analysis where data was coded and separated according to themes and subthemes identified.

The dispossession and/or displacement of people and the fate of IK

Traditional leaders of the AmaNgwane, AmaSwazi and AmaZizi concur that they were removed from the mountains, the Okhahlamba-Drakensberg Mountains, for the creation of the Okhahlamba-Drakensberg National Park. They were promised a better life on the hinterlands, employment and monetary gain. Thereafter, people were disregarded until the present. On the other hand, park representatives claim that it is not the case; the land was purchased from a farmer who had made all of the above arrangements with the local community.

Firstly, the community leaders declare that they have no knowledge or communication regarding the current practices of conservation (especially AmaSwazi and AmaNgwane). However, the park representative refers to the Integrated Management Plan which is reviewed after five years. Unfortunately, this plan mostly contains scientific concepts and explanations difficult for ordinary community members to comprehend. Secondly, the traditional leaders believe that they have lived for many years in harmony with the surrounding environment and therefore their IK can be actively utilised. The community leaders say that there are many community members who efficiently utilise their IKS in conserving the environment. Conversely, given the above, according to the park representative, the status of IKS is very low in the conservation and management of the environment. This is due to the fact that most of the conservation regulations that exist today are predisposed by political rationalisations and/or hegemonic subjugation, unlike in the past when conservation was regulated by Inkosi of the area utilising their IK (if and when an individual in the community is in contravention of the laws enacted for conservation, they are disciplined in view of that). Additionally, the three traditional leaders agree with the latter, explaining that these practices of IK in achieving their community conservation objectives are still vigorous and are still applied by community members. Therefore, according to the leaders, the current status of IKS in their community is sufficient in the conservation of their surrounding environment.

According to the park representatives, IKS and the local communities are included in the current practices and the co-management plan of the park. Community engagements are conducted; however, attendance at these engagements is often very low. Some of the IKS considered in the park practices include permission for access to the Royal burial site, often in caves where the Kings (Inkosi) of the area are buried (Elibeni). Annually during a certain time of the year, the community is granted access to hunt the Eland (*Taurotragus oryx*) which is immeasurably protected in the park for the cultural practices, also the Inkosi is permitted to pluck one feather (usiba) from the blue crane (*Anthropoides paradiseus*) which is the national bird of South Africa. This is important in the cultural attire of a community leader.

Marginalisation and the impacts on livelihoods

In terms of benefits and access to natural resources, all three community leaders complain about the lack or no access to grasslands for their cows to graze in times of need as well as the limited access to gathering firewood. Access for gathering firewood is permitted if the individual has a permit; also there is a certain amount of firewood and grass for crafts they are allowed to gather. There is regulated access and almost no access at all to plants and trees that contain traditional health/medicinal properties or value for local community members. Likewise, the access to grasslands, grass that is used by different community members for different purposes, for example, those that utilise the grass for craftwork, different types of clay stones mainly found near the river and caves (inside the protected area) for artwork to be vended and others that use the grass to construct sheltering roofs for their homes (and as a skill for income). Thus, the inability to access these natural resources hinders their ability to sustain their livelihoods.

Remunerations and employment opportunities as promised to community members, have not been fulfilled. According to AmaZizi, in the past community members used to be given permanent employment by the park in their various subdivisions; however, over the years, that has been radically reformed. Local people only acquire temporary employment. Even so, only two to three individuals are employed out of ten from the local community; the rest are people from external regions far from the Drakensberg.

The latter, according to the leaders, affects their livelihoods and increases the inability for families to sustain their well-being. Also, local people have been basing their grievances on the fact that employment advertisements from the head office do not reach the local community members until it is too late for them to apply. This is a breach of the initial agreement and authority that was granted to community leaders, empowering them to find suitable applicants from within the community for a certain form of employment and then direct that information to the park. Also, benefits from the community's areas such as the Mahaye River and the Vivane area (that borders South Africa and Lesotho) of heritage significance are remunerated to the Ingonyama Trust Board. And lastly, the community leaders assert that these strict regulations and marginalisation promote illegal activities such as illegal grazing of cows, hunting and gathering which thereby breeds further conflicts.

Conclusion

The findings of this study show that even after so many years following the dispossession of people from their aboriginal land to create protected areas (Brockington and Wilkie, 2015), local communities are still disregarded. Parks have attempted to respect their cultural heritage by allowing them access to sacred sites and the performance of some rituals (such as royal funerals, the cultural attire). However, practices of environmental conservation have not been considered. Also, given that local community members have no knowledge of current practices that are in place for ecological conservation, that there is insufficient communication and engagements between the park and the people. The fact that people do not attend these meetings shows that there are not good relationships between the people and the parks. Maluleke (2018) asserts that the conflicts between people and the park are strongly influenced by how Western approaches of conservation have disregarded their traditional practices. The latter is true given local people and their IKS are still marginalised by the restrictions on the access and consumption of natural resources which overall impact negatively on their sources of livelihood. Moreover, relationships and conflicts can be resolved if and when local communities are involved in environmental conservation and the benefits ecosystem services are structured so that they can also improve their livelihoods (Alexander *et al.*, 2016).

Based on the findings, this paper suggests the following recommendations. First, the local community should be educated by the park regarding the Integrated Management Plan so they can take back the knowledge to the local community members in simpler terms. Second, the community should re-establish conservation forums with the assistance of the park. These forums can be utilised to use their opportunities to present their IKS practices that can be integrated with Western policies of conservation management. At this point, various stakeholders can be included, for example Intellectual Property experts for the protection of local people's knowledge and to ensure they benefit from such. Third, there is a need to re-establish or modify existing policies with regard to the access to and consumption of natural resources so that they can improve their livelihoods, create good relationships with these communities to solve and end conflicts.

References

- Adger, W. N., Benjaminsen, T. A., Brown, K. & Svarstad, H. 2001. Advancing A Political Ecology of Global Environmental Discourses. *Development and Change*, 32, 681-715.
- Alexander, S., Aronson, J., Whaley, O. & Lamb, D. 2016. The Relationship Between Ecological Restoration and The Ecosystem Services Concept. *Ecology and Society*, 21.
- Andersson, J., De Garine-Wichatitsky, M., Cumming, D., Dzingirai, V. & Giller, K. 2017. *Transfrontier Conservation Areas: People Living on The Edge*, Taylor & Francis.
- Brockington, D. & Wilkie, D. 2015. Protected Areas and Poverty. *Philosophical Transactions Of The Royal Society B: Biological Sciences*, 370, 20140271.
- Carelse, S. L. 2016. *A System For Integrated Environmental Management In Local Authorities To Inform Departmental Decision-Making: The Case Of Hessequa Municipality*. Stellenbosch: Stellenbosch University.
- Chomba, S., Kariuki, J., Lund, J. F. & Sinclair, F. 2016. Roots of Inequity: How The Implementation Of Redd+ Reinforces Past Injustices. *Land Use Policy*, 50, 202-213.
- Fuente-Carrasco, M. E., Barkin, D. & Clark-Tapia, R. 2019. Governance from Below and Environmental Justice: Community Water Management from The Perspective Of Social Metabolism. *Ecological Economics*, 160, 52-61.
- Gilmour, P. W. 2013. *Factors and Processes Affecting Co-Management of Natural Resources*.
- Heinen, J. 2012. International Trends in Protected Areas Policy and Management. *Protected Area Management*. Intechopen.
- Kabra, A. 2018. Revisiting Canons and Dogmas in The Conservation-Versus-Human Rights Debate. *Ecology, Economy and Society*, 1.
- Kitamura, K. & Clapp, R. A. 2013. Common Property Protected Areas: Community Control In Forest Conservation. *Land Use Policy*, 34, 204-212.
- Kohler, F. & Brondizio, E. S. 2017. Considering the Needs of Indigenous and Local Populations In Conservation Programs. *Conservation Biology*, 31, 245-251.
- Kull, C. A., Arnauld De Sartre, X. & Castro-Larrañaga, M. 2015. The Political Ecology of Ecosystem Services. *Geoforum*, 61, 122-134.
- Larson, A. M. & Dahal, G. R. 2012. Forest Tenure Reform: New Resource Rights for Forest-Based Communities? *Conservation and Society*, 10, 77.
- Ludwig, D. 2016. Overlapping Ontologies and Indigenous Knowledge. From Integration to Ontological Self-Determination. *Studies in History and Philosophy of Science Part A*, 59, 36-45.

- Machado, C. C. C., Gonçalves, C. U., Albuquerque, M. B. D. & Pereira, E. C. 2017. Protected Areas and Their Multiple Territorialities-A Social and Environmental Reflection On Catimbau National Park-Brazil. *Ambiente & Sociedade*, 20, 239-260.
- Maluleke, G. 2018. Rethinking Protected Area Co-Management in The Makuleke Region, South Africa (SA).
- Martín-López, B. & Montes, C. 2015. Restoring the Human Capacity for Conserving Biodiversity: A Social–Ecological Approach. *Sustainability Science*, 10, 699-706.
- Mehta, S. 2017. Role of Traditional Practices in Conserving Environment: A Case Of Manesar Village, Gurgaon. *Iosr Journal of Humanities and Social Science (Iosr-Jhss)* 22, 10-16.
- Mose, I. 2016. *Protected Areas and Regional Development in Europe: Towards A New Model for the 21st Century*, Routledge.
- Mostert, E. 2015. Who Should Do What in Environmental Management? Twelve Principles for Allocating Responsibilities. *Environmental Science & Policy*, 45, 123-131.
- O'brien, K., Eriksen, S., Nygaard, L. P. & Schjolden, A. N. E. 2007. Why Different Interpretations of Vulnerability Matter in Climate Change Discourses. *Climate Policy*, 7, 73-88.
- Robin, L. 2013. Being First: Why the Americans Needed It, And Why Royal National Park Didn't Stand In Their Way. *Australian Zoologist*, 36, 321-331.
- Sandlos, J. & Keeling, A. 2016. Aboriginal Communities, Traditional Knowledge, and the Environmental Legacies of Extractive Development In Canada. *The Extractive Industries and Society*, 3, 278-287.
- Soliku, O. & Schraml, U. 2018. Making Sense of Protected Area Conflicts and Management Approaches: A Review of Causes, Contexts And Conflict Management Strategies. *Biological Conservation*, 222, 136-145.
- Stolton, S., Dudley, N., Avcioglu Çokçalışkan, B., Hunter, D., Ivanić, K., Kanga, E., Kettunen, M., Kumagai, Y., Maxted, N. & Senior, J. 2015. Values and Benefits of Protected Areas. *Protected Area Governance and Management*, 145-168.
- Stone, L.S. & Nyaupane, G. P. 2016. Africans And Protected Areas: North–South Perspectives. *Annals of Tourism Research*, 58, 140-155.
- Thondhlana, G., Cundill, G. & Kepe, T. 2016. Co-Management, Land Rights, and Conflicts Around South Africa's Silaka Nature Reserve. *Society & Natural Resources*, 29, 403-417.
- Uitto, J. I. 2014. Evaluating Environment and Development: Lessons from International Cooperation. *Evaluation*, 20, 44-57.
- Wang, J.-H. Z. 2019. National Parks In China: Parks For People Or For The Nation? *Land Use Policy*, 81, 825-833.
- Winters, O. J. 2015. The Botswana Bushmen's Fight for Water & Land Rights in The Central Kalahari Game Reserve. *Consilience*, 285-299.

Section D: Globalisation and regional economic integration in Africa

Chapter 14: Africa inaction in globalisation: contests and prospects

Phemelo Olifile Marumo

North-West University

Phemelo.Marumo@nwu.ac.za

Abstract

The paper examines the inaction of Africa's participation in the Fourth Industrial Revolution which is embedded in globalisation. This inaction has resulted in Africa being underdeveloped, especially with regard to human capital and economic transformation. Formerly, some countries like Zimbabwe were known as bread-baskets of Africa, due to their sustainability which was based on their richness in raw materials. However, that did not last long, as Africa encountered an onslaught of colonialism through the partition of Africa which did not sanction Africa's participation in global economics. The non-participation of Africa in globalisation has resulted in Africa being the consumers in the stream of economic development. Africa was left with no option but to accept the exported goods which in most cases did not serve their purpose because they were not tailor-made for them. Thence, Africa has become a silent trader and contender due to its lack of economic capacity, infrastructure development, and human capital. From this premise, the paper will look at the economic stance of Africa and how the exploitation of its raw material has contributed to its inaction in globalisation. Thereafter, the paper will seek a solution that will contribute towards development in Africa as demystifying the inaction of Africa in globalisation.

Keywords: globalisation; Africa; development; human development; global economic

Introduction

According to Davis (2019), the Fourth Industrial Revolution can be described as the advent of “cyber-physical systems” involving entirely new capabilities for people and machines. While these capabilities are reliant on the technologies and infrastructure of the Third Industrial Revolution, the Fourth Industrial Revolution represents entirely new ways in which technology becomes embedded within societies and even our human bodies. Examples include genome editing, new forms of machine intelligence, breakthrough materials and approaches to governance that rely on cryptographic methods such as the blockchain.”

Schwab (2019) clarifies the above by referring to previous revolution and their impacts and how they have brought about the emancipation of humans: “previous industrial revolutions liberated humankind from animal power, made mass production possible and brought digital capabilities to billions of people. This Fourth Industrial Revolution is, however, fundamentally different. It is characterized by a range of new technologies that are fusing the physical, digital and biological worlds, impacting all disciplines, economies and industries, and even challenging ideas about what it means to be human. The resulting shifts and disruptions mean that we live in a time of great promise and great peril. The world has the potential to connect billions more people to digital networks, dramatically improve the efficiency of organizations and even manage assets in ways that can help regenerate the natural environment, potentially undoing the damage of previous industrial revolutions.”

Despite the good intentions of the 4th Industrial revolution, Schwab is concerned that it might be too early or too late because this will have a problematic side for adaptation by the organisations; on the other hand, governments may fail to employ and regulate new technologies to reap the benefits. As might be a problem always with change, the same can be realised by the shifting of power and may create important new security concerns, e.g. inequality may grow and societies may fragment.

Drawing from Schwab's concern, the paper indicates that the problematic issues may also affect Africa in development in areas like human capital and economic transformation which were obstructed by the erstwhile colonialism. The relevant example is Zimbabwe and other countries in Africa which were impoverished and developmentally curtailed due to the partition of Africa. This is evident from Sochone's (2004) argument that by the mid-1970s a series of economic crises in the global economies, such as the rapid increase in the oil price which benefited very few oil-exporting African countries, culminated in the slowing down and stagnation of the African economy. As government revenues fell, the huge debt increased and that suffocated development in both economic and human capital. This was due to a decline in social spending which led to fees being imposed by schools and hospitals and the general poverty level across the continent escalated at a very alarming speed. That is why Sochone concludes by seeing the period from the 1970s to the 1990s as the "lost decades" in African development.

Africa post-independent scenario

Salifu (2010), paints the following picture of Africa's post-independence era as being in political and economic turmoil. To entrench its presence although not being physically there, colonialism replaced the pre-colonial structures with Western ones, thereby creating a kleptocracy. Within these ruling structures, colonial rulers placed Africans in positions of leadership and enticed them with status and/or wealth. Economic rewards given to African elites were trapped within elite circles, creating a dominant class at the expense of other Africans and the continent's natural resources. Through this strategy, the African elites remained in power after independence and maintained their relationships with the former colonialists. In this way, elites were continually rewarded for draining their states' natural resources. Colonialism furthermore created single-crop economies, which sentenced African economies to market-based fluctuations. Forced integration of developing states into the international trading arena aggravated the already prevalent inequality between developed and developing states (Oguejifor, 2015).

Makki (2015:142) in his concluding remarks on his article "*Post-colonial and World Economy*" points out that Africa is facing an economic dilemma which is compounding problems for Africa's participation in the global economic markets. He highlights that the West has in a way contributed towards that economic degradation by infusing competition among Africa countries. A new pattern of neoliberal primitive accumulation has emerged that has effectively strangled Africa's weak economies. He maintains that the economic impact on Africa needs to be addressed as a matter of urgency if Africa desires to participate in the mainstream of the global economy. As he concludes he states that, "But if this restructuring is to be converted into an enduring social gain for Africa's citizens, the neoliberal reification of the market and the consequent downplaying of human agency, and the anaesthetising effect this has had on critical thought, will all have to be overcome. The condition of Africa today is an outcome of its asymmetrical integration into the world system and any credible alternatives beyond it will require a concerted effort to transform the relational structures of power that have continued to reproduce it."

The above can be correlated firstly to what Thomson (2016:16) affirms: that the aftermath of the independence of many African countries has been characterised by a lack of development of economic and human capital. This was exacerbated by the 'dependence syndrome' which the colonisers left in the independent countries. The bond between the colonisers and the states was not severed but was strengthened because the West had a say in political, economic as well as social issues of each country which was supposed to be 'independent'. That was problematic in a sense that countries could not take a decisive stand on how to deal with their internal as well as external matters, they had to refer matters to the Western countries for endorsement and ratification. Thomson argues that: "the continent had been systematically underdeveloped by imperial interest, and this now left the new independent states in a highly vulnerable 'dependent' position. As such, colonial administrators had failed to provide Africa with basic economic foundations that governments now needed if their countries were to flourish." This was based on the premise that all states operate in a single global system; however, not all countries are equal in that economic mainstream. There are those developed states at the centre of the core (Western countries) and the less developed countries on the periphery, like Africa.

Thomson further claims that due to the above, the West today has been founded on exploitation of the periphery's resources. Economic activity which could have assisted African economies has instead advanced the position of the West. Imperial rule was the formal political authority that underwrote the process of exploitation. This exploitation was evident during the slave trade and didn't stop after the independence of the countries in Africa; it took another turn. People who could advance the development of African economies and societies were instead forced to contribute to capital accumulation elsewhere through the promise of better status and job opportunities. Thus skills which were supposed to be utilised in the development of Africa were exported together with the mineral resources to the West for its development. This crippled human capital resource development and that placed Africa in a catastrophic position developmentally.

As he put more enlightenment in his argument, Thomson (2016:18) states that:

Underdevelopment also resulted from the 'export of surplus'. Instead of Africa economies benefitting from the new economic activity on the continent, raw materials extracted and profits raised by African labour were simply whisked away from the periphery in order to develop the economies of the West. For economic advancement to occur anywhere in the world not only does a surplus have to be produced, but also it has to be invested productively. Reinvestment of profits into the economies of Africa could have stimulated growth locally. Instead, the West expropriated this surplus for its own use. It is no coincidence that the economies of the core expanded at a previously unprecedented rate during the years of colonialism.

From the above deliberations the paper reaches the conclusion that even if Africa was 'liberated and independent' Africa was economically weak. The weakness made Africa a lame dog to compete and participate in the mainstream of the global economy. Africa inaction in globalisation was evident and Africa was a loser before even starting to participate. This has hampered development and made Africa economically redundant and human capital short. This scenario clearly shows how it is going to take time for Africa to be on its feet as an economic partner in the global arena. The example of this crippling is Zimbabwe which was left with modern coal mines to produce power for any post-independence industrial development, while Algeria has a small steel industry to build upon. But all these developments could not bear the fruits of development.

Secondly, for a country to participate fully in the global stream of economies and development, it needs stable and effective political leaders who can influence and steer the countries to economic competition. That was not to be seen in Africa. According to Thomson (2016:20), the political institutions which were left by the imperial powers was weak. As decolonisation approached, the majority of these countries opted for negotiation and the result was the multiparty election with the victor of this poll taking the reins of power under a new independence constitution. These new constitutions guaranteed pluralist democracy and the rule of law. The political structures were not ready or trained to midwife the new dispensation due to the intervention of the West. That is why a Western mentality was rife was during the transition. This interference was predestined for Africa to fail economically and politically. Mention should be made that the political rule in Africa is bureaucratic; it does not include civil society, hence the worldview of the inhabitants is undermined and what the politicians in power say must be implemented. There is a problem of accountability which is endemic in the African continent.

The above can be inferred from the manner in which leaders who are keen to participate in the mainstream of global economy cannot do it. Most leaders from the independent states have tried to participate by diversifying their economies and breaking the continent's dependence on primary exports. According to Thomson (2016:188), some states went to the extent of drawing up development plan striving to build on what it could salvage from its colonial inheritance. They tried to establish local manufacturing plants to produce goods which were previously imported from the West. However, since development requires investment capital and little economic surplus was generated within Africa itself, the governments were left with no alternative but to borrow from the West to implement their development plans. This left the countries reliant on foreign aid/debt. Beside the failure on their part to raise financing, African countries face external and internal factors. One of the foremost factors was that they envisaged that they would be in a position to service the debt and pay it off. However, in the process of securing funding, they mortgaged future harvests and mining outputs for funds and oil prices also put a strain on the economy of the African states.

The above situation portrays Africa as a continent which is irresponsible in a sense that they cannot service their debts. In order to address this shortcoming, Africa was to increase borrowing from the West to execute development plans. This was done despite the vast sums of capital leaving the continent in debt service: little progress was made on repaying the capital owed. The more the West demanded, the less impression was made on the total owed, the less Africa had in developing and generating income to clear the debts. In the meantime, there were the human capital costs which saw the death of many African infants who could not access primary health care, especially during the ebola epidemic due to the debt crisis.

Igbohor (2015), argues that the debt lies at the door of the leaders who were puppets of the West. Leaders were imposed on the communities/states and benefited from the wealth of the country and they were bound by the West to implement stringent economic laws which can cripple the economy and promote poverty. This type of action led to the downgrading of development and human capital. People were now beggars on their own continent. To make matters worse people were beggars when there were mineral resources that could be utilised to address their pleas. The raw minerals produced were exported to the West and the people's welfare was sacrificed. This can be likened to the common practice in Africa where the leaders are filthy rich and the subjects are in abject poverty. This can also be analysed to indicate that the Western perspective of development is not for the Africans; Africans must stay underdeveloped so that they cannot participate in the mainstream of global economy.

From the above, the paper noted that the economic development plan envisaged by the African states plunged them into more debt. Furthermore, their development plan, in fact, promotes reliance on the West in that the human capital which the plan was meant for could not get basic healthcare and the countries were in dire need of addressing the basic needs and pending the development plan. The pending of the development plan meant that African states were retrospectively and could not move forward in terms of economic and human capital developments. This placed African states in a precarious position that validated foreign debt as the answer to their developmental plans. This made it easier for the West to infiltrate the political and social levels of the African states. Africa was reduced to a silent trader and contender due to its lack of economic capacity, infrastructure development, and human capital in globalisation.

The contests of globalisation in Africa

Even when the countries had attained independence, they were not free from the West: their attachment was shaped in such a way that they needed to ask for everything from the West. The other thing which killed independence was that during the West's stay, they ignored human capital, didn't train the indigenous people and that meant some qualified artisans and engineers had to stay in behind as the economic human capital and backbone of an independent state.

According to Kuwuno (2016), Sanusi Lamido, the former governor of the central bank of Nigeria, was disturbed at how the West is controlling the economy of Nigeria even after it has attained independence. His observation was that most infrastructure in Nigeria was created by the Chinese and huge resources were being utilised for the importation of consumer goods which were supposed to be produced locally. Although China has set up mining operations across Africa and is heavily involved in building infrastructure, much of its activities on the continent involves imported equipment and labour and no skill transfers. From that observation, Lamido states; "So China takes our primary goods and sells us manufactured ones."

Lamido further observed that Nigeria which has reserves of crude oil was also importing oil. For example, in 2012 Nigeria exported \$89 billion of crude oil, according to the Excess Crude Account (ECA) report, but imported \$5.5 billion of refined oil because its refineries have all but collapsed due to neglect. There are deliberate trade policies and practices consistent with African countries. Nigeria offers a classic example of what has been happening to many sub-Saharan African countries that have concentrated on exporting raw commodities while paying scant attention to processing some of the commodities into finished goods as part of a deliberate policy on industrialisation.

Oguejifor (2015) reasons that it was important to control the economy of the independent states, therefore the West made it easy for governments to obtain loans from different institutions. There was the World Bank, International Monetary Fund (IMF), International Finance Corporation (IFC) who were willing to give loans and grants to the countries at exorbitant interest rates which made it difficult for the countries to pay back the debt. The offer of loans stalls the development and promotes dependency. The other way was to fix prices by keeping them low to make Africa remain dependent on their aid. Thus these nations are perpetually kept in a situation of unequal exchange.

Oguejior (2015) further argues that in terms of manipulating and promoting dependency, there is a minimum transfer of skills and training to the indigenous people. The West becomes stingy with knowledge and that means the independent countries are non-functional after the departure of the West, e.g. in Nigeria. The Coca-Cola Company brings machinery but does not allow staff members from Nigeria to access the technological know-

how of the manufacturing process of soft drinks. This makes it clear that money is made in these countries but is spent outside it because money for the purchase of the machinery and expertise returns to the developed countries of the West.

Colonialism lasted in Africa for only a period of about eighty years. During that time, colonial governments built a substantial infrastructure, introduced a cash crop system of agriculture, and changed the traditional standards of wealth and status. According to Settle (1996) “education reforms were introduced and in many areas modern state systems were implemented. However, the long-term economic impact of European development held some very negative consequences for Africa as well. The infrastructure that was developed was designed to exploit the natural resources of the colonies. Also, the technological and industrial development that had been occurring in Africa was stalled by the imposition of colonialism. Prior to the partition of Africa, local production provided Africans with a wide variety of consumer goods. The policies of colonialism forced the demise of African industry and created a reliance on imported goods from Europe.”

The African Economic Outlook (AEO) 2011 report has found that African states experienced high economic growth during the 2000s due to good macroeconomic management, growth in trade, and foreign investment into oil-rich states. However, this growth did not coincide with poverty elimination, because it was not linked to activities and economic sectors that affect the poor.

Further development plans must make economic opportunities available for a greater portion of the population, by creating jobs and supporting local production. From this context, Godoy (2011), reasons that the AEO reports on high fuel and mineral commodity prices have strongly influenced economic growth in many of the fastest growing African economies in the period from 1996 to 2008, given that fuels and minerals account for the largest share of Africa's exports. But this growth and its limited impact in reducing poverty creates a vicious cycle, for higher poverty diminishes even further the effects of economic growth in reducing poverty.

The above shows that even if the economic future of Africa is blank, there are possibilities that Africa can address its shortcomings. The paper has highlighted the problems that Africa was facing in pre-colonial and post-colonial eras. The main cause of the economic crisis was the debt to be serviced. Following the settling of that, Africa should, first of all, end its dependency relationship with the West. Africa should realise its potential of wealth from what they export to the West which could have been used locally to promote the economy and development for the indigenous people of the continent. The African development prospects can assist Africa to be a global partner.

Prospects for economy and development

The paper has interpreted the reports from the developmental institutions such as AOE reports that give clarity on what Africa is facing and that the *status quo* is not as dire as it appears. From the reports, Africa can improve economically and that can assist Africa internally. There are people in diaspora who are willing to go back home and assist in re-building the African continent. Looking around the globe Africans are holding positions and they are well-conversant with what they are doing. Others are engineers, architects, financial gurus, etc. who are ready to go back home and be part of the rediscovery plan for Africa.

Africa should start by advocating and spreading the spirit of self-determination that will, in turn, promote patriotism with all people having an identity and becoming proud of their own Africa. Initiatives have been effected through the formation of OAU (Organisation of African Unity) which has done a splendid job in Africanising Africa for the African. The sequel to that body, the OAU, was the AU (African Union), that has also contributed to the unification

of Africa through efforts of gaining sustainability. That should not be overlooked but must be implemented. There are bodies which are the arms of the AU which can assist on the economic and human development for Africa. e.g. The Economic Community of Central African States (ECCAS) is a collection of Central African States dedicated to promoting and strengthening cooperation between member states. The ECCAS focuses on topics such as bolstering international trade, customs, human capital, and tourism. The ECCAS also seeks to create peace and solidarity among members.

Leadership is problematic in Africa, according to Masango (2002:176); the African leaders are now focusing the energy of Africans on achieving common goals. Through the African Union, leaders will ensure that member states are held accountable and live up to the strict demands of accountability and good governance. At the Durban conference, for example, some African countries were not invited, because their leaders took power without being elected. The New Partnership for Africa's Development (NEPAD), felt that these leaders who took power on their own will not be able to serve the interests of their people.

The prospects of Africa going forward can be inferred from multiple papers and conferences as well as consultative meetings which are held with a focus on Africa. There is only a problem of implementation which can be addressed through proper leadership. Africa is reeling from under-development and the economic crisis due to a lack of honest, trustworthy leadership, which will look after the interests of the people.

The strategic position of Africa has placed it as the strategic partner of the West and also the East. But this is achievable if the self-seeking of leaders in Africa is eradicated, then Africa will be in a position to participate in the global economy when all is in place and Africa is ready and the self-serving has been eradicated, then Africa can participate in the global economy and its inaction in globalisation can be seen as a myth. If it is in a strategic position it can be in a position to control its exports and imports, thereby addressing the problem of the debts which are ravaging Africa.

According to Odusula (2019), Africa's economic growth prospects are among the world's brightest. Six of the world's 12 fastest-growing countries are in Africa (Ethiopia, Democratic Republic of the Congo, Côte d'Ivoire, Mozambique, Tanzania, and Rwanda). Further, between 2018 and 2023, Africa's growth prospects will be among the highest in the world, according to the IMF. Good news: sectors where foreign companies could have a comparative advantage, such as banking, telecommunications, and infrastructure, are among the drivers of the current economic growth in Africa, creating clear investment opportunities for foreign businesses. Africa's growing, youthful population, as opposed to an aging population in most other regions, constitutes a formidable market. The continent's population is predicted to quadruple from 1.19 billion in 2015 to 4.39 billion by 2100. In 2015 alone, 200 million Africans entered the consumer goods market. Maximising this burgeoning market calls for actively engaging Africa's structural economic transformation.

From the above, it is clear that if Africa can be serious about economic development and human capital empowerment it can be in a position to participate globally and face globalisation with its Fourth Industrial Revolution which as discussed above, goes with the human factor. Mention should be made that even if the 4th Industrial Revolution is seen as replacing humans especially in the labour sector, that is not the case. The author of this paper's opinion is that the economy and the manufacturers will need labour to manufacture what they want to use in the Fourth Industrial Revolution. The aftermath is that the cybers that are going to be used need to be serviced and that requires human capital. Therefore, Africa stands a chance of participating in the Fourth Industrial Revolution and have partners globally.

Conclusion

Investing in social sectors will produce sustainable human development if investment is accompanied by efforts to create more economic opportunities that benefit a large segment of the population. In a way that will mean creating job opportunities for the indigenous. Africa's race in the 4th Industrial revolution is open. Africa must implement and stop theorising about economy and globalisation.

References

- Davis, N. 2017. What is the fourth industrial revolution? World Economic Forum, viewed in <https://www.weforum.org/agenda/2016/01/what-is-the-fourth-industrial-revolution/>
- Godoy, J. 2011. 'Africa: Poor Excluded From Benefits of High Economic Growth', Global Policy Forum viewed in <https://www.globalpolicy.org/...economic.../poverty-and-development-in-africa.html>
- Ighobor, K. 2015 Billions now required to save depleted healthcare systems, viewed in <https://www.un.org/africarenewal/.../august.../using-trade-boost-africa's-industrializati...>
- Kuwono, F. Using trade to boost Africa's industrialization/ African Renewal, viewed in <https://www.un.org/africarenewal/.../august.../using-trade-boost-africa's-industrializati...>
- Makki, F., 'Post-Colonial Africa and the World Economy: The Long Waves of Uneven Development'. Journal of World-Systems Research, 124-146. Available at: <https://jwsr.pitt.edu/ojs/index.php/jwsr/article/view/546/558>.
[doi:https://doi.org/10.5195/jwsr.2015.546](https://doi.org/10.5195/jwsr.2015.546).
- Masango, M. 2002. 'Leadership in the African context' *verbum et ecclesia* jrg, 23 (3).
- Odusula, A. 2019. Africa's Economic Growth Prospects Amongst the World's Brightest, IPS (Inter Press Service News Agency, viewed in www.ipsnews.net/2018/.../africas-economic-growth-prospects-amongst-worlds-brighte...
- Oguejiofor, P.W.O. 2015. 'The Interrelationships between Western Imperialism and Underdevelopment in Africa', *Arts and Social Sciences Journal*, 6(3),
- Salifu, U. 2010, 'The legacy of colonialism in Africa: Fifty years and counting' viewed in <https://www.polity.org.za/.../the-legacy-of-colonialism-in-africa-fifty-years-and-countin...>
- Schwab, K. 2019. The Fourth Industrial Revolution, by Klaus Schwab, World Economic Forum, viewed in <https://www.weforum.org/about/the-fourth-industrial-revolution-by-klaus-schwab>
- Settle, J.D. 1996 'The Impact of Colonialism on African Economic Development', University of Tennessee Honors Thesis Projects in trace.tennessee.edu/cgi/viewcontent.cgi?article=1182&context=utk_chanhonoproj
- Sichone, O. 2004. New African Social Movements in a Globalising World, in Africa Since 1990, eds, Seleti, Y.N. Ministry of Education, South Africa.
- Thomson, A. 2016. *An Introduction to African Politics*, London and New York: Routledge Taylor & Francis Group.

Chapter 15: L'intégration économique et politique africaine à l'ère du numérique

Loukou Alain François

Maitre de conférences

Université Alassane Ouattara (Bouaké, Côte d'Ivoire)

alain_loukou@hotmail.com

Résumé

Quelle que soit leur nature, les infrastructures physiques de communication (voies routières, ferroviaires, aériennes et maritimes), à côté des actions politiques, ont longtemps été les principaux supports du processus d'intégration économique et politique des États. Depuis le développement fulgurant du numérique à partir du 21^{ème} siècle, les Technologies de l'Information et de la Communication ont massivement infiltré la plupart des activités économiques, commerciales, culturelles, etc. et donc les relations interétatiques. De ce fait, ces nouvelles infrastructures sont devenues des facteurs déterminants du processus d'intégration sur tous les continents. L'Afrique n'est pas en marge de ces évolutions dynamisées par l'écosystème numérique qui se développe relativement vite sur le continent. Dans un tel contexte (ère numérique), cette étude vise à offrir un cadre de réflexion sur un type de modélisation des possibilités d'intégration opérationnelle et fonctionnelle des États africains à travers les Technologies de l'Information et de la Communication. Les résultats obtenus à partir d'une combinaison de sources (littérature scientifique, articles de presse et observations directes) mettent en lumière le fait que les technologies numériques impriment une nouvelle dynamique d'intégration des États africains. Les TIC facilitent aussi bien la dispersion spatiale de certaines activités (activités boursières) que l'inclusion de nombreuses populations dans d'autres types d'activités (services financiers aux particuliers), à l'échelle de vastes régions du continent, qu'elles connectent en temps réel ou en temps légèrement différé.

Mots clés: intégration régionale, mondialisation, TIC, ère numérique, Afrique

African economic and political integration in the digital age

Abstract

Whatever their nature, physical communication infrastructures (road, rail, air and sea), alongside political actions, have long been the mainstays of the states' economic and political integration process. Since the rapid development of the digital world since the 21st century, Information and Communication Technologies have massively infiltrated most economic, commercial, cultural and other activities, etc. and therefore interstate relations. As a result, these new infrastructures have become decisive factors in the integration process on all continents. Africa is not on the fringe of these evolutions driven by the digital ecosystem that is developing relatively quickly on the continent. In such a context (digital age), this study aims to provide a framework for reflection on a type of modeling of the possibilities of operational and functional integration of African States through Information and Communication

Technologies. The results obtained from a combination of sources (scientific literature, press articles and direct observations) highlight the fact that digital technologies are creating a new dynamic of integration of African states. ICTs facilitate the spatial dispersion of certain activities (stock market activities) as well as the inclusion of many populations in other types of activities (financial services to individuals), across large areas of the continent, that they connect in real time or in slightly delayed time

Keywords: regional integration, globalization, ICTs, digital age, Africa

Introduction

Partout dans le monde, de grands blocs politiques et économiques se mettent en place ou se renforcent sans cesse pour ceux qui existent déjà (Union Européenne, Mercosur, ALENA, etc.). L'union faisant la force, l'intégration apparaît ainsi comme une nécessité pour tous les États quelle que soit leur force initiale. Elle l'est davantage pour les États aux économies faibles comme ceux d'Afrique. Le phénomène de mondialisation/globalisation sous-tendu par les Technologies de l'Information et de la Communication (TIC) a rendu les économies encore plus interdépendantes accroissant le besoin d'intégration des États. S'il est admis que la réussite de l'intégration est d'abord liée à une forte volonté politique des dirigeants politiques, il convient aussi de relever qu'elle est opérationnellement tributaire de certaines infrastructures (moyens de transports, électricité, moyens de télécommunications, etc.) qui permettent la mise en connexion physique des États. De ce point de vue, et au regard de l'ère numérique ambiante, les Technologies de l'Information et de la Communication apparaissent comme de nouveaux facteurs clés de l'intégration régionale. L'immersion des individus dans la société de l'information ainsi que la numérisation croissante de la plupart des activités économiques, commerciales et financières ont considérablement modifié les processus, modalités et fonctionnements des rapports interétatiques. Désormais, une grande partie de ces processus et leurs fonctionnements s'accomplissent à travers les réseaux numériques. Ainsi, pour stimuler ou pour accélérer la fluidité des transactions financières et commerciales entre les États, les infrastructures et services numériques sont indispensables. Si une telle dynamique semble évidente, il apparaît, pourtant, que la littérature scientifique est relativement silencieuse ou à tout le moins peu prolixe pour le moment à propos de la relation entre TIC et intégration. Cette articulation est donc faiblement documentée, justifiant des études, telle que celle-ci, en vue de contribuer à un éclairage sur le sujet.

Cet article, qui est essentiellement une contribution théorique, vise donc à montrer, à travers le raisonnement théorique cependant étayé par deux exemples éclairants, le rôle déterminant que peuvent jouer les TIC dans les nouvelles formes d'intégration sous régionale. Dans cette logique, il est structuré en trois parties. La première partie pose la problématique de l'intégration régionale comme une nécessité dans un contexte de mondialisation/globalisation. La deuxième partie montre, d'un point de vue théorique, que les TIC sont fondamentalement au cœur des processus actuels d'intégration. Étant admis que toute hypothèse tire sa validité de l'accord entre la réflexion théorique et l'observation (ou l'expérience, selon le type d'étude), à titre illustratif, la troisième partie est consacrée à deux exemples d'utilisation concrète des TIC dans les formes d'intégration régionale en Afrique. Cette illustration sera faite, d'une part à travers la Bourse Régionale des Valeurs Mobilières (BRVM) et d'autre part à travers les systèmes de transactions financières interétatiques.

En tout état de cause, cet article obéira à une rédaction classique de type introduction, développement, conclusion, suivant les recommandations du Conseil Africain et Malgache de l'Enseignement Supérieur (CAMES) pour une contribution théorique, comme c'est le cas en l'occurrence.

1. L'intégration régionale, une nécessité dans un contexte de mondialisation

1.1. L'intégration, un processus entre idéal de vivre ensemble et nécessité de développement

L'histoire montre que le souci de vivre ensemble, de partager en commun les valeurs de bonne entente, de solidarité et de paix ont toujours constitué un idéal pour les peuples et les nations. Dans cette optique, l'analyse de cette sous-section s'appuiera en grande partie sur les réflexions de certains hauts dirigeants politiques africains dont les décisions et actions déterminent parfois durablement le destin des réalisations africaines.

Dans des contextes politiques, économiques et sécuritaires parfois troubles et récurrents en Afrique, l'approche intégrée est une solution plus que nécessaire, et montre le lien entre paix, sécurité et développement. **L'exemple des ex-AOF (Afrique Occidentale Française) et ex-AEF (Afrique Équatoriale Française)** est révélateur à ces titres. Selon l'ancien secrétaire général de l'Organisation de l'Unité Africaine (OUA) [ancêtre de l'Union Africaine (UA)], Edem Kodjo (2011), ces organisations constituaient un capital qu'il aurait fallu perpétuer. Il estime même qu'il est regrettable que l'indépendance ait été donnée aux États membres et non pas plutôt à ces entités elles-mêmes. Pour lui, la réussite d'alors de ces organisations était liée à une volonté ferme du colonisateur qui avait compris que sans regroupement, certains pays ne survivraient pas.

Qu'on la considère sous l'angle politique ou sous l'angle économique, l'intégration régionale apparaît comme un instrument essentiel pour aider l'Afrique à garantir la paix, à accroître sa compétitivité, à diversifier sa base économique. Toujours selon Edem Kodjo, **contrairement à ce que certains prétendent, l'intégration africaine n'est pas un serpent de mer, c'est-à-dire un projet dont l'aboutissement ne semble jamais arriver. Pour lui, c'est plutôt une mystique (croyance absolue ou divine en quelque chose).** Selon lui, il s'agit de sauvegarder dans l'esprit des générations africaines, actuelles et futures, la conviction que cette mystique finira par se traduire dans les faits; même si le continent est vaste, même si les populations sont diverses, et même si certaines personnes sont tentées de parler de « les Afriques » au lieu de « l'Afrique ». L'important, ajoute-t-il, c'est que cette mystique existe et perdure.

L'intégration est donc une nécessité pour les États africains dans la mesure où elle leur offre la possibilité de faciliter leurs échanges, de combler leur retard de compétitivité, de mutualiser leurs infrastructures, d'investir dans des pôles de croissance, etc. Selon le Rapport 2013 de la Banque mondiale sur la compétitivité de l'Afrique, les progrès réalisés par les économies africaines pour parvenir à la croissance économique doivent s'accompagner d'efforts visant à stimuler leur compétitivité à long terme, si l'on veut que le continent parvienne à des améliorations durables.

Il apparaît toutefois que l'intégration ne se fait pas uniquement par l'économie. Elle a aussi un volet politique. Il semble indispensable de réussir des intégrations politiques régionales avant de rechercher une intégration économique à l'échelle continentale. Ce qui ne semble pas être le cas aujourd'hui sur le continent. En effet, à l'instar de l'intégration européenne, l'intégration des États africains est fortement marquée par l'esprit du choix initial à savoir l'intégration économique évoluant par la suite vers l'intégration politique. Certes, dans une vision économiste, l'économie constitue la principale motivation d'une intégration régionale. Ainsi, selon Dr Ibrahim Assane Mayaki [Secrétaire exécutif du Nouveau Partenariat

pour le Développement de l'Afrique (NEPAD)] (2013), quand on prend des secteurs comme l'énergie, les banques, etc., les meilleures solutions ne se situent pas au niveau national mais régional. Mais, la dimension politique de l'intégration est primordiale pour le volet économique. Dans le cas spécifique de l'Afrique, l'on note que les communautés économiques se sont plus souvent empêtrées dans des questions de règlements de conflits, en oubliant que leur vocation première était la construction d'économies régionales solides.

Pour l'ancien président sénégalais Abdou Diouf (2006), l'Afrique doit aujourd'hui vivre, comme partout ailleurs, à l'heure de ce que l'on appelle la mondialisation. Il estime néanmoins que contrairement à d'autres régions du Sud, l'Afrique demeure mal outillée pour affronter les contraintes auxquelles elle est confrontée et pour profiter des nombreuses opportunités dont elle bénéficie. Une des raisons de cette situation réside, selon lui, dans son extrême fragmentation, dans sa « balkanisation ». De son point de vue, à l'heure où les autres régions du monde s'organisent en espaces intégrés (économiques, géopolitiques ou culturels), l'Afrique semble échapper à cette tendance, même si elle tente désormais de l'infléchir. Pourtant, remarque-t-il, l'intégration présente des avantages certains qui devraient pousser les États africains à tendre plus rapidement vers ce processus.

1.2. L'intégration régionale, un processus avantageux pour l'Afrique

L'intégration présente de nombreux avantages en termes de compétitivité, de facilitation des échanges, de mutualisation d'infrastructures, d'investissements communs dans les pôles de croissance économique, etc. Les efforts de développement qu'entreprennent les États africains devraient donc obéir à une logique d'intégration.

Comblant le retard de compétitivité

Les experts en développement sont unanimes pour dire que la compétitivité de l'Afrique dans son ensemble est à la traîne par rapport à celle des régions émergentes. Surtout s'agissant de la qualité des institutions, des infrastructures, des politiques macro-économiques, de l'éducation et de l'adoption de technologies innovantes. De larges écarts sont observés entre les économies les mieux classées du continent (Maghreb, Afrique du sud, Maurice) et celles qui arrivent en queue de peloton (la plupart des pays au sud du Sahara).

Faciliter les échanges

Le constat est que les exportations africaines restent encore trop fortement axées sur les produits de base (certes abondants); de sorte que la part du continent dans les échanges mondiaux reste très faible (3% en 2014, selon l'OMC). Malgré l'existence de nombreuses communautés économiques et politiques régionales (CEDEAO, CEMAC, EAC, SADC, UMA, etc.)², les échanges intra-africains sont particulièrement limités. Le rapport de la Banque mondiale, cité plus haut, identifie une série de carences systémiques : une administration frontalière lourde et opaque, en particulier pour les procédures d'import-export, l'utilisation encore limitée des Technologies de l'Information et de la Communication (TIC) dans les échanges ainsi que, plus largement, des déficits persistants en matière d'infrastructures de tous types comme étant les principaux obstacles à des niveaux d'intégration régionale plus poussés. Il montre également que ces défis sont particulièrement prononcés pour les économies africaines enclavées.

Mettre en place de meilleures infrastructures à travers une politique de mutualisation

Le déficit de l'Afrique en matière d'infrastructures de qualité constitue une grave entrave à l'intégration régionale. Tous les secteurs sont concernés : transports, santé, éducation, énergie,

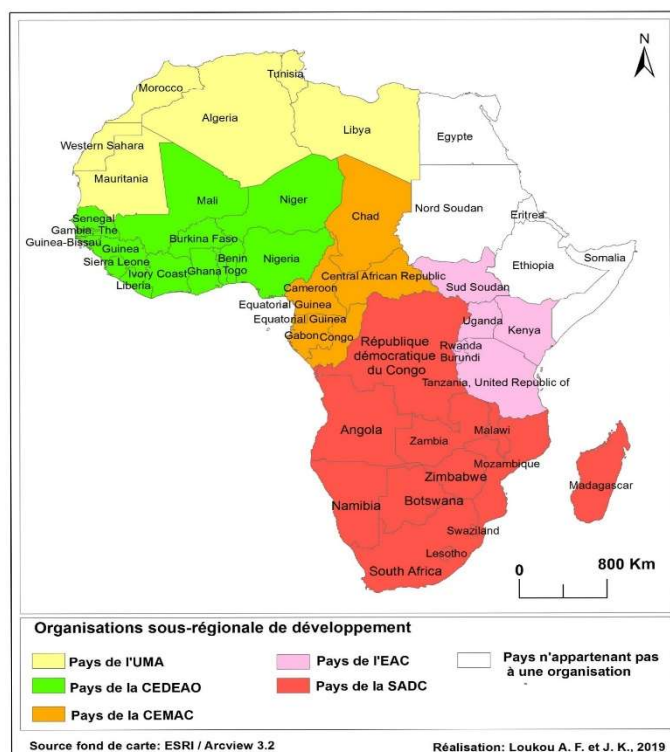
² Ces sigles ou acronymes signifient respectivement Communauté Économique des États de l'Afrique de l'Ouest ; Communauté Économique et Monétaire d'Afrique Centrale ; East African Community ; Southern African Development Community ; Union du Maghreb Arabe.

etc. Cette situation est davantage accentuée par la croissance de la population, des marchés de consommation et par l'urbanisation galopante. Les experts en développement estiment que la mise en place d'infrastructures suffisantes et efficaces, à travers une bonne politique de mutualisation, aiderait les économies africaines à accroître la productivité relative à la fabrication de biens et la fourniture de services; contribuerait à améliorer la santé et l'éducation et aiderait à assurer une distribution plus équitable des richesses nationales. Le rapport examine la manière dont les progrès de l'énergie, des transports et des TIC peuvent être déployés afin de maximiser les avantages de l'intégration régionale.

Investir dans des secteurs de croissance

Sont actuellement considérés comme secteurs de croissance, l'énergie, les services financiers, les transports, les télécommunications et l'informatique. Ces secteurs constituent des vecteurs importants pour consolider la capacité productive et stimuler l'intégration régionale en attirant des investissements et en facilitant les communications. Il convient donc d'examiner la manière de déployer, dans ces différents domaines, de bonnes pratiques communautaires afin de fournir de plus grands avantages à l'ensemble du continent. Les efforts d'intégration régionale qu'entreprennent les États africains doivent par ailleurs obéir à la logique de mondialisation/globalisation qui gouverne le mode de fonctionnement contemporain des activités.

Figure 15.1 : Carte des Communautés Économiques Régionales (CER) d'Afrique



1.3. La mondialisation rend l'intégration sous régionale encore plus indispensable

Cette section vise à développer une analyse critique des rapports dialectiques entre les emboitements spatiaux que représentent l'intégration régionale et la mondialisation.

Depuis quelques décennies, les États, les continents évoluent dans un contexte de bouleversement de l'économie et de la société à l'échelle mondiale, communément désigné par

le terme mondialisation. Ce phénomène éminemment géographique et dont beaucoup de disciplines se font aujourd'hui l'écho, n'est pas en soi quelque chose de nouveau. Entendu au sens d'extension spatiale de processus socioéconomiques divers, ce phénomène existe depuis fort longtemps. Les entités géographiques, petites et moyennes, fondent leur existence scalaire dans un vaste ensemble géographique mondial, en l'occurrence la mondialisation.

La médiatisation de ce phénomène au cours des dernières décennies, qui l'a fait accaparer par tous (universitaires, hommes politiques, diplomates, journalistes, etc.), semble être directement liée à l'avènement des Technologies de l'Information et de la Communication (TIC) qui structurent les activités modernes. Quand la mondialisation est animée et accélérée par les Technologies de l'Information et de la Communication elle devient globalisation.

La mondialisation/globalisation correspond à une dynamique et à un processus qui conduisent vers un monde nouveau, inédit et plus intégrateur, différent de celui qui était connu auparavant. Elle correspond surtout à une échelle spatiale mondialisée des différents phénomènes (économiques, politiques, culturels, scientifiques, sportifs, etc.). De ce point de vue, la mondialisation/globalisation rend l'intégration indispensable dans la mesure où pour appartenir avec plus de réussite au système mondialisé et globalisé, les entités géographiques, politiques et économiques doivent passer par l'intégration. L'intégration devient donc une étape pour aller vers la mondialisation/globalisation. La formalisation conceptuelle de la dynamique entre le régional et le global, développée ici, permet de mieux proposer, plus loin, des outils opératoires de l'intégration des États telle qu'envisagée.

La croissance de l'Afrique doit être replacée dans le contexte international plus large (la mondialisation/globalisation), où les gains encourageants dans la croissance économique contrebalancent la faiblesse sous-jacente de sa compétitivité à long terme. L'intégration régionale est la clef qui permet de remédier à cette faiblesse en apportant des avantages économiques et sociaux plus larges. De ce point de vue, elle est à considérer comme une priorité par les dirigeants africains.

Au total, il apparaît que l'intégration régionale est un instrument essentiel pour aider l'Afrique à s'insérer dans la mondialisation/globalisation en vue d'accroître sa compétitivité, de diversifier sa base économique. Dans cette optique, il apparaît que les efforts d'intégration régionale resteraient vains si les pays africains ne deviennent pas partie prenante à l'économie mondiale à rythme rapide et sans cesse accéléré par les technologies numériques.

Les TIC, des outils au cœur des processus actuels d'intégration

2.1. Les TIC sont un facteur indispensable de l'intégration à l'ère du numérique

Pour stimuler la fluidité des transactions économiques et commerciales entre les États africains, les infrastructures, quelle que soit leur nature, sont indispensables. Dans les économies qui se numérisent de plus en plus, les infrastructures de TIC sont dès lors un facteur incontournable.

L'intégration, qu'elle soit régionale, continentale ou globale est une des modalités de la construction du processus de développement. Elle implique des adaptations fonctionnelles au gré des évolutions contextuelles de nature politique, économique ou technologique. À l'heure où le numérique structure profondément la plupart des activités humaines, l'intégration ne peut se faire efficacement et durablement sans infrastructures de TIC nécessaires pour soutenir cette intégration. En effet, indépendamment de ses dimensions politique et économique qui la fondent, l'intégration obéit à des règles opérationnelles de fonctionnement consistant à mettre en connexion permanente des entités géographiques, économiques et politiques parfois éloignées ou dispersées sur de vastes étendues spatiales. Pendant longtemps, la plupart des pratiques ou politiques d'intégration en Afrique ont ignoré (peut-être inconsciemment) la dimension TIC. Aujourd'hui, en raison du contexte de la société et de

l'économie de l'information, les Technologies de l'Information et de la Communication sont incontournables dans les projets et les processus d'intégration entre les États. Ainsi, la dimension TIC de l'intégration figure au nombre des trois principales conditions fixées par le Rapport VI de la Commission Économique des Nations Unies pour l'Afrique sur l'état de l'intégration régionale en Afrique (2013). Ces trois principales conditions préalables à remplir pour ouvrir la voie à un marché continental sont : a) les règles d'origine; b) les instruments de facilitation du commerce; c) les liaisons transfrontalières dans le domaine des Technologies de l'Information et de la Communication. Concernant précisément le volet TIC-intégration, ledit rapport mentionne que l'informatique a le pouvoir de révolutionner l'économie en Afrique, en stimulant l'esprit d'entreprise, le commerce, l'innovation et la croissance économique.

L'intégration régionale est une étape mécanique et fonctionnelle vers la mondialisation puis vers la globalisation, cette dernière étant une évolution du système économique et social mondial tel qu'il existait. Cette évolution est caractérisée par l'intrusion des Technologies de l'Information et de la Communication dans les différentes activités humaines quelles qu'elles soient. Dans cette optique, les Technologies de l'Information et des Communications jouent un rôle majeur dans le développement de l'intégration puis de la mondialisation qui devient globalisation. Ce rôle des TIC s'observe à travers l'influence forte des progrès technologiques sur les facteurs de production; la croissance plus dans les secteurs qui utilisent efficacement les TIC ; la part de plus en plus grande jouée par l'information dans l'économie ; les facilités offertes par la technologie pour délocaliser les activités; les possibilités de piloter au plus près des activités pourtant éloignées; l'accès généralisé à un monde commun et unificateur à savoir la galaxie de l'Internet en perpétuelle expansion.

Dans son livre « *The world is flat* », Thomas Friedman (2006) souligne le rôle essentiel joué par les TIC dans le processus de mondialisation. Il montre par exemple qu'à Schentzen (Chine), à Séoul (Corée du Sud) ou à Bangalore (Inde), les sociétés, grandes ou moyennes, ne se reposent pas sur leurs avantages salariaux, mais implémentent aussi des systèmes intégrés de télématique de gestion pour la performance de leurs activités partout dans le monde où elles sont représentées. Pour faire face au défi de l'intégration, de la mondialisation et de la globalisation, souplesse et innovation dans les processus sont indispensables. Les TIC sont des moyens efficaces pour affronter ces défis. Ce sont par ailleurs de véritables accélérateurs de processus de mise en relation à distance et donc de regroupement d'entités géoéconomiques dispersées.

2.2. Les TIC sont des accélérateurs de processus régionaux conduisant aux processus globaux

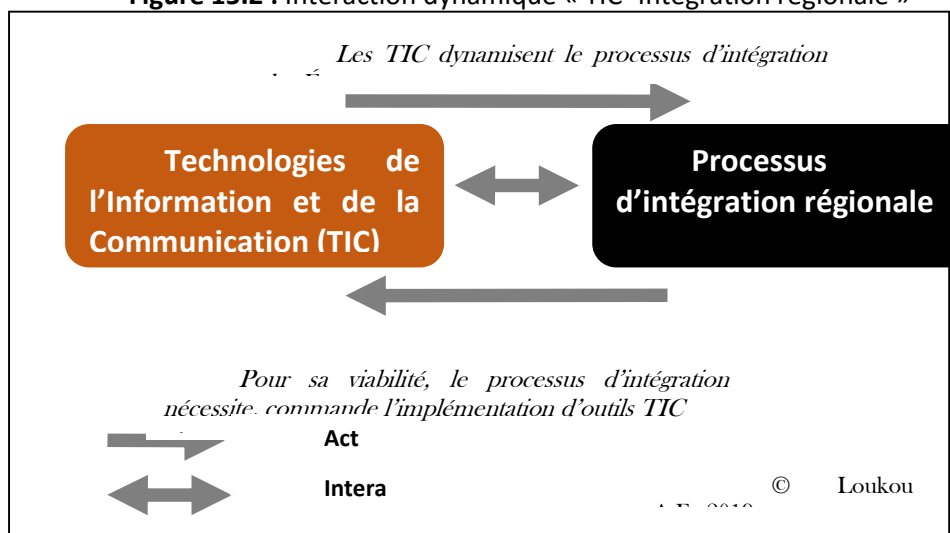
Dans la société de l'information qui se développe partout et à grande vitesse, les TIC apparaissent comme de formidables accélérateurs des processus régionaux et globaux, permettant ainsi de répondre aux exigences de l'intégration des États et de la mondialisation.

À l'ère numérique, les TIC jouent un rôle majeur dans les transitions d'échelles géoéconomiques consistant à passer du local au national, au régional puis au global. Elles jouent davantage un rôle dans l'articulation de ces échelles à travers la formule « *think global and act local* » (penser global et agir local). Façonnant le mode d'organisation des activités, les Technologies de l'Information et de la Communication imposent de nouveaux modèles de regroupement et de développement tant à l'échelle locale qu'à l'échelle globale. De sorte que les notions de global, de régional, de national et de local ainsi que leurs articulations fonctionnelles respectives apparaissent dorénavant indissociables de ces TIC. L'action des TIC dans les processus s'opère de multiples façons : par la réduction exponentielle des coûts de communication entre les États, par la part de plus en plus grande jouée par l'information dans

l'économie et les échanges, par leurs effets structurants de plus en plus déterminants. De ces points de vue, parce qu'elles animent les échanges dans la course accélérée du monde, les TIC apparaissent comme un moyen idéal pour permettre à l'Afrique de mieux faire face aux défis et enjeux de la globalisation et briser sa marginalisation. En effet, comparativement aux secteurs des infrastructures classiques de transport où l'Afrique est beaucoup sous équipée, le jeune secteur des TIC est quant à lui relativement bien développé sur l'ensemble du continent en dépit de l'existence d'une fracture numérique évidente avec les autres continents. Aujourd'hui, avec le téléphone mobile cellulaire ou avec l'Internet, l'on peut communiquer rapidement, pour différents motifs (économiques ou sociaux), entre les États et avec le reste du monde, même de certaines zones rurales reculées de l'Afrique. Ces instruments de communication électronique ont la capacité intrinsèque d'accélérer l'intégration des États. Dans ces conditions, qu'il s'agisse de transactions de flux immatériels ou même de flux matériels au sein des regroupements régionaux ou avec le reste du monde, les TIC sont aujourd'hui l'instrument privilégié pour la gestion, la coordination et le suivi des échanges internationaux.

L'importance structurante et opérationnelle des TIC dans les activités économiques et sociales ne se limite pas seulement à leur capacité inédite à modifier sans cesse les modalités et le fonctionnement des processus d'intégration. Elle s'étend aussi à des mesures parfois non encore prévisibles qui confirment leur prégnance continue dans le fonctionnement globalisé des échanges entre les humains. Il est donc impératif que la planification des projets d'infrastructures, tant nationaux que régionaux, prenne en compte le volet TIC, car il est admis que l'intégration est dynamique et durable lorsqu'il existe un développement significatif des infrastructures matérielles d'intégration. Dès lors, cette idée montre comment l'intégration elle-même mobilise en retour les outils TIC dans son processus, mettant en évidence l'interaction dynamique entre les deux types d'éléments.

Figure 15.2 : Interaction dynamique « TIC- Intégration régionale »



Le raisonnement théorique à lui seul n'étant jamais suffisant pour convaincre, nous allons illustrer notre réflexion par deux exemples concrets traduisant le rôle des TIC dans les processus d'intégration régionale en Afrique. Il s'agit, d'une part, de la Bourse Régionale des Valeurs Mobilières (BRVM) et de l'autre, des Systèmes de Transfert Électronique Monétaires (STEM).

1) 3. La Bourse Régionale des Valeurs Mobilières (BRVM) de l'UEMOA et les Systèmes de Transferts Électroniques Monétaires (STEM) : deux modèles d'intégration par les TIC en Afrique de l'Ouest

Le développement des réseaux et systèmes numériques de communications électroniques, notamment l'Internet et la téléphonie mobile, a eu des implications remarquables dans les activités financières en Afrique. Dans l'espace géographique et économique UEMOA (Union Économique et Monétaire Ouest Africaine), tout particulièrement, à travers la Bourse Régionale des Valeurs Mobilières et les activités de transfert d'argent, les outils numériques contribuent au renforcement des relations d'intégration entre les États.

3.1. La Bourse Régionale des Valeurs Mobilières (BRVM) de l'UEMOA : un exemple d'intégration financière en Afrique de l'ouest par les TIC

La Bourse Régionale des Valeurs Mobilières de l'UEMOA est une institution financière sous régionale. Par son modèle de fonctionnement en réseau, elle offre un exemple concret et unique des possibilités d'intégration fonctionnelle de plusieurs États grâce aux Technologies de l'Information et de la Communication qui permettent la dispersion spatiale d'activités boursières au sein d'une union économique.

Bourse des temps modernes, la BRVM n'a pas connu les modes traditionnels de cotation telles que les cotations à la criée ou autres. Elle est directement entrée dans l'ère de la cotation dite électronique, avec les réseaux informatiques et de télécommunications modernes desquels dépendent le fonctionnement et l'efficacité de ce type de cotation, voire la performance même des Bourses modernes.

La BRVM est un instrument essentiel d'intégration et de développement des huit (08) pays membres de l'espace UEMOA. En tant qu'élément de l'arsenal d'intégration politique et économique de cette union économique, la BRVM doit son fonctionnement voire sa viabilité aux Technologies de l'Information et de la Communication qui garantissent l'équité des cotations entre les pays membres à travers un processus d'émission/réception, en temps réel, des flux de données des séances de bourse. La cotation électronique décentralisée qui en est la modalité assure la viabilité des activités de la BRVM et le principe d'intégration de l'institution.

Les progrès technologiques réalisés dans le domaine des réseaux informatiques et de télécommunications ont permis à l'UEMOA d'honorer un engagement politique historique³ et de passer d'une Bourse nationale (Bourse des Valeurs d'Abidjan) à une Bourse régionale, avec tous les avantages qui se rattachent à ce changement de statut et de taille. En effet, la viabilité, la rentabilité et la compétitivité d'une Bourse dans cette zone aux économies de petite taille sont conditionnées par cette espèce de collectivisme économique. Ce système de copropriété, en permettant la mutualisation des moyens (financiers et techniques) et des risques, favorise l'effet de taille, les économies d'échelle et la compétitivité avec les autres places boursières du continent. Par ce regroupement rendu possible grâce aux outils de télématique, la BRVM est

³ C'est en 1973 qu'a été prise l'initiative de fonder une place boursière commune au sein de l'UEMOA. La décision politique devrait cependant être accompagnée de solutions techniques pour la réalisation effective du projet dans un vaste espace géoéconomique de près de 4 millions de km². C'est l'avènement des Technologies de l'Information et de la Communication qui a enfin permis, en 1999, la mise en œuvre de ce projet d'intégration régionale qu'est la Bourse Régionale des Valeurs Mobilières dont le siège est à Abidjan, en Côte d'Ivoire.

devenue l'un des marchés boursiers les plus innovants⁴ et les plus dynamiques de toute l'Afrique.

Au-delà de la bourse des valeurs mobilières, un modèle d'intégration plus simple, plus large et plus inclusive, par les outils numériques, est celui des systèmes électroniques de transferts monétaires.

3.2. Les Systèmes de Transferts Électroniques Monétaires classiques et les paiements *via* téléphones mobiles : un exemple d'inclusion financière et d'intégration économique par les technologies numériques

Initiée par la firme américaine Western Union, leader mondial du transfert de fonds transfrontaliers, l'activité de transfert non physique d'argent a connu un boom spectaculaire avec le développement des réseaux télématiques (l'Internet et la téléphonie mobile) dans les pays en développement. La combinaison des différents types de procédures sollicitées, a eu un impact considérable sur la fourniture de services financiers entre les États, permettant une forme d'inclusion financière et d'intégration entre les États.

En Afrique où le taux de bancarisation moyen est encore très faible (15,7% en 2017, selon Rémy Darras de l'hebdomadaire Jeune Afrique), et où par ailleurs les services postaux sont défaillants et peu adaptés aux besoins nouveaux des clients, les activités de transferts électroniques monétaires (qu'elles soient le fait des entreprises spécialisées ou celui d'opérateurs de téléphonie) représentent une solution idéale aux besoins de services financiers des populations, en termes d'envois et de réceptions d'argent. Partout sur le continent (dans les zones rurales comme dans les zones urbaines), l'on a de plus en plus facilement accès à ce type de services financiers en cas de besoin. De ce fait, ils ont non seulement un impact social important (en termes d'inclusion financière⁵) mais en plus ils constituent un facteur appréciable d'intégration financière et économique entre les États. L'offre récente d'internationalisation des solutions de transferts d'argent et de paiements mobiles par certains opérateurs de téléphonie vient renforcer le vaste réseau existant des entreprises spécialisées (Western Union, Money Gram et autres). Préalablement réduits à des transferts/réceptions intra-nationaux, les services de transferts mobiles ont depuis peu commencé à s'internationaliser au grand bonheur notamment des travailleurs immigrés qui ont désormais la possibilité de faire plus facilement des transactions financières vers leurs pays d'origine par les canaux mobiles beaucoup plus répandus. De façon générale, peu ou pas bancarisées, les populations africaines recourent à ces services de transactions financières d'une souplesse technique et commerciale exceptionnelle. Ainsi, avec les technologies numériques et le paiement mobile, une partie croissante de la population africaine s'intègre dans le circuit financier moderne, soulignant le pouvoir d'inclusion et d'intégration de ces technologies.

⁴ Lors du 9ème Forum sur l'Investissement en Afrique organisé par Africa Investor, le 19 septembre 2016 à New York, la Bourse Régionale des Valeurs Mobilières de l'UEMOA a été désignée, pour l'année 2016, la Bourse la plus innovante en Afrique devant notamment celles d'Afrique du Sud, du Nigéria et d'Égypte.

⁵ L'inclusion financière est généralement définie comme étant l'accès aux services financiers, à moindre coût, des populations exclues du système bancaire. Ces populations comprennent aussi bien celles des zones urbaines que celles des zones rurales. Littéralement, l'inclusion financière vise donc à inclure au sein du système financier les populations marginalisées. Elle peut s'opérer à travers diverses sortes de mécanismes et modalités (innovations technologiques, décentralisation des services existants, création de nouveaux services, octrois de facilités).

Il convient de relever qu'à l'analyse, il apparaît que les activités de transferts monétaires classiques (opérées par les entreprises spécialisées telles que Western Union, Money Gram et autres) ainsi que le *mobile money* (par les opérateurs de téléphonie mobile) sont davantage des innovations technologiques que financières. Depuis leurs origines, les activités financières de Western Union et de Money Gram se sont toujours appuyées sur des infrastructures télématiques qui fondent leur modèle économique et leur existence commerciale (réseaux dédiés et téléphones au départ puis ordinateurs et Internet de nos jours). De même, le *mobile money*, n'est pas, en réalité, un produit financier, mais plutôt un canal innovant de distribution de services financiers à travers un outil numérique, le téléphone portable. En tout état de cause, les services financiers, nationaux ou internationaux, fournis par les entreprises spécialisées ou par les opérateurs de téléphonie ne sont possibles que grâce aux Technologies de l'Information et de la Communication.

Conclusion

L'intégration régionale en Afrique continue à occuper une place centrale dans les tentatives des dirigeants africains de parvenir à un développement socioéconomique intégré. À cet égard, il existe plusieurs communautés économiques régionales (CER) fonctionnelles susceptibles d'être des éléments constitutifs de la future communauté économique africaine élargie. Certes, tous les États africains ne sont pas encore disposés à consentir les abandons de souveraineté nationale indispensables à la mise en œuvre efficace de l'intégration à l'échelle continentale. Mais peu ou prou, ils sont condamnés à l'intégration. Face à la mondialisation sous tous ses aspects et surtout au regard de la faiblesse de leurs économies, l'intégration régionale apparaît comme une nécessité absolue pour les pays africains.

À l'ère du numérique, les stratégies régionales d'intégration ont peu de chance d'être réellement dynamiques si elles ne prennent pas en compte la dimension Technologies de l'Information et de la Communication. Ces outils numériques permettent la mise en relation plus rapide des États. En effet, les équipements et les services de TIC sont non seulement indispensables au fonctionnement des activités des entreprises, des administrations et des individus, mais ils permettent également la mise en relation des différents États appelés à fonctionner davantage dans un mode d'interaction, d'interdépendance compte tenu de la mondialisation qui régit les activités de notre époque.

Introduire des changements dans les façons de faire le développement a souvent constitué un obstacle en Afrique. Dans un tel contexte, théoriser ou faire l'hypothèse sur le pouvoir intégrateur des Technologies de l'Information et de la Communication peut sembler un exercice intellectuel improbable là où les modalités conventionnelles d'intégration ont donné des résultats très mitigés. Mais, le monde change vite et avec lui les voies et modèles de développement et donc d'intégration. Dans la société de l'information et l'économie numérique, les Technologies de l'Information et de la Communication constituent de nouveaux facteurs d'intégration régionale et d'insertion dans la mondialisation comme l'ont montré les deux exemples en appui de la théorisation.

Si le recours intensif aux outils numériques dans le fonctionnement de l'institution communautaire qu'est la BRVM ainsi que dans les activités de transfert d'argent répond à première vue à des nécessités de facilitation des opérations de cotation ou de services financiers à la clientèle, il répond aussi, directement ou indirectement aux enjeux politiques et économiques de l'intégration régionale que facilitent ces outils. L'intégration régionale présente en effet la meilleure perspective de développement des pays africains. Les technologies numériques, par leur souplesse inédite, y contribueront de plus en plus, car jusqu'ici l'intégration a été souvent ralentie, dans la pratique, par la carence caractéristique des

moyens classiques de communication sur le continent (routes, chemins de fer, voies aériennes, dont les mises en œuvre sont souvent difficiles, longues et trop coûteuses).

Bibliographie

- Banque mondiale 2013. L'intégration régionale est la clef de l'avenir de la compétitivité de l'Afrique, <http://www.banquemondiale.org/fr/news/press-release/2013/05/09/regional-integration-key-to-africa-s-future-competitiveness>
- Bonjawo Jacques 2002. Internet, une chance pour l'Afrique, Karthala, Paris.
- Bourse Régionale des Valeurs Mobilières (BRVM) : (<http://www.brvm.org>)
- Chéneau-Loquay Annie 2004, Mondialisation et technologie de la communication en Afrique, Karthala, Paris, 322 p.
- Cockborne M.-A. 1976, Guide commenté de la bourse et des valeurs mobilières, Éditions de Vecchia, Paris.
- Cohen Daniel 2004, La mondialisation et ses ennemis, Grasset, Paris.
- Darras Rémy 2017, « Bancarisation : la rentabilité ne se mesure pas à court terme », www.jeuneafrique.com document consulté le 12 avril 2019
- Desbarrières N. 2001, La bourse et ses back-offices, Economica, 3ème édition, Paris.
- Deschanel J.-P. et Gizard B. 1999, À la découverte du monde de la Bourse. Manuel d'économie boursière, Presses Universitaires de France, Collection Major, Paris.
- Dicken Peter 2003, Global shift: reshaping the global economic map in the XXIst century, Sage Publications, 4th edition, London
- Diouf Abdou 2006. « Afrique : l'intégration régionale face à la mondialisation. », Politique étrangère 4/2006 (Hiver) p. 785-797
URL : www.cairn.info/revue-politique-etrangere-2006-4-page-785.htm.
DOI : 10.3917/pe.064.0785.
- Friedman Thomas 2006. La terre est plate. Une brève histoire du XXIème siècle, Éditions Saint-Simon (pour la traduction française)
- Ibi Ajayi 2001, La mondialisation et l'Afrique. Comment l'Afrique peut bénéficier de la mondialisation, in Finances et développement, décembre 2001 sur <http://www.imf.org/external/pubs/ft/fandd/fre/2001/12/pdf/ajayi.pdf>, page consultée le 18-08-2014
- Ki-zerbo Joseph 2003, A quand l'Afrique ?, Paris, Editions de l'Aube
- Kodjo Edem 2011, L'intégration africaine, entre espoir et utopie, <http://www.jeuneafrique.com/191412/politique/l-int-gration-africaine-entre-espoir-et-utopie/>
- Loukou Alain François 2016, « Les enjeux sociaux et géographiques des banques numériques en Côte d'Ivoire », in Revue Échanges, Université de Lomé, Togo, vol. 2, n°006 juin 2016, pp. 501-514.
- Loukou Alain François 2015 « Le développement des Technologies de l'Information et de la Communication (TIC) en Côte d'Ivoire face aux contraintes d'énergie électrique », in ANYASA, Revue des Lettres et Sciences Humaines, Laboratoire de Recherche sur la Dynamique des Milieux et des Sociétés, Université de Lomé, no 3, juin 2015, pp. 36-51.
- Loukou Alain François 2015, « Les Technologies de l'Information et de la Communication (TIC) et l'insertion efficace de l'Afrique dans la mondialisation/globalisation », in Revue de Géographie du Laboratoire Leïdi (RGLL) Sénégal, n°13, décembre 2015, pp. 1-17.
- Loukou Alain François 2014 « Sous-information et sous-développement en Afrique.

- Eléments de recherche corrélacionnelle », in Revue Afrique et développement du Conseil pour le Développement de la Recherche en Sciences Sociales en Afrique (CODESRIA), Vol. XXXIX, No. 2, 2014, pp. 69-91.
- Loukou Alain François 2012, « L'aménagement numérique des territoires : une exigence nouvelle du développement encore ignorée en Afrique », in actes du colloque Villes et territoires numériques. Sociétés de l'information, sociétés de la connaissance : le rôle des collectivités locales», Centre National de Recherche Scientifique (CNRS), Paris, 6-7 février 2012, pp.132-145, [en ligne] <http://opst.iut-tlse3.fr/territoires/colloques-seminaires/>
- Loukou Alain François. 2011, « Les Technologies de l'Information et de la Communication (TIC) au service du développement en Afrique. Simple slogan, illusion ou réalité ? », in Revue électronique TIC et société, Vol. 5, n°2-3 (2e sem. 2011 / 1er sem. 2012), Les TICs dans les pays des Suds, pp.49-67 <http://ticetsociete.revues.org/1047>
- Loukou Alain François 2005, Télécommunications et développement en Côte d'Ivoire à l'ère de la société de l'information et de la mondialisation, thèse de doctorat, Université Montpellier 3.
- Maged Abdelaziz et Ibrahim Mayaki 2013, Une vision de l'intégration africaine, in Afrique Renouveau: <http://www.un.org/africarenewal/fr/magazine/d%C3%A9cembre-2013/une-vision-de-l%E2%80%99int%C3%A9gration-africaine>.
- McLuhan H. Marshall & Powers R. Bruce 1989, The Global Village, Transformations in World Life and Media in the 21th Century, Oxford University Press, New-York
- Mehdi Rais 2013, Union africaine: Les raisons de l'échec de l'intégration en Afrique, http://www.huffpostmaghreb.com/mehdi-raais/union-africaine-les-raiso_b_4411349.html
- Nations Unies, Union Africaine, Banque Africaine de Développement (2013, Harmonisation des politiques visant à transformer l'environnement commercial État de l'intégration régionale en Afrique VI (p.47-p.68).
- Organisation Mondiale du Commerce (OMC), <http://www.wto.org/indexfr.htm>
- Ossama François 2001, Les nouvelles technologies de l'information. Enjeux pour l'Afrique subsaharienne, L'Harmattan, Paris.
- Paulet Jean-Pierre 1998, Les régions à l'heure de la mondialisation, A. Colin, Paris.
- Picon Olivier 1998, La Bourse. Comment gérer son portefeuille, 13ème édition, Éd. Dalloz, Paris.
- Sadin Éric 2013, L'humanité augmentée. L'administration numérique du monde, Éditions L'échappée, Montreuil
- Samir Amin 1996, Les défis de la mondialisation, L'Harmattan, Paris, Montréal
- Sylla Aly 2012, L'intégration africaine en question, <http://gereaphilo.over-blog.com/article-l-integration-africaine-en-question-i-108125860.html>
- Tévoédjré Albert. 1978, La pauvreté, richesse des peuples, Éditions économie et humanisme, Paris
- Thiam Papa Demba 1991, Stratégies d'interface Intégration économique et développement, Éditions scientifiques européennes, Berne
- Traoré Djénéba 2015, Le rôle des TIC dans l'intégration régionale et le développement économique en Afrique de l'Ouest, https://www.researchgate.net/publication/281273478_Le_Role_des_TIC_dans_l'Integration_Regionale_et_le_Developpement_Economique_en_Afrique_de_l'Ouest.

Section E: Rural development

Chapter 16: Nutritional composition and sensory acceptability of cowpea wheat biscuits by rural youth in KwaZulu-Natal

T.P. Kheswa¹, M. Siwela², U. Kolanisi¹, N. Ngobese³ and S. Zulu¹

¹Department of Consumer Sciences, University of Zululand,
P/Bag X1001, KwaDlangezwa, KwaZulu -Natal, South Africa

²School of Agricultural, Earth and Environmental Sciences,
University of KwaZulu-Natal, Pietermaritzburg, South Africa.

³Department of Botany and Plant Biotechnology, University of Johannesburg,
PO Box 524, Auckland Park, Gauteng, South Africa.

Abstract

Cowpea (Vigna unguiculata) is an underutilised African legume with limited utilisation in South Africa. The aim of the study was to determine the nutritional composition and consumer acceptability to the rural youth in KwaZulu-Natal (KZN) of biscuits made from indigenous or hybrid cowpea flour blends. For biscuit preparation, flour blends are made from commercial wheat and cowpea obtained from two rural communities in KZN. Formulations tested were: 0% cowpea (control); 10% hybrid/indigenous; 20% hybrid/indigenous variety. The color and texture, spread ratio of the resulting biscuits were instrumentally measured and consumer acceptability was determined by 61 rural youth panelists. The biscuits progressively darkened with increased proportions of cowpea.

Biscuit samples of the control were the lightest (L^ 72.37) in color, followed by the samples with 20% cowpea (L^* 62.71), then with 10% cowpea varieties (L^* 60.71 and 61.47). The softest biscuits, which required the least force (51.31 N) to shear were of the control. Biscuits incorporating cowpea were harder, requiring more force to shear. The panelists found the 10% cowpea biscuits as acceptable as those of the control with respect to colour, crispness, taste and overall acceptability. The 20% cowpea biscuits received lower scores for colour, taste and crispness because they were harder instead of crunchy in texture. Biscuits produced from the wheat/cowpea blends had increased macro- and micronutrient levels compared to the control wheat biscuits. The results of this study suggest that supplementation of wheat flour with 10% cowpea could produce acceptable biscuits with a potential to alleviate food insecurity challenges in rural communities.*

Keywords: youth, cowpea, biscuit, nutrient composition, sensory evaluation

Introduction

It is projected that by 2050 the total world population will reach 9.8 billion people, which implies a growing demand for food (The World Bank, 2016). At the same time, there are emerging concerns about unhealthy eating patterns stemming from poor awareness of nutrition and food choices, and food security challenges related to climate change (FAO, 2014). In South Africa (SA), food insecurity affects one in five households, many of which are located in rural communities (Govender *et al.* 2017). Studies indicate that there is no improvement in the hunger situation in SA (Ntwenya *et al.* 2015; Ngema *et al.* 2018).

The proper use of indigenous knowledge (IK) as a locally owned and managed resource, is a cost-effective survival strategy for empowering local communities and increasing the sustainability of food security efforts (Gorjestani, 2000; Shiuan-Huei Wu, *et al.* 2014). The utilisation of vegetable protein is gaining increasing attention due to the world need for low-cost options, particularly for low-income countries (Wang, Lewi qp, Brennan and Westby, 1997; Akpalu, Salaam, Oppong-Sekyere and Akpalu, 2000).

Cowpea (*Vigna unguiculata*) is a warm-season African legume, that is underutilised. It is an important source of vegetable protein (Rufina, 2016; Hama-Ba, Siedogo, Ouedraogo, Dao, Dicko, Diawara, 2017). The crop has not received much attention in the country and available information is fragmented. The majority of studies done on cowpea in South Africa are based on agricultural production, highlighting the performance of breeding lines, disease management and storage constraints (Asiwe, 2009; Dzemo, Niba and Asiwe 2010). Mathews (2010) identified cowpea among traditional legumes in Mpumalanga Province, Anyango *et al.* (2011) evaluated the functional quality of cowpea-fortified traditional sorghum foods and Asiwe (2009) investigated household cowpea processing in KZN. Little consideration has been given to the potential of cowpea in value addition. Cowpea utilisation is limited by its long cooking-time requirements, few known dishes, susceptibility to disease and pest attack during growth and storage and negative consumer perceptions as a traditional food (Mathew, 2010; Odedeji and Oyeleke, 2011; Ebert, 2014; FAO, 2014; Olapade and Odeyemo, 2014). While the negative perceptions of traditional foods are changeable, such foods are considered a cultural delicacy and are served to visitors on special occasions (Mnguni and Giampiccolli, 2015), and there is a need to promote their utilisation. Addressing such a need should be linked to improving the preservation practices of traditional legumes and extending their shelf life to ensure long-term availability to consumers.

Flour is a popular storage product, which allows for the incorporation of crops into different recipes. Development of new flours can promote the integration of traditional crops into the mainstream food industry and increase the nutritional options available (Olapade and Odeyemo, 2014).

Biscuits are a convenient flour-based product that has been consumed by humans for centuries. They are consumed before, after and in-between meals and are accepted by most people and command a broad popularity in both urban and rural communities. Reasons for their popularity include affordability, long shelf life and diversity of recipes compared to other baked products' energy (McWatters, 2003; Ullah *et al.* 2016). Although consumption of biscuits is high, most recipes rely on wheat flour for biscuit preparation and the inferior nutritional quality of wheat flour has been an important concern associated with its utilisation. The refined wheat flour used in biscuit preparation is deficient in several nutrients, including dietary fiber, minerals and vitamins (Ullah *et al.* 2016). Legumes can improve the quality of cereal protein by supplementing it with limiting amino acids such as lysine, tryptophan and threonine (Dabels Nanyen, 2016). Therefore, the aim of this study is to determine the nutritional quality and consumer acceptability of cowpea-supplemented biscuits among the rural youth in South Africa. The production of biscuits from composite flours of wheat and cowpea could provide a nutrient-rich and cheaper product that would alleviate food and nutrition security challenges in the country.

Materials and methods

Procurement of raw material

Wheat cake flour (Golden Cloud, South Africa- SA), shortening (Checkers No Name brand,

SA), granulated white sugar (Hulets, SA), eggs (Eggbert), baking powder (Royal Baking Powder, SA), salt (Iodized Cerebos, SA) were purchased from retail shops in Empangeni. Cowpea grains of two varieties were acquired from local farmers in Mngobokazi (multicoloured indigenous type) and Mbazwana (uniform brown small type), Northern Zululand (Figure 16. 1).



Figure 16.1: Cowpea (*Vigna species*) local grain varieties cultivated in Northern Zululand

Preparation of cowpea flours

Cowpea grains were manually cleaned, freed from dust and foreign materials, and washed in distilled water. Cowpea flour was produced following a method by Onyenekwe *et al.* (2000). The method involved hot water soaking at 80°C for 4 hours, boiling at 100°C for 40 minutes and oven drying at 60°C in a Defy Thermo fan stove (Model 731 MF) for 12 hours to reduce moisture content. The method has the following benefits: 1) the technique produces oligosaccharide free cowpea flour that can be used to produce products free from flatulence inducing effects[2) the product is intact with no disruption of the cotyledon, fairly cooked and the “off” odour observed in cold water soaking is eliminated. Unheated raw cowpea flour has been reported to produce unacceptable product, suggesting the need for preliminary heating (McWatters *et al.* 2003). The dried grains were milled in a commercial blender TM767, sieved using a 125µm mesh screen for uniform particle size and then packed in moisture proof polyethylene freezer bags and stored in the freezer until needed.

Preparation of composite flours

Composite flour was prepared from refined cake wheat flour supplemented with cowpea flour at different levels. Cowpea flour was used in incremental proportions for a cake wheat flour and cowpea blend biscuit formulation as indicated in Table 16.1.

Table 16.1: Formulations of flour blends for biscuit preparation

Sample		Wheat %	Indigenous Cowpea Flour %	Hybrid Cowpea Flour							

1				100			0				0
2				90			10				0
3				80			20				0
4				90			0			10	
5				80			0			20	

Production of biscuits

Biscuits were prepared from the cowpea wheat flour blend using the basic creaming technique of Van Wyk (1980:325) (Table 16. 2).

Table 16.2: Weight of ingredients used in biscuit samples

Ingredients					Quantity				
Cake wheat flour					333g				
Sugar							166g		
Shortening						166g			
Eggs							2		
Baking powder					8ml				
Salt							3ml		

A known weight of shortening and sugar was creamed together until light and fluffy using an electric beater. Whole eggs were added to the creamed mixture one by one, beating well after each addition. Sifted dry ingredients were folded in and mixed well. The biscuit dough was kept in a refrigerator for 15 minutes. The dough was rolled out to a thickness of 5mm on a lightly floured surface and biscuits pressed out with a round cutter. Biscuits were placed on a greased baking sheet lined with baking paper and baked in the oven at 180°C for 10 minutes. Biscuits were allowed to cool at room temperature for 8-10 min and were sealed in polyethylene bags, kept frozen for subsequent analysis.

Physical quality assessment

The physical quality of the resulting biscuits was determined by following the example of Olapade and Adeyemo, (2014). Three biscuits from each batch of the five treatments were weighed on an electronic digital scale (Radwag Model PS 210/C/2 Poland), and the height and diameter were determined using a 200 mm digital caliper (Vernier EAVRD200, France). The cookies were rotated at an angle of 90° for triplicate readings. The spread factor was expressed as the ratio of the diameter to the thickness of the cookies. All measurements were carried out in triplicate.

Colour was measured using a HunterLab ColorFlex Colorimetric Spectrophotometer (Model 45/0, HunterLab, USA). A standard reading to calibrate the calorimeter of the top and bottom surfaces of each biscuit was based on McWatters *et al.* 2003). Three readings of each sample were taken. The mean values for L*, a* and b* were determined. For the texture measurements, a bending test was performed following Patil and Kalse's (2011) method. The

three point blade attachment was connected to a 30 kg load cell of a universal TA-XT texture analyser. The maximum peak force (Newton) from force deformation curve was recorded.

Determining nutritional composition

Wheat, cowpea and cassava ours were analyzed for carbohydrates, protein, fat, fibre, ash and mineral content according to the official methods of AOAC (2002).

Consumer acceptability assessment

To assess whether developed biscuits would be acceptable, the rural youth and young adults from two rural wards, Makhasa and Mngobokazi in UMkhanyakude District, KZN, were recruited to participate in the tasting sessions. A purposive sampling method was used to invite available participants through health practitioners, chairpersons of food gardens and members of the community. The youth category was selected because they are likely to take up the technology transfer if their perceptions towards the innovative products are positive.

The following additional qualification criteria to participate in the study were used: non-allergic reactions (to legumes, gluten or strong flavours), availability for and interest in participating in the sensory evaluation. Sixty one youth and young adult consumers (aged 18-45 years) participated. 69% of the participants were females and the majority were of the age range between 20-35 years, making up 64% of the sample. The socio-economic profile of participants indicates low levels of education, not beyond Grade 12, and almost half of the sample (54%) are unemployed. Boiling was the most common preparation method, followed by stewing. Informal conversations with the youth revealed that boiled and stewed cowpea (boiled cowpea mixed with a relish of fried onion, tomatoes and stock cubes) was preferred because that is what the youth are familiar with.

Ethical clearance was granted by the Traditional Council of the wards and by the University of KwaZulu-Natal to work with the communities (HSS/1735/017D). Informed consent details were explained, after which participants gave approval and were accepted into the consumer taste panel. The panellists were given a sensory evaluation scorecard with a 5 point hedonic scale (1 = 'disliked a lot' to 5 = 'liked a lot') to use for assessment

Panelists were first trained in IsiZulu, their local language, on how to fill in the score card and then served biscuit samples in a random order with a randomly assigned unique three-digit code. Water was provided for rinsing the mouth between tasting samples. The qualities assessed included colour, crispness, aroma, taste and overall acceptability. These attributes were explained in IsiZulu prior to tasting.

Statistical analysis

Statistical analysis on nutritional composition and sensory quality data was conducted using SPSS version 25 for frequencies, mean values and standard deviations.

Results and discussion

Physical characteristics of cowpea biscuit blends

The spread ratio is an indication of the ability of the biscuit to rise, therefore the lower the value, the better the ability. Biscuits that have a high spread ratio are considered most desirable (Dabel Nanyem *et al.* 2016). The spread ratio ranged from 6.98 – 7.87. Biscuits from wheat flour (control) had the highest spread ratio, 7.87 as indicated in Table 4. McWatters *et al.* (2003) reported similar findings for a control 100% wheat biscuit which had a 5.86 spread ratio out of eight formulations with wheat/fonio/cowpea biscuit blends. These values were also in line with

cowpea/wheat biscuit 10/90 whose spread ratio was 7.6 (Sushma *et al.* 2016) and confirm work by Dabel *et al.* (2016) where biscuit formulations with mungbean/acha/wheat at 20/20/60 and 20/30/50 were reported with spread ratios 7.15 and 7.70 respectively. This was contrary to Olapade and Odeyemo's (2014) study which found that biscuits containing wheat/cassava/cowpea at 20/70/10 formulation had the highest ratio of 4.93. Spread ratio is restricted by dough viscosity as the dough with low viscosity causes biscuits to spread faster. Low spread ratio suggests that starch in the biscuit is hydrophilic (Sushma *et al.* 2016).

Table 16.3: Physical properties of biscuits

Sample	Weight	Height	Diameter	Spread				
		(g)		(cm)		(cm)		ratio (D/H)
0% Control	17.03		0.84			6.36		7.87
10% HCp	17.69		0.91			6.36		6.98
10% ICp	16.05		0.81			6.33		7.81
20% HCp	16.39		0.91			6.36		6.98
20% ICp	15.78		0.78			6.13		7.85

Values are means of triplicate determination.

Cp- cowpea; HCp- hybrid cowpea; ICp- indigenous cowpea

The instrumental colour results are indicated in Table 16.5. The top surface of 0% Cp control wheat biscuit had the lightest colour (L^* 72.37) and the 20% HCp wheat flour biscuit had the darkest (L^* 56.18). The low L^* values are an indication of darkening colour of biscuits, which can be due to the browning reaction brought about by interaction of ingredient composition.

Table 16.4: Mean values of colour measurements with varying levels of wheat and cowpea flours

Biscuit	Flour	L^*	a^*	b^*
TOP	0% Cp Control	72.37	11.13	38.35
	10% HCp	60.71±1.12	11.50±0.69	31.15±0.08
	20% HCp	56.18±1.18	11.08±0.93	27.29±0.49
	10% ICp	61.47±2.21	13.00± 0.88	33.60±0.24
	20% ICp	62.71±1.18	10.36± 0.83	30.40±0.46
BOTTOM	0% Cp Control	65.96	13.33	38.64
	10% HCp	54.74± 2.77	14.90±0.91	33.42±0.70
	20% HCp	46.80± 0.98	16.20± 0.15	30.93±0.74
	10% ICp	51.45± 4.10	15.60± 1.10	29.40±1.60
	20% ICp	50.16± 2.98	16.55± 0.60	33.37±0.69

W = Wheat; HCP = hybrid cowpea; ICP = Indigenous cowpea; L^* = lightness (0= black to 100 = white); a^* = redness to greenness; b^* = yellowness to blueness, ± STDEV

Olapade *et al.* (2012) also confirm that products get progressively darker when the proportion of cowpea in the composite flour increases. The high lysine content of cowpea might have contributed to the low sensory scores for colour in the cowpea rich products when compared

with the control.

Texture is a very important property which makes a significant contribution to the overall acceptance of food products. It is one of the three main acceptability factors used by consumers to evaluate food; the other two being appearance and flavour (Kulthe *et al.* 2017). The average peak force is the measure of biscuit hardness. A low force is indicative of a product which requires little effort by the consumer to break. The distance at the break point indicates the degree of flexibility or brittleness that the product possesses (Stable Micro System, undated).

When cake wheat flour was replaced by cowpea flour, hardness values increased, making the biscuit less crisp as shown in Table 7 compared to the control biscuit with 100% wheat flour only.

Table 16.5: Hardness and fracturability of biscuits samples for a bending test

Biscuit	Hardness (N)	Fracturability (mm)
	Mean 1 st peak	Mean distance at break
Cp 0%	51.31 ±8.50	2.81±0.59
HCp 10%	82.72 ±20.74	3.83±0.57
HCp 20%	55.77 ±6.21	3.41±2.07
ICp 10%	62.36 ±15.81	2.89±0.17
ICp 20%	69.92 ±6.64	2.74±0.52

Cp = cowpea; HCp = hybrid cowpea; ICp = indigenous cowpea; ±STDEV

It was observed that there was a significant increase in the hardness of cookies from 51.31N to 69.92N with increasing levels of cowpea flour. Biscuits incorporating cowpea were harder, requiring more force to shear. The highest force, 69.92N, was required to break the biscuit blend with 20% indigenous cowpea. The high shear force may be attributed to the interaction of protein, fiber with flour during baking resulting in a harder texture. The softest biscuit, which required the least force (51.31N) to shear, was the control (100% cake wheat), with fracturability of 2.81mm. McWatters *et al.* (2003) reported similar findings on biscuit blends where 50% fonio/ 50% cowpea and 50% wheat/50% cowpea, had the highest peak forces :720N and 634N respectively.

Fracturability, a distance at fracture with which the biscuit breaks, ranged from 2.74 – 3.83mm. The biscuit with 20% indigenous cowpea broke at 2.74 mm, a shorter distance compared to others, meaning it had a high fracturability and less crispness.

Nutritional composition

The results of nutritional composition of flours and biscuits are presented in Figure 17.2. The results reveal that cowpea flours had lower carbohydrate values (22.63 -25.15%) than the control wheat flour (64.53%). This is in contrast with the values reported by Odedeji and Oyeleke (2011), where the carbohydrate content of whole cowpea flour was 61.67%.

The fat content of all three flours was generally low, from 1.56 – 2.02%. Similar results were obtained by Odedeji and Oyeleke (2011) for whole cowpea flour with a fat content of 1.83%. Rufina *et al.* (2016) reported a much higher fat content on local cowpea varieties: 7.98% and 6.65%. The fat content in cowpea flour may be attributed to the presence of the seed coat

The two cowpea variety flours had high levels of protein 22.63% and 25.15%, which is in line with values recorded for cowpea flour 22.9% and 22.85% (McWatters *et al.* 2003 and Odedeji and Oyeleke, 2011). A similar comparison by Rufina *et al.* (2016) recorded 26.22% and 20.88% protein in two local cowpea varieties; Olapade, Aworh and Oluwole (2011) reported 25.4% and Olapade and Adeyemo (2014) recorded a 20-26% protein content of cowpea.

The fibre contents of whole cowpea flours were 42.38%, 47.21%. The high fibre contents exceeded those reported by Rufina *et al.* (2016) of 4.91% and 5.49% and Odedeji and Oyeleke (2011) of 0.65% on whole cowpea flour.

The ash contents of indigenous and hybrid cowpea flours were 2.54%, 2.75% respectively, comparable to values by Hama-Ba *et al.* (2018) at 2.92%, but lower than Rufina's *et al.* (2018) study with 3.87% and 3.13% cowpea varieties and McWatters *et al.* (2003) who found 3.2% ash content. The whole cowpea flour studied by Odedeji and Oyeleke (2011) had 1.12% ash content. The ash content is a function of mineral content, and products with a high ash content are expected to have a relatively higher mineral content. Iron and zinc contents were generally low in all flours. On the contrary, the cowpea variety used in Hama-Ba *et al.* (2016) had 7.06g/100g of iron. Similarly the two cowpea varieties in Rufina *et al.* (2016) had 0.95 and 1.61mg/100g zinc, while the iron content was 8.62 and 6.49mg/100g. The observed differences could be attributed to differences in species, location and soil conditions.

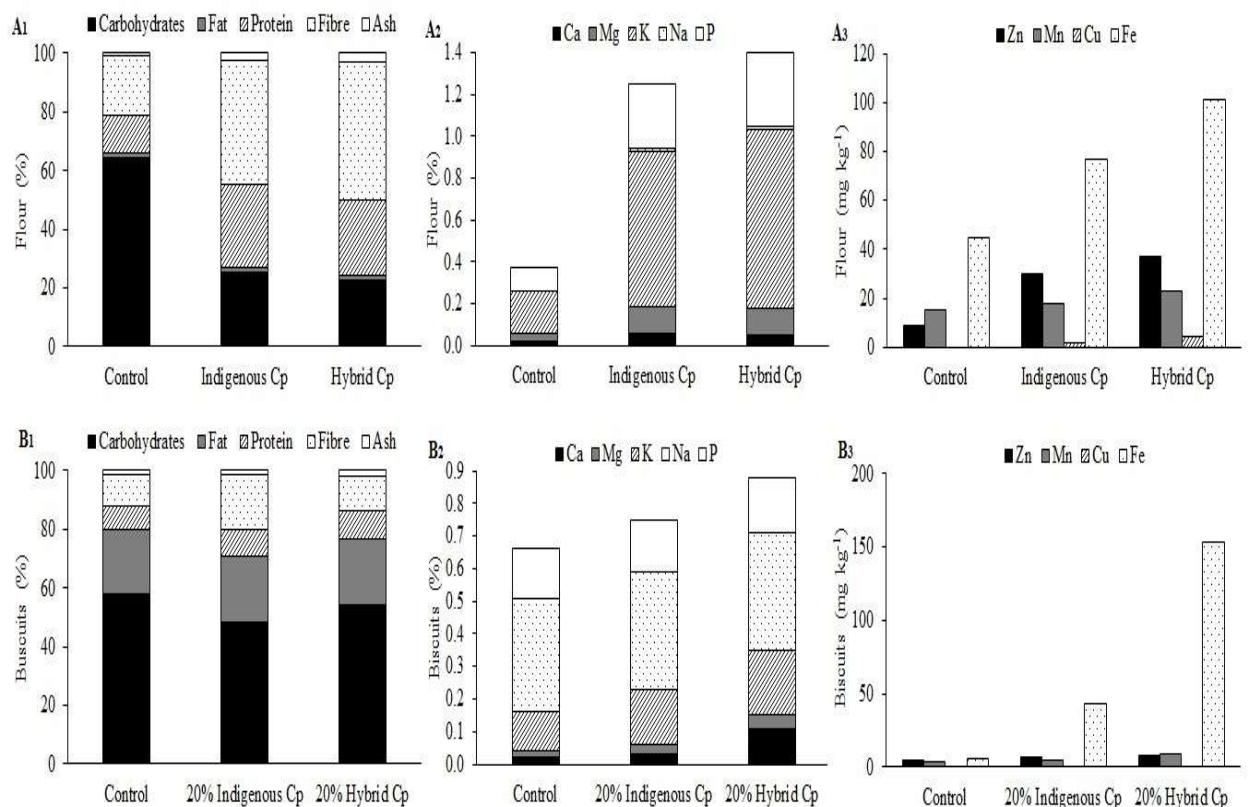


Figure 16.2: Proximate composition of flours and biscuits from the two cowpea varieties

Figure 16.2 shows that the biscuits produced from the wheat/cowpea blends had increased macronutrient levels for protein and fibre compared to the control wheat biscuits, except for carbohydrates. Similarly, micronutrient levels of biscuit blends were increased compared to the

control biscuits (Figure 16.2). This shows that cowpea can be used to complement wheat flour in baked products.

Consumer acceptability of cowpea supplemented biscuits

The frequencies for all the quality attributes evaluated are presented in Figure 16.3. Overall, 69% of panelists liked the control biscuits ‘a lot’, followed by 10% ICp and 10%HCp biscuits which were ‘liked a lot’ by 66% and 56% respectively. Biscuits with a 10% cowpea substitution of either of the varieties were not significantly different based on overall acceptability. Dabel Nanyem *et al.* (2016) obtained similar findings in their work on acceptability of wheat (80%), acha (10%) and mung bean (10%) composite flour biscuits. Biscuits with 20% cowpea substitution levels of either variety had lower scores than the control in all the quality attributes. Overall acceptability decreased with increasing levels beyond 10%. Colour is an important sensory attribute, as it influences the acceptability of food. The colour of biscuit scores ranged from 3.5 to 4.4. An increase in the substitution levels for both cowpea flour varieties resulted in a decrease in colour and crispness scores. Olapade and Odenyika (2014) attribute this effect on colour and crispness to the high fat absorption capacity of cowpea flour.

The biscuits containing 100% wheat scored high (4.4) for colour and high L* value (72.37) indicating lightness. The cowpea biscuits at 10% substitution level were favourably scored across all sensory attributes compared to the control, which scored highest in all sensory properties. Higher substitution levels of cowpea for both varieties at 20% resulted in the darker colour of the biscuit, shown by lower scores of 3.9 for hybrid cowpea and 3.5 for indigenous cowpea biscuits.

The scores of crispness decreased with an increase in the amount of cowpea flour. The decrease may be attributed to the high fat absorption capacity of cowpea flour (Olapade and Odeyemo, 2014). Similar trends were reported by McWatters (2003); Hama-Ba *et al.* (2018), namely that overall acceptability decreased when the level of cowpea flour exceeded 15%.

Figure 16.3 shows that the control had the highest overall acceptability, followed by 10% cowpea biscuits and then 20% supplemented biscuits. The results on sensory evaluation indicate that the nutritional advantage of the use of wheat/cowpea blends must be encouraged.

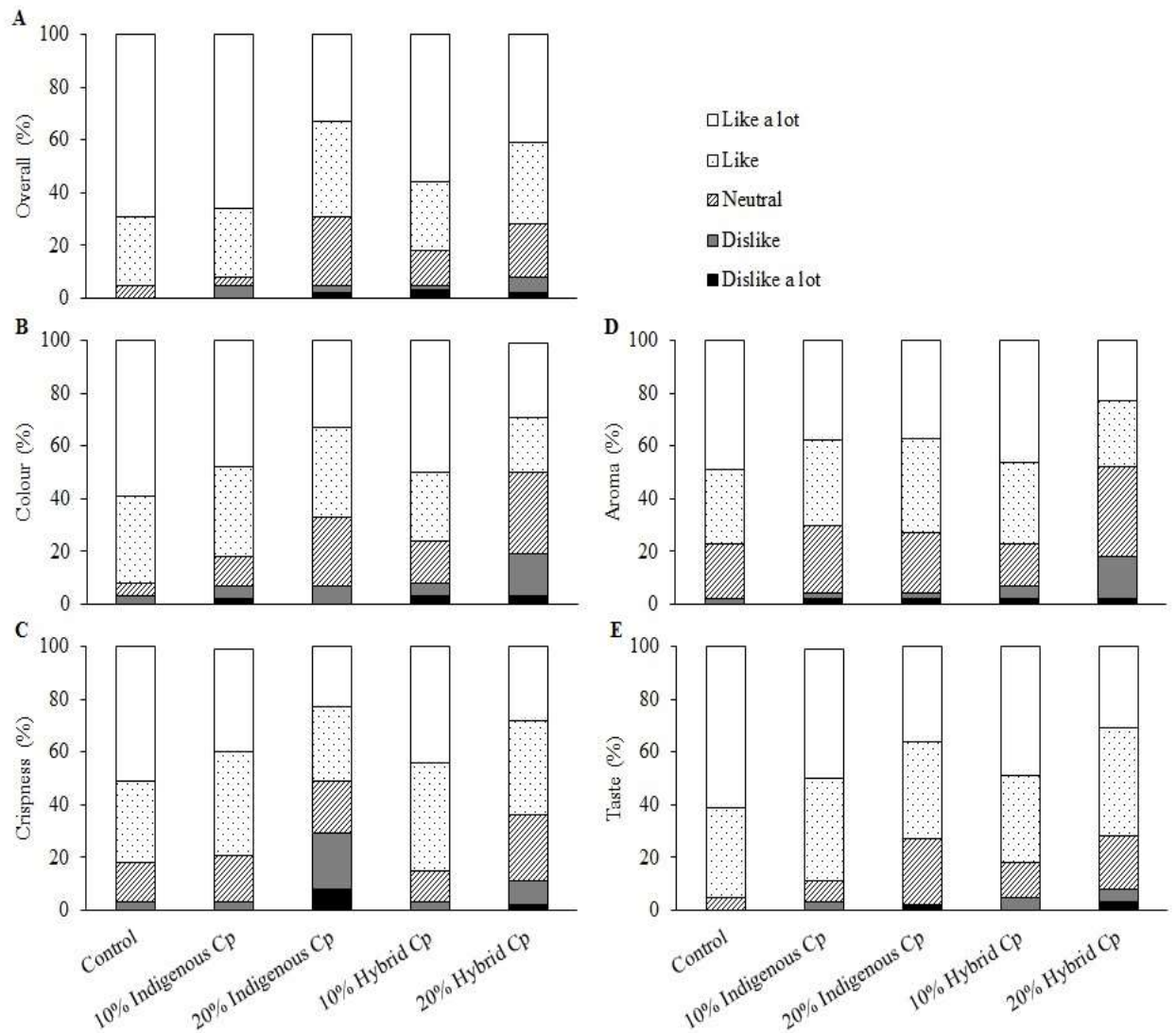


Figure 16.3: Consumer acceptability of cowpea biscuits from two cowpea varieties

Conclusion

Biscuits of acceptable quality could be produced from wheat and cowpea. The study shows that supplementation of wheat with 10% cowpea of both varieties produced well-accepted biscuits. At 10% the supplemented biscuits from both varieties were not significantly different from the control wheat flour biscuit in terms of colour, taste, crispness and aroma. Overall, the hybrid variety was more acceptable than the indigenous variety. However, the 20% indigenous cowpea biscuits were still within an acceptable range. Strategies to improve the texture and colour should be employed as both varieties increased the nutrient profile of macro- and micronutrients. The use of cowpea in biscuits will go a long way in enhancing consumption and will diversify the use of cowpea, while changing perceptions and reducing food insecurity. This study will be of interest to the agri-food industries working for the promotion of local products.

Acknowledgements

We wish to acknowledge the University of Zululand Teaching and Learning Unit and

University of Kwa-Zulu Natal Centre for Indigenous Knowledge Systems for funding, UniZulu Consumer Science students and Mngqobokazi - Makhasa communities in Hluhluwe for their participation.

Conflict of interest

None declared.

References

- Akpalu MM, Salaam M, Oppong-Sekyere D and SE Akpalu. 2000. Farmers' Knowledge and Cultivation of Cowpea (*Vigna unguiculata (L.) Verdc.*) in Three Communities of Bolgatanga Municipality, Upper East Region, Ghana. *British Journal of Applied Science & Technology* 4(5): 775-792, 2014. SCIENCEDOMAIN international www.sciencedomain.org
- Anyango JO, De Kock HL and JRN Taylor. 2011. Evaluation of the functional quality of cowpea-fortified traditional African sorghum foods using instrumental and descriptive sensory analysis. *Food Science and Technology* 44, 2126-2133
- Asiwe JAN 2009. Needs assessment of cowpea production practices, constraints and utilization in South Africa. *African Journal of Biotechnology* 18, 20, 5383-5388
- Association of Official Analytical Chemists (AOAC). Official methods of analysis. Washington, DC. 2002.
- Ayogu RNB, Naum NM & M Mbah 2016. Evaluation of two local cowpea species for nutrient, anti-nutrients and phytochemicals compositions and organoleptic attributes of their wheat-based cookies, *Food and Nutrition Research* 60:29600. [Doi:103402/fnr.v60.29600](https://doi.org/10.103402/fnr.v60.29600). <https://www.researchgate.net/291391938>. Accessed 15 February 2019
- Dabels Nanyen, Dooshima Igbabul Bibiana, Amove Julius & Benbella Iorliam .2016. Nutritional composition, Physical and Sensory properties of cookies from wheat, Acha and Mungbean Composite flours. *International Journal of Nutrition and Food Sciences* 5:6:401-406.[doi.10.11648/jn.ijnfs](https://doi.org/10.11648/jn.ijnfs).
- Dzemo WD, Niba AS and JAN Asiwe. 2010. Effects of insecticide spray application on insect pest infestation and yield of cowpea [*Vigna Unguiculata (L) Walp*] in the Transkei, South Africa. *African Journal of Biotechnology* 9:11:1673-1679 [doi: 10.589/AJB](https://doi.org/10.589/AJB)
- Ebert AW. 2014. Potential of Underutilized Traditional Vegetables and Legume Crops to Contribute to Food and Nutritional Security, Income and More Sustainable Production Systems. *Sustainability* 6: 319-335.
- FAO. 2014. Promotion of underutilized indigenous food resources for food security and nutrition in Asia and the Pacific. Food and Agriculture Organization of the United Nations. Regional office for Asia and Pacific Bangkok.
- Gorjestani N 2000. Indigenous Knowledge for development. Opportunities and Challenges. www.worldbank.org (Accessed September,18, 2016).
- Govender L, Pillay K, Siwela M , Modi A and T Mabhaudhi 2017. Food and Nutrition Insecurity in selected rural communities of KwaZulu Natal, South Africa- Linking Human Nutrition and Agriculture. *International Journal of Environmental Research and Public Health* 14 (17): 1-21 [Doi:10.3390/ijerph14010017](https://doi.org/10.3390/ijerph14010017)
- Hama-Ba, Siedogo M, Ouedraogo M, Dai A, Dicko HM and B. Diawara 2017. Modalities of consumption and nutritional value of food legumes in Burkina Faso. *African Journal of Food, Agriculture, Nutrition and Development* 17 (4): 12871 -12888.

- Hama-Ba F, Ouattara F, Savadogo A, Simpoire M and B Diawara 2018. The Study of the Nutritional Quality and Acceptability of Millet Biscuits (*Pennisetum glaucum L.*) supplemented with Cowpea (*Vigna unguiculata L.*) and Bambara Groundnuts (*Vigna subterranean L.*) *Journal of Agricultural Science and Food Research*, 9:1
- Kulthe AA, Thorat SS and SB Lanole 2017. Evaluation of Physical and Textural properties of cookies prepared from Pearl Millet flour. *International Journal of Current Microbiology and Applied Sciences* 6 (4) 692-701. Accessed 19 February 2019.
- Mathews C 2010. An overview of indigenous crop development by the Mpumalanga Department of Agriculture and Land Administration (DALA). *South African Journal of Plant & Soil* 27(4): 337-340, DOI:10.1080/02571862.2010.10640005. Accessed 10 June 2018.
- McWatters KH, Ouedraogo JB, Resurreccion AVA, Yen-C Hung and RD Phillips. 2003. Physical and sensory characteristics of sugar cookies containing mixtures of wheat, fonio (*Digitaria exilis*) and cowpea (*Vigna unguiculata*) flours. *International Journal of Food Science and Technology* 38: 403-410.
- Mnguni EM and A Giampiccoli 2015 Indigenous Food and Tourism for Community Well-Being: A Possible Contributing Way Forward. *Mediterranean Journal of Social Sciences*. 6(3):S2 24-34
- Ngema ZN, Sibanda M, and L Musemwa 2018 Household Food Security and its Determinants in Maphumulo Local Municipality, South Africa, *Sustainability* 10, 3307, 1-23 doi: 10.3390/su10093307
- Ntwenya J, Kinabo J, Msuya J, Mamiro P, Mamiro D and L Katalambula 2015 Household food insecurity and associated factors in rural communities: A case of Kilosa District, Tanzania. *African Journal of Agricultural Research*, 10 (52), 4783-4794. DOI:10.5897/AJAR2012.1718
- Odedeji JO and WA Oyeleke 2011. Proximate, Physico-chemical and Organoleptic Properties of Whole and Dehulled Cowpea Seed Flour (*Vigna unguiculata*). *Pakistan Journal of Nutrition*, 10(12) 1175-1178.
- Onyenekwe PC, Njoku GC and DA Ameh 2000. Effect of Cowpea (*Vigna Unguiculata*) processing methods on flatus causing oligosaccharides. *Nutrition Research*. 20(3) 349-358.
- Olapade AA, Aworh OC and OB Oluwole 2011. Quality attributes of biscuits from Acha (*Digitaria exilis*) flour supplemented with Cowpea (*Vigna unguiculata*) flour. *African Journal of Food Science and Technology* 2:9:198-203.
- Olapade AA and AM Adeyemo. 2014. Evaluation of cookies produced from blends of wheat, cassava and cowpea flours. *International Journal of Food Studies* (3):175 – 185.
- Patil MM & Kalse SB 2011. Textural studies of soy-jambul seed powder fortified biscuit. *International Journal of Processing and Post-Harvest Technology* 2:1:52-5520160506.15
- Rufina NB Ayogu, Ngozi M Nnam and Mirabel Mbah 2016. Evaluation of two local cowpea species for nutrient, antinutrient, and phytochemical compositions and organoleptic attributes of their wheat-based cookies. *Food and Nutrition Research* 60:29600. <http://dx.doi.org/10.3402/fnr.v60.29600>
- Stable Micro System (undated). Texture Analysis Application Overview. Confectionary Products. <http://textureanalysisprofessionals.blogspot.com/2015/04/texture-analysis-in-action-three-point.html>. Accessed 21 November 2018.

- Shiuan-Huei Wu, Chi-Tang Ho, Sui-Lin Nah & Chi-Fai Chau 2014. Global Hunger: A Challenge to Agricultural, Food, and Nutritional Sciences. *Critical Reviews in Food Science and Nutrition*, 54(2): 151-162. DOI:10.1080/10408398.2011.578764
- Sushma Thongram, Beenu Tanwar, Ambika Chauhan and Vikas, Kumar (2016). Physicochemical and organoleptic properties of cookies incorporated with legume flours. *Cogent Food and Agriculture* 2:1172389. <http://dx.doi.org/10.1080/23311932.2016.1172389>. Accessed 10 August, 2017.
- The World Bank, 2016, 'Population Total.' <http://search.worldbank.org/> Ullah F, Ahmad S, Wahab S, Zeb A, Khattak MK, Khan S and M Kang 2016). Quality Evaluation of Biscuits Supplemented with Alfafa Seed Flour. *Foods* 5, 68. Doi10.3390/foods5040068. www.mdpi.com/journal/foods
- Van Wyk, M. 1980.. The Complete South African Cookbook. *Cape Town: Struik*.
- Wang, N.M.J., Lewi qp, J.G., Brennan, O. and A. Westbyb. 1997. Effect of processing methods on nutrients and anti-nutritional factors in cowpea. *Food Chemistry*, 58 (1-2): 59-68.

Section F: Water resources in Africa

Chapter 17: Assessment of water quality indicators within a mining environment using Landsat reflectance data– the case study of Mooi River near Carletonville, South Africa

Modiegi O. Monaledi^{1*}, Isaac T. Rampedi¹
and Solomon G. Tesfamichael¹

¹Department of Geography, Environmental Management, and Energy Studies,
University of Johannesburg, Auckland Park Kingsway Campus,
PO Box 524, Johannesburg 2006, South Africa

*Corresponding author: sgtesfamichael@uj.ac.za

Abstract

The mining sector is one of the important sources of revenue for the South African economy; however, it can have detrimental impacts on water quality. Efficient assessment and monitoring are needed to protect water bodies in mining-related environments. While remote sensing has proven to be an effective monitoring tool in various sectors, efforts must be intensified to apply it in the mining sector in order to combat the impacts of mining pollution on water resources. This study assessed the performance of remote sensing in quantifying water quality indicators along the Mooi River located near mining activities using data obtained from the Landsat Operational Land Imager (OLI) satellite. Seventy-eight samples were collected along the river and analyzed in the laboratory for selected physicochemical parameters (pH, electrical conductivity, fluoride, iron, chloride, sulphate, hardness, calcium, sodium, and total dissolved solids). All-subset regression technique that lists all possible models was applied to estimate the laboratory-measured parameters using statistical mean values derived from the individual bands of Landsat data as explanatory variables. Models were then compared by first ranking them according to Akaike Information Criterion (AIC) followed by adjusted coefficient of determination (adjusted R^2) and root-mean-squared-error (RMSE). The maximum adjusted R^2 was 0.26 for a model to estimate sodium. The study demonstrated the potential of Landsat reflectance data in water quality measurements; however further studies are needed to improve the modelling capability of the data.

Keywords: Mooi River, water quality, remote sensing, mining, all-subset regression.

Introduction

The quality of water in rivers, groundwater and lakes has been declining worldwide as a result of various sources of contamination (Khan *et al.* 2013; Behmel *et al.* 2016; Mhlongo *et al.* 2018). Mining is one of the stressors affecting water quality since most mines operate adjacent to ecologically sensitive environments such as water bodies and wetlands (Durán *et al.* 2013; Poswa and Davies, 2017). Continuous monitoring, therefore, is vital to improve the quality of water bodies and thereby ecological services derived from them (Wang *et al.* 2014).

Traditional methods of monitoring water resources using field surveys provide accurate *in situ* measurements (El Saadi *et al.* 2014). Nonetheless, timely monitoring systems using extensive field surveys are invasive, time-consuming and relatively expensive. Remote sensing overcomes the challenges of traditional field-based monitoring methods as the technology

provides cost-effective alternatives and data over large spatial areas for efficient water quality monitoring. As a result, various studies have successfully used remote sensing to estimate water quality parameters of inland waters (e.g. Wen and Yang, 2011; Thilagavathi and Subramani, 2012; Chetty, 2013; Barnes *et al.* 2014; Jose *et al.* 2018; Sakala *et al.* 2018; Bonansea *et al.* 2019).

Different multispectral sensors have been applied to assess water quality parameters. Examples include Landsat (Bonansea *et al.* 2014; Lim and Choi, 2015; Olmanson *et al.* 2016; Markogianni *et al.* 2017; González-Márquez *et al.* 2018; Masocha *et al.* 2018), Sentinel-2 (Palmer *et al.* 2015; Toming *et al.* 2016; Karaoui *et al.* 2019; Elhag *et al.* 2019), ASTER (Nas *et al.* 2009; Sivanpillai and Miller, 2010; Abdelmalik, 2018; Tesfamichael and Ndlovu, 2018) and WorldView (El-Din *et al.* 2013; El Saadi *et al.* 2014; Novoa *et al.* 2015; Shi *et al.* 2018). Accuracies of these data mainly depend on spatial and spectral resolutions. Applicability of multispectral data also depends on data availability; in this regard Landsat has been widely used in different areas due to its free availability and long historical records. Furthermore, Landsat data provides a wide spatial coverage (Bucher *et al.* 2019) making it suitable for earth features characterisation that would be impractical using traditional field-based inventory methods. As a result, Landsat has been extensively used for characterising water bodies (Bonansea *et al.* 2014; Lim and Choi, 2015; Olmanson *et al.* 2016; Markogianni *et al.* 2017; González-Márquez *et al.* 2018; Masocha *et al.* 2018). For example, González-Márquez *et al.* (2018) used Landsat 8 OLI for the estimation of turbidity, dissolved oxygen, electrical conductivity, pH and depth in a reservoir while Masocha *et al.* (2018) tested the utility of Landsat 8 in estimating water quality parameters in two subtropical African reservoirs. Although Landsat has been used extensively in water quality assessments, applications focusing on mining environments are rare (e.g. Ong and Cudahy, 2014; Zheentaev, 2016; Tesfamichael and Ndlovu, 2018), despite the need for employing the technology for ecological studies in mining-related environments (Shepard, 2017). Moreover, most studies used sparsely distributed or a limited number of samples that may not represent fully the variation in water qualities of interest. The present study, therefore, aims to estimate water quality parameters at short sampling intervals (approximately 100 m) along a river system (Mooi River) near a mining area. The Department of Water Affairs (DWA) investigated the ecological status of water resources in the Vaal water management areas and classified the Mooi River as one of the river systems with the highest water quality impact in the area (DWA, 2011). It is, therefore, critical to design an efficient water quality monitoring system that will allow relevant authorities to implement mitigation plans and sustain ecosystem services derived from the water bodies.

Methodology

Study area

The Mooi River is located in the town of Carletonville and surrounding area within the south-western part of Gauteng, South Africa (Figure 17.1). Carletonville forms part of the Merafong City local municipality situated in the West Rand district municipality. The town was developed around the 1930s and is widely known for its mining and agricultural activities. In addition, the Mooi River joins the Vaal River – a major river that supplies water to the Gauteng Province of South Africa. Site inspections during fieldwork revealed several signs of abandoned mine tailings (Figure 17.1), which most likely contaminate surrounding water bodies along the Mooi River.

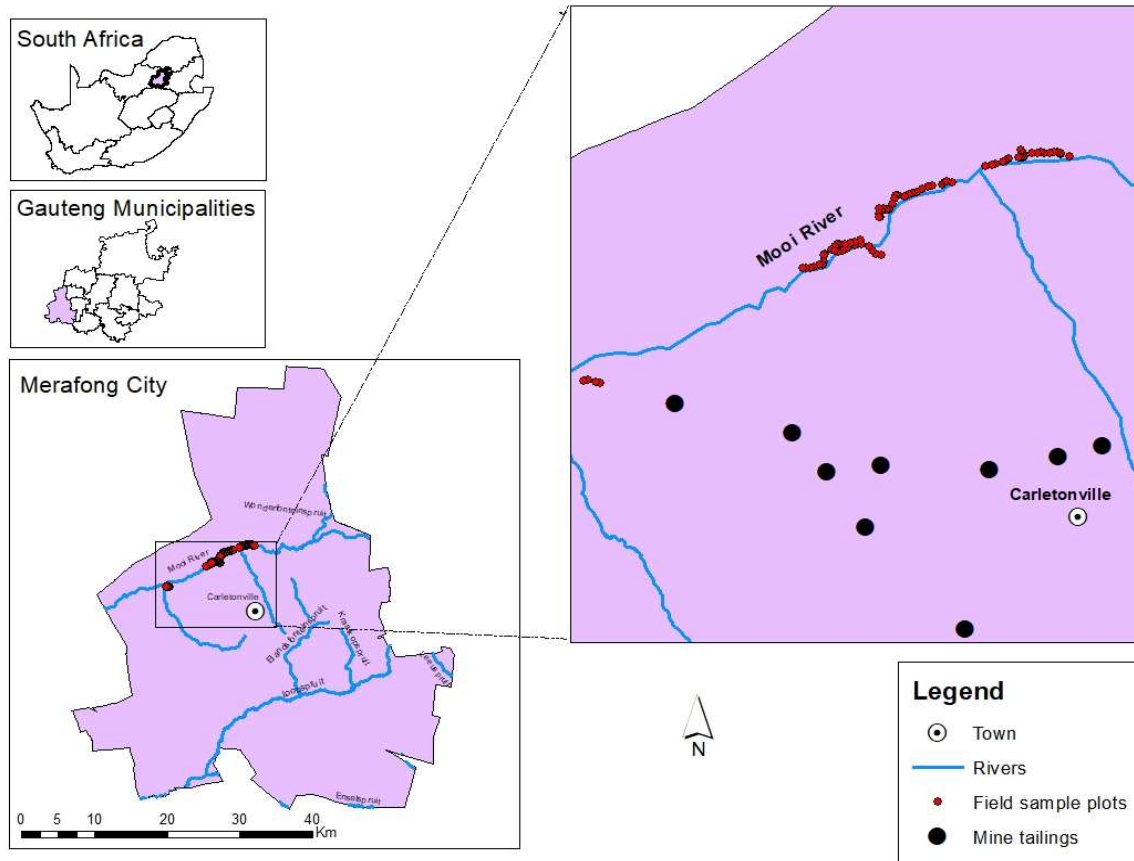


Figure 17.1: Study area in the south-western part of Gauteng, South Africa

Field survey

Field surveys were made during April - June 2018, in which 78 water samples were collected along the Mooi River and adjacent waterbodies following a sampling strategy described as follows. This is an autumn/winter period for the study area (South African Weather Services, 2019); as a result it is associated with low photosynthetic activity and vegetation vigour, allowing for a clear view of waterbodies using remote sensing systems. Approximate sampling locations were located on Google Earth at an interval of ~100 m stretching for ~12 km segment of the Mooi River. The relatively small interval was specified to represent variations well within the entire river system. We also decided against placing samples too close to each other to avoid information mixing between neighbouring samples. The initial aim was to collect as many samples as possible ; however, some of the water bodies were inaccessible as they fell within private properties. In addition, we had to specify a minimum distance between neighbouring samples to avoid an overlap of information between nearby pixels on Landsat imagery; accordingly we used a distance of ~100 m between samples. We believe that this sampling strategy captured the variability present in the water quality parameters along the river. A 250 ml plastic container was used to collect water samples from each sampling location. A Global Positioning System (GPS) unit with 3 m accuracy was used to record the position of each sampling point. Various physical and chemical contents (pH, electrical conductivity, fluoride, iron, chloride, sulphate, permanent hardness, calcium, sodium, and total dissolved solids) were quantified from each sample through laboratory analyses. Table 17.1 summarises the statistics of the physicochemical parameters of the samples used in the study.

Table 17.1: A summary of water quality parameters used in the study.

Variables*	Mean	Median	Minimum	Maximum	Number of samples	Standard Error	Standard deviation	Sample variance
Ph	1.3	1.2	0.7	2.6	56	0.0	0.4	0.1
EC (mS/m)	2194.7	1938.5	180.0	8830.0	56	206.4	1544.8	2386398.2
F ⁻ (1.5)	21.7	6.7	0.0	314.1	56	6.1	45.4	2064.7
Cl ⁻ (250)	3137.2	2707.2	58.2	13196.3	56	335.6	2511.7	6308791.7
SO ₄ ²⁻ (500)	605.3	495.6	228.7	3714.2	56	65.3	488.8	238900.2
Na (400)	68.9	70.6	2.8	82.8	78	1.2	10.5	110.4
Ca (200)	83.0	84.9	24.7	95.3	78	1.1	9.4	88.5
Perm. H	368.6	368.6	294.3	498.8	56	5.0	37.2	1387.1
TDS	4762.9	3902.5	751.0	32087.0	56	639.7	4787.0	22915600.6
Fe	0.4	0.18	0.0	3.8	78	0.1	0.6	0.4

*pH= potential hydrogen; EC= electrical conductivity; F⁻=fluoride; Cl⁻=chloride; SO₄²⁻=sulphate; Na= sodium; Ca= calcium; Perm. H= permanent hardness; TDS= total dissolved solids; Fe= Iron.

Remotely sensed data

Landsat 8 OLI imagery acquired on the 7th of May 2018 and with 0% cloud cover was downloaded from the United States Geological Survey (USGS) portal (<http://glovis.usgs.gov>). The data acquisition date falls within the field survey period and thus is deemed suitable to ensure reliable temporal matching recommended for accurate predictive models (Bonansea *et al.* 2015). The image had 11 spectral bands; however, only eight bands were used in the analysis, including Band 1 (coastal aerosol ~ 0.43–0.45), Band 2 (Blue ~ 0.45–0.51), Band 3 (Green ~ 0.53–0.59), Band 4 (Red ~ 0.64–0.67), Band 5 (NIR ~ 0.85–0.88), Band 6 (SWIR 1 ~ 1.57–1.65), Band 7 (SWIR 2 ~ 2.11–2.29) and Band 9 (Cirrus ~ 1.36–1.38). The digital numbers of pixels of the image were calibrated radiometrically to derive reflectance values. A 15 m buffer was created about each field sampling point and overlaid on the calibrated Landsat imagery. Subsequently, statistical values including mean, minimum, maximum, range and standard deviation of reflectance were quantified within each buffer zone. The laboratory-analysed data and the reflectance statistics were then correlated using regression analysis as described in Section 2.4.

Statistical analysis

In this study, ordinary least squares regression was employed. A regression analysis that creates all possible models was used, relating the laboratory-analysed water quality parameters (dependent variables) to mean reflectance of the Landsat (independent variables). The approach, therefore, generates $2^n - 1$ (for n = number of independent variables; eight in this study) models; a total of 255 models can be developed in this study. We limited the number of models by selecting the best model with the same number of predictors; that is, one best model containing 1 predictor, one best model containing two predictors, one best model containing three predictors and so on. This resulted in eight models that were subsequently compared using Akaike Information Criterion (AIC), coefficient of determination (R^2) and Root Mean Square Error (RMSE). According to the AIC statistic, the best model has the lowest AIC value, which measures the difference between the best model and the ideal model that generated the data (Burnham and Anderson, 2002). The coefficient of determination quantifies the degree of association between the predictor and independent variables as defined by Equation 1

$$R^2 = 1 - \frac{\sum(y - y')^2}{\sum(y - \bar{y}')^2} \quad (1)$$

where y is the actual value, y' is the predicted value of y and \bar{y}' is the mean of the y values, with model preference increasing with increase in R^2 . The RMSE provides a reliable indication of model accuracy since it compares observed and modelled data, as defined by the equation:

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (Observed_i - Predicted_i)^2}{n}} \quad (2)$$

where n is the total number of observations. Model accuracy increases as the RMSE decreases. All the spatial analyses that prepared the spatial data were carried out in ArcGIS version 10.6.1 (ESRI®, Redlands, CA) and the regression analysis was undertaken in the Number Cruncher Statistical System (NCSS) version 12 (NCSS, LLC, USA).

Results

Model fit statistics for estimating the physiochemical variables are presented in Table 18.2. Only Landsat OLI bands that generated the best models to estimate field observed water quality parameters are listed (Table 17.2). Other seven competing models of each water quality parameters are not presented in the table due to the length of the list. For each water quality parameter, the model that had the lowest AIC is reported. Models based on three or four number of Landsat bands were considered as the best models for estimating water quality parameters using zonal statistics of Landsat in most cases. As shown in Table 17.2, the best model for pH was estimated using the reflectance of Green, SWIR 2 and Cirrus bands (AIC = 48.68, $R^2 = 0.05$; RMSE = 0.35 (26%) Table 17.2). Although this model did not comprise the lowest AIC value, the model showed good comparability with the best model (consisting of two predictors), with AIC difference of 0.13 units. Electrical conductivity (EC) was best estimated using four bands, presenting an R^2 of 0.07.

The best model for estimating Na was generated using three Landsat OLI bands, yielding an R^2 of 0.26 and AIC value of 508.33. This model had the lowest AIC value compared to competing models. The best model for permanent hardness (Perm. H) estimation, which is the hardness in water due to the presence of elements that cannot be easily precipitated by boiling, also had three predictor variables. As shown in Table 17.2, water quality parameters such as chloride (Cl^-), sulphate (SO_4^{2-}), total dissolved solids (TDS) and calcium (Ca) were poorly correlated with R^2 well below 0.10 across various statistical models.

Figure 17.2 illustrates the relationships between observed and estimated water quality parameters for the best models used to estimate pH, EC, perm. H, Na, and Fe. Sodium (Na) had a better correlation between observed and predicted values compared to other variables. A good fitness was also noted between the observed and predicted values of permanent hardness, confirming the low RMSE (9%) value reported in Table 17.2. Apart from electrical conductivity (EC) and pH presenting R^2 values below 0.10, the variables showed a fairly good correlation between observed and predicted variables. Iron (Fe), is amongst the variables with an R^2 slightly above 0.10, however, as depicted in Figure 17.2, the relationship between the observed and predicted values demonstrated a weak correlation, confirming the high relative RMSE (139%) value presented in Table 17.2. A similar trend was noted for fluoride (F^-) but unlike Fe, the correlation was confirmed by both lower R^2 and RMSE values (0.03 and 207%, respectively).

Water quality parameter	Predictor bands in best model	AIC	Adjusted R ²	RMSE
pH	Green, SWIR 2 & Cirrus	48.68	0.05	0.35 (26%)
EC	Green, NIR, SWIR 1 & Cirrus	948.09	0.07	1490.99 (68%)
Fe	Coastal Aerosol, Green, Red & SWIR 2	138.11	0.16	0.56 (139%)
Na	Green, Red & SWIR 2	508.33	0.26	6.32 (9%)
Perm. H	Coastal Aerosol, Green & Red	559.60	0.17	33.96 (9%)
F ⁻	NIR, SWIR 1 & SWIR 2	590.94	0.03	44.93 (207%)
Cl ⁻	Coastal Aerosol, Blue & NIR	1041.92	0	2519.09 (80%)
SO ₄ ²⁻	Coastal Aerosol & SWIR 1	854.56	0.05	476.82 (79%)
Ca	Coastal Aerosol	575.35	0	9.43 (11%)
TDS	Green & SWIR 1	1112.58	0	4773.65 (100%)

Figure 17.2 also shows that the majority of pH values were underestimated, as the observed pH values ranged from ~0.70 mg/L to ~2.57 mg/L, compared to predicted pH values, which ranged from ~1.03 mg/L to ~1.53 mg/L. Similarly, predicted EC values ranged from ~1067.76 mg/L to ~3395.40, compared to observed EC values ranging from ~180 mg/L to ~8830 mg/L. EC was the most underestimated, compared to other variables. Observed values of Na ranged from 39.6 to 82.8 mg/L, compared to the predicted range of 57.67 to 77.6 mg/L. Predicted mean values of permanent hardness had a narrower range (~335 to 410 mg/L), compared to observed mean values (294 to 498.78 mg/L).

Discussion

The mining sector is a major contributor to South Africa's economy; however, the sector has detrimental impacts on the natural environment (McCarthy, 2011). Most mining activities are located near some of the most ecologically sensitive environments. This has proved a threat to numerous ecosystems, thus downgrading the quality of water bodies, by way of pollution incidents (Poswa and Davies, 2017). Since the town of Carletonville is surrounded by a number of mining activities, this study sought to quantify physiochemical variables along the Mooi River and surrounding waterbodies in order to determine the status of water quality in the area. The all-subset regression method was used to explore the relationship between selected water quality parameters and mean reflectance values of Landsat imagery. The results obtained through this method had varying success. Most of the parameters were best estimated using

three or four independent variables. The RMSE, which is often preferred over R^2 , penalised models with increasing predictor variables. Therefore, parsimonious models were given a higher preference in this study.

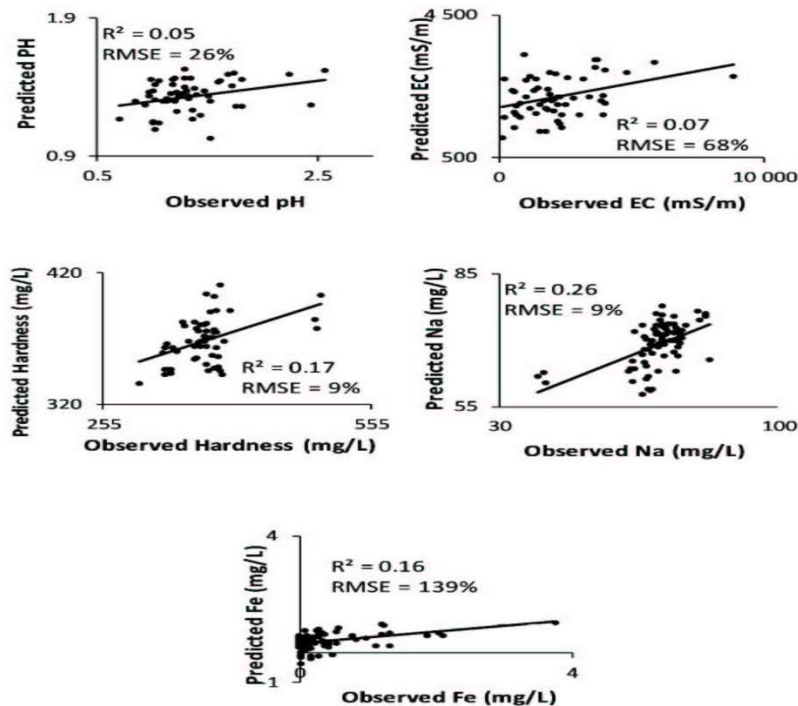


Figure 17.2: Comparison of observed and predicted values using the reflectance of Landsat OLI bands. Predictor variables used to estimate these water quality parameters are presented in Table 17.2.

Most models were generated using the reflectance of the Green, Red and SWIR 1 and 2 bands. Table 17.2 also shows that B1 (Coastal Aerosol) of Landsat OLI was an input for a number of models. In this study, pH was best estimated using a model with three predictor variables (Table 17.2). However, our findings for pH are relatively low ($R^2 = 0.05$) compared to those obtained in other studies. For example, Ong and Cudahy (2014) found an R^2 of 0.72, which shows the relative strength of the statistic in representing model performance. Their study, however, utilised hyperspectral data and soil samples, thus making it difficult to make direct comparisons. Tesfamichael and Ndlovu (2018) estimated pH using SWIR 1 of Landsat 7. Their estimation accuracy for this variable was better than ours with $R^2 = 0.24$ compared to R^2 of 0.05 obtained in our study. Despite the weakness in estimating pH, both studies demonstrated the potential of the reflectance in the SWIR region for identifying water characteristics.

Na showed better prediction accuracy compared to other variables (R^2 of 0.26 and relative RMSE of 9%) using the green, red and SWIR 2 bands. The correlation obtained in our study was slightly better compared to the findings of Tesfamichael and Ndlovu (2018), who reported an R^2 of 0.21 using the blue band of Landsat-5. Although the R^2 obtained is comparable to that of the present study, the relative RMSE value obtained in their study for Na was relatively higher (96%). Parameters such as Cl^- , SO_4^{2-} , and Ca were poorly correlated

with the Landsat OLI bands. The low R^2 values, high relative RMSE, and underestimation of these variables indicate the weakness of their predictive models. Chloride (Cl^-) correlated poorly with the reflectance of Coastal Aerosol, Blue and NIR Landsat bands. The best model for estimating this variable yielded an adjusted R^2 of 0 and a RMSE of 80% (Table 18,2). In contrast to our findings, Tesfamichael and Ndlovu (2018) correlated Cl^- with the Red band of Landsat-5 and obtained R^2 of 0.28 and RMSE of 57%. Nonetheless, the overall accuracy in both studies for estimating Cl^- was weak.

Of all eight models, calcium was best estimated using a model with one predictor (Coastal Aerosol band); however, the R^2 obtained was relatively low (0) with a RMSE of 11%. A similar characteristic was observed for SO_4^{2-} . Such weak correlations were also noted in the findings of Tesfamichael and Ndlovu (2018). However, in their study, they also assessed the utility of ASTER in quantifying water quality parameters and found improved results. Drawing from these (ASTER results obtained by Tesfamichael and Ndlovu (2018) and Ong and Cudahy (2014)), the high spatial and spectral resolution of advanced sensors (e.g. ASTER, Sentinel, SPOT 6/7, etc.) can yield improved estimation accuracies for water quality parameters in mining environments.

Conclusions

This study has demonstrated the potential of applying remote sensing to quantify water quality parameters (pH, EC, Na, permanent hardness, Fe, F^- , Cl^- , SO_4^{2-} , TDS and Ca) in a river system within a mining area. The findings demonstrated varying degrees of success. Specifically, somewhat promising accuracies were observed in the estimation of sodium and permanent hardness (Table 17.2; Figure 17.2). In contrast, parameters such as chloride, calcium, sulphate and total dissolved solids were estimated at low accuracy levels. Further studies are underway in the study area using different data sources. These studies are anticipated to generate more promising results that will improve the efficiency of monitoring efforts in the area.

Acknowledgments

The research was funded by the University of Johannesburg and the National Research Foundation (NRF). Digby Wells Environmental provided one of the authors with a bursary.

References

- Abdekmalik, K.W. 2018: Role of statistical remote sensing for inland water quality parameters prediction. *Remote sensing and Space Sciences*, 21 (1), 193–200.
- Barnes, B.B., Hu, C., Holekamp, K.L., Blonski, S., Spiering, B.A., Palandro, D., Lapointe, B. 2014: Use of Landsat data to track historical water quality changes in Florida Keys marine environments. *Remote sensing of Environment*, 140 (1), 485–496.
- Behmel, S., Damour, M., Ludwig R., Rodriguez, M.J. 2016: Water quality monitoring strategies - A review and future perspectives. *Science of the Total Environment*, 571 (1), 1312–1329.
- Bonanse, M., Bazán, R., Ledesma, C., Rodriguez, M.C., Pinotti, L. 2014: Monitoring of regional lake water clarity using Landsat imagery. *Hydrology Research*, 46 (5), 661–670.
- Bonanse M, Rodriguez, M.C., Pinotti L. Ferrero, S. 2015: Using multi-temporal Landsat imagery and linear mixed models for assessing water quality parameters in Rio Tercero Reservoir, Argentina. *Remote Sensing of Environment*, 158 (1), 28–41.
- Bonanse, M., Ledesma, M., Rodriguez, M.C., Pinotti, L. 2019: Using new remote sensing satellites for assessing water quality in a reservoir. *Hydrological Sciences Journal*, 64

- (1), 34–44.
- Burnham, K.P., Anderson, D.R. 2002: *Model selection and multimodel inference: A practical- information-theoretical approach*. Second edition., New York: Springer-Verlag.
- Butcher, G., Owen, L., Barnes, C. Landsat: the cornerstone of global land imaging. 2019: Available from: <https://www.gim-international.com/content/article/landsat-the=cornerstone-of-global-land-imaging> [Accessed on 2 May 2019].
- Chetty, P. 2013: Monitoring of mine tailings using satellite and LIDAR data. SRK Consulting: Cape Town. Available from: <http://www.ee.co.za/wp-content/uploads/2014/05/Prevlan-Chetty.pdf> [Accessed on 6 June 2018].
- Department of Water Affairs (DWA). 2011: Classification of significant water resources in the three Vaal water management areas- Newsletter No. 1. Available from: <http://www.dwa.gov.za/rdm/WRCS/doc/Vaal%20Classification%20Newsletter%20No.%201%20-%20September%202011.pdf> [Accessed on 20 May 2018].
- Durán, A.P., Rauch, J., Gaston, K.J. 2013: Global spatial coincidence between protected areas and metal mining activities. *Biological Conservation*, 160 (1), 272–278.
- El-Din, M.S., Gaber, A., Koch, M., Ahmed, R.S., Bahgat, I. 2013: Remote sensing application for water quality assessment in lake Timsah, Suez Canal, Egypt, *Journal Remote Sensing Technology*, 1 (3), 61–74.
- El Saadi, A.M., Yousry, M.M., Jahin, H.S. 2014: Statistical estimation of Rosetta branch water quality using multi-spectral data. *Water Science Journal*, 28 (1), 18–30.
- Elhag, M., Gitas, I., Othman, A., Bahrawi, J., Gikas, P. 2019: Assessment of water quality parameters using temporal remote sensing spectral reflectance in arid environments, Saudi Arabia. *Water*, 11 (3), 556.
- González-Márquez, L.C., Torres-Bejarano, F.M., Torregroza-Espinosa, A.C., Hansen-Rodríguez, I.R., Rodríguez-Gallegos, H. B. 2018: Use of Landsat 8 images for depth and water quality assessment of El Guájaro reservoir, Colombia. *Journal of South American Earth Sciences*, 82 (1), 231–238.
- Jose, D.M., Venkata, R.M., Saladi, S.V.S., Rao, N.S., Moses, S.A. 2018: Assessment of coastal water quality along south-west coast of India using multiple regression analysis on satellite data. *Journal of Rural Development*, 37 (2), 269–284.
- Karaoui, I., Arioua, A., Boudhar, A., Hssaisoune, M., El Mouatassime, S., Ouhamchich, K.A., Elhamdouni, D. 2019: Evaluating the potential of Sentinel-2 satellite images for water quality characterization of artificial reservoirs: The Bin El Ouidane Reservoir case study (Morocco). *Meteorology Hydrology and Water Management Research and Operational Applications*, 7 (1), 31–39.
- Khan, K., Lu, Y., Khan, H., Zakir, S., Ullah, I., Khan, S., Khan, A.A., Luo, W., Tiewu, W. 2013: Health risks associated with heavy metals in the drinking water of Swat, Northern Pakistan. *Journal of Environmental Sciences*, 25 (10), 2003–2013.
- Lim, J., Choi, M. 2015: Assessment of water quality based on Landsat 8 operational land imager associated with human activities in Korea. *Environmental Monitoring and Assessment*, 187 (1), 1–17.
- Markogianni, V., Kalivas, D., Petropoulos, G., Dimitriou, E. 2017: Analysis on the feasibility of Landsat 8 imagery for water quality parameters assessment in an oligotrophic Mediterranean Lake. *World Academy of Science, Engineering and Technology International Journal of Geological and Environmental Engineering*, 11 (9), 906–914.

- Masocha, M., Dube, T., Nhiwatiwa, T., Choruma, D. 2018: Testing utility of Landsat 8 for remote assessment of water quality in two subtropical African reservoirs with contrasting trophic states. *Geocarto International*, 6049 (1), 1–14.
- McCarthy, T.S. 2011: The impact of acid mine drainage in South Africa. *South African Journal of Science*, 107 (1), 1–7.
- Mhlongo, S., Mativenga, P.T., Marnewick, A. 2018: Water quality in a mining and water-stressed region. *Journal of Cleaner Production*, 171 (1), 446–456.
- Nas, B., Karabork, H., Ekercin, S., Berktay, A. 2009: Mapping chlorophyll-a through in-situ measurements and Terra ASTER satellite data. *Environmental Monitoring and Assessment*, 157 (1–4), 375–382.
- Novoa, J., Chokmani, K., Nigal, R., Dufour, P. 2015: Quality assessment from a hydrological perspective of a digital elevation model derived from WorldView-2 remote sensing data. *Hydrological Sciences Journal*, 60 (2), 218–233.
- Olmanson, L.G., Brezonik, P.L., Finlay, J.C., Bauer, M.E. 2016: Comparison of Landsat 8 and Landsat 7 for regional measurements of CDM and water clarity in lakes. *Remote Sensing of Environment*, 185 (1), 119–128.
- Ong, C.C., Cudahy, T.J. 2014: Mapping contaminated soils: using remotely-sensed hyperspectral data to predict pH. *European Journal of Soil Science*, 65 (1), 897–906.
- Palmer, S.C.J.; Kutser, T.; Hunter, P.D. 2015: Remote sensing of inland waters: Challenges, progress and future directions. *Remote Sensing of Environment*, 157 (1), 1–8.
- Poswa, T.T., Davies, T.C. 2017: The nature and articulation of ethical codes on tailings management in South Africa. *Geosciences*, 7 (4), 101.
- Sakala, E., Fourie, M.G., Coetzee, H. 2018: GIS-based groundwater vulnerability modelling: A case study of the Witbank, Ermelo and highveld coalfields in South Africa. *Journal of African Earth Sciences*, 137 (1), 46–60, doi: 10.1016/j.jafrearsci.2017.09.012.
- Shepard, P. 2017: The application of satellite remote sensing in the mining sector. SRK Consulting: Cape Town. Available from: <https://www.na.srk.com/en/newsletter/mine-water-management-2017/application-satellite-remote-sensing-mining-sector> [Accessed on 17 June 2018].
- Shi, L., Mao, Z., Wang, Z. 2018: Retrieval of total suspended matter concentrations from high resolution WorldView-2 imagery: a case study of inland rivers. *Earth and Environmental Science*, 121 (1), 1–12.
- Sivanpillai, R., Miller, S.N. 2010: Improvements in mapping water bodies using ASTER data. *Ecological Informatics*, 5 (1), 73–78.
- Tesfamichael, S.G., Ndlovu, A. 2018: Utility of ASTER and Landsat for quantifying hydrochemical concentrations in abandoned gold mining. *Science of the Total Environment*, 618 (1), 1560–1571.
- South African Weather Services. 2019: Seasonal climate watch. Available from: <http://www.weathersa.co.za/images/data/longrange/gfcsa/scw.pdf> (Accessed 14 May 2019).
- Thilagavathi, N., Subramani, T. 2012: Hydrochemical evaluation of groundwater in mine region, Salem, Tamil Nadu. *Pollution Research*, 31 (3), 499–505.
- Toming, K., Kutser, T., Laas, A., Sepp M., Paavel, B., Nõges, T. 2016: First experiences in mapping lake water quality parameters with Sentinel-2 MSI imagery. *Remote Sensing*, 8 (8), 640.
- Wang, C., Harbottle, D., Liu, Q., Xu, Z. 2014: Current state of fine mineral tailings treatment: A critical review on theory and practice. *Minerals Engineering*, 58 (1), 113–131.

- Wen, X., Yang, X. 2011: Monitoring of water quality using remote sensing data mining. In: Kimito Funatsu (Ed.), *Knowledge-Oriented Applications in Data Mining*, ISBN 978-953-307-154-1.
- Zheentaev, E. 2016. Application of remote sensing techniques for the environmental impact analysis in Kumtor gold mining company. *International Journal of Geoinformatics*, 12 (4), 31.

Chapter 18: Assessing chlorophyll-a and turbidity in the Hartbeespoort Dam (South Africa) using Landsat imagery

Craig Mahlasi¹, Richard Greenfield², Modiegi O. Monaledi¹ and Solomon G. Tesfamichael^{1*}

¹Department of Geography, Environmental management and Energy Studies, University of Johannesburg, Auckland Park – Kingsway Campus, PO Box 524, Johannesburg 2006, South Africa;

²Department of Zoology, University of Johannesburg, University of Johannesburg, Auckland Park – Kingsway Campus, PO Box 524, Johannesburg 2006, South Africa

*Corresponding author: sgtesfamichael@uj.ac.za

Abstract

The water quality of global inland lakes is deteriorating as a result of various anthropogenic influences. Addressing this problem requires accurate monitoring programmes. Traditional water quality assessments rely on sample-based in-situ observations that are expensive, time-consuming and labour-intensive. In contrast, remote sensing based approaches overcome most of the problems inherent in traditional methods, and have shown a great potential in the estimation of water quality parameters. Most studies however utilised coarse spatial resolution data in an effort to cover wide spatial areas. Inland lake systems, by contrast, have received limited attention. Inland lakes exhibit relatively large localised variations of water quality, compared to large water-bodies such as the oceans. Such water-bodies therefore require assessments at an appropriate level of detail. The objective of this study was to evaluate the utility of individual spectral bands, Normalised Difference Vegetation Index (NDVI) and Normalised Difference Water Index (NDWI) of Landsat imagery in characterising chlorophyll-a concentrations and turbidity of the Hartbeespoort Dam, South Africa. Ordinary least-square regression analysis was used to relate field observed chlorophyll-a concentrations and turbidity with remotely sensed data. Chlorophyll-a concentrations were best estimated using NDVI ($R^2=0.91$; $RMSE=0.67$), while the best correlation for turbidity was observed with NDWI ($R^2=0.60$; $RMSE=3.44$). The study demonstrated that moderate resolution satellite imagery provides an empirical method of retrieving information on the status and dynamics of water quality for inland water-bodies.

Keywords: inland water quality, Landsat, chlorophyll-a, turbidity, Hartbeespoort Dam

Introduction

Aquatic ecosystems perform vital roles in the environment. They are crucial elements in various environmental processes such as carbon, nutrient and hydrological cycles (Dörnhöfer and Oppelt, 2016). Water also provides habitats for aquatic life (Moss, 2012). Humans utilise inland lakes for several purposes including consumption, irrigation, energy generation, transportation, aquaculture and recreation (Carpenter *et al.* 2011). However the quality of inland lakes is deteriorating as a consequence of various factors including the discharge of pathogens, endocrine disrupting compounds (EDCs), pharmaceuticals, pesticides, heavy

metals and nutrients into rivers and dams (Harding, 2015; Akpanyung *et al.* 2014; Siri *et al.* 2011). Eutrophication is one of the causes of deteriorating water quality (Matthews, 2014). Eutrophication refers to the process in which excessive levels of nutrients are introduced into water systems mainly from nitrogen and phosphorus run-off sources such as effluent and agricultural land.

Decision making on water management requires information on the dynamics of eutrophication and general water quality. Traditional water quality assessments are dependent on *insitu* measurements, which make continuous monitoring difficult, often resulting in significant temporal gaps. Furthermore, they are inherently time-inefficient, labour-intensive and require substantial financial investment (Nazeer and Nichol, 2016). Remote sensing offers a viable alternative, overcoming most of the drawbacks associated with field-based assessment. The application of remote sensing in water quality is based on the principle that optically active constituents in water-bodies determine reflectance and absorbance of electromagnetic radiation typically in the visible and near-infrared wavelength regions (400–900 nm) (Gordon *et al.* 2012; Dekker *et al.* 2002). Several studies have investigated the application of satellite remote sensing data for estimating water quality indicators, including chlorophyll (Keith *et al.* 2012; Bonansea *et al.* 2015) turbidity (Bonansea and Fernandez, 2013; Giardino *et al.* 2015), pH (Theologou *et al.* 2015; Schroeter and Gläßer 2011) and water temperature (Ding and Elmore 2015; Bonansea *et al.* 2015). Much of the existing literature on the remote sensing of water quality has focused on the application of sensors including the MERIS (Medium Resolution Imaging Spectrometer), MODIS (Moderate Resolution Imaging Spectrometer), ENVISAT-1 and SeaWiFS (Sea-viewing Wide Field-of-view Sensor). Inland lake systems display high spatial heterogeneity of variables such as temperature, light, oxygen and nutrients as a result of the biological, meteorological, physical and chemical dynamics of aquatic systems (Lau and Lane 2001). While coarse spatial resolution imagery is able to effectively resolve water quality indicators in large open inland lakes and open oceans where there is little variation in these indicators (O'Reilly *et al.* 2000; Reinart and Kutser, 2006), it cannot be reliably applied to smaller inland lakes that exhibit localised variation in water quality.

Several authors have suggested the application of medium resolution imagery for the improved characterisation of water quality indicators. Shekede *et al.* (2008) used time-series Landsat data to map the spatial distribution and profusion of aquatic weeds in Lake Chivero, Zimbabwe. Field measurements and biomass estimations were related to NDVI histograms generated from Landsat data. The study found that Landsat derived NDVI can distinguish between water surfaces as well as different aquatic weeds. Munyati (2015) used SPOT-5 data to estimate the spatial extent and pattern of eutrophication in four dams in the North West Province of South Africa. Field sample points of chlorophyll-a were interpolated using ordinary kriging. Semivariograms models were used to fit the distributions. The frequencies of distribution and the SPOT-5 were subsequently related using cross validation statistics. The results showed the capability of SPOT-5 data in discriminating between eutrophic and hypertrophic dams. However, these studies do not attempt to establish empirical relationships between *insitu* measurements and spectral information. There is a vital need to assess the utility of medium resolution imagery to characterise water quality indicators as a tool for efficient management of inland lakes. This study aims to assess the relationship between Landsat 8 data and *in situ* water quality indicator data. To this end this study will (1) determine the utility of individual Landsat 8 bands in characterising chlorophyll-a and turbidity and (2) assess the performance of the Normalised Difference Vegetation Index (NDVI) and Normalised

Difference Water Index (NDWI) in characterising chlorophyll-a and turbidity in the Hartbeespoort Dam (South Africa).

Methods

Study area

The Hartbeespoort Dam is a water reservoir in the North West Province, 50 km south west of the City of Tshwane (Figure 18.1). The dam covers an area of approximately 20 km². The maximum length and width of the dam are approximately 5.6 km and are 12 km respectively. Mean annual precipitation at the dam is approximately 700 mm, most of which falls between the months of October and March (Zohary and Breen, 1989). Atmospheric temperature at the dam ranges from < 2 °C during winter to > 32 °C in summer. The mean annual temperature is approximately 19.5 °C (Oberholster *et al.* 2004). The mean depth of the dam is 9.6 meters, with a maximum depth of 32.5 meters (Ashton *et al.* 1985).

Field and laboratory data

A field survey was conducted on the March 22, 2015. Seventy sample sites spaced at approximately 500 meters were visited. At each site surveyed, turbidity was determined using a wide range mode, 0.0 to 100000 Nephelometric Turbidity Unit (NTU), probe-type turbidity meter (152TM, Analite Novasina, Lachen, Switzerland). At the same time, a 1-liter surface water sample was collected using a plastic bottle from each sampling site for laboratory analysis. The location of the sampling position was recorded using a GPS. Laboratory analysis was carried out on the samples to quantify chlorophyll-a concentrations using the Holm-Hansen and Riemann (1978) method. Results of the field and laboratory measurements are summarised in Table 18.1, in which both parameters show a great deal of variation

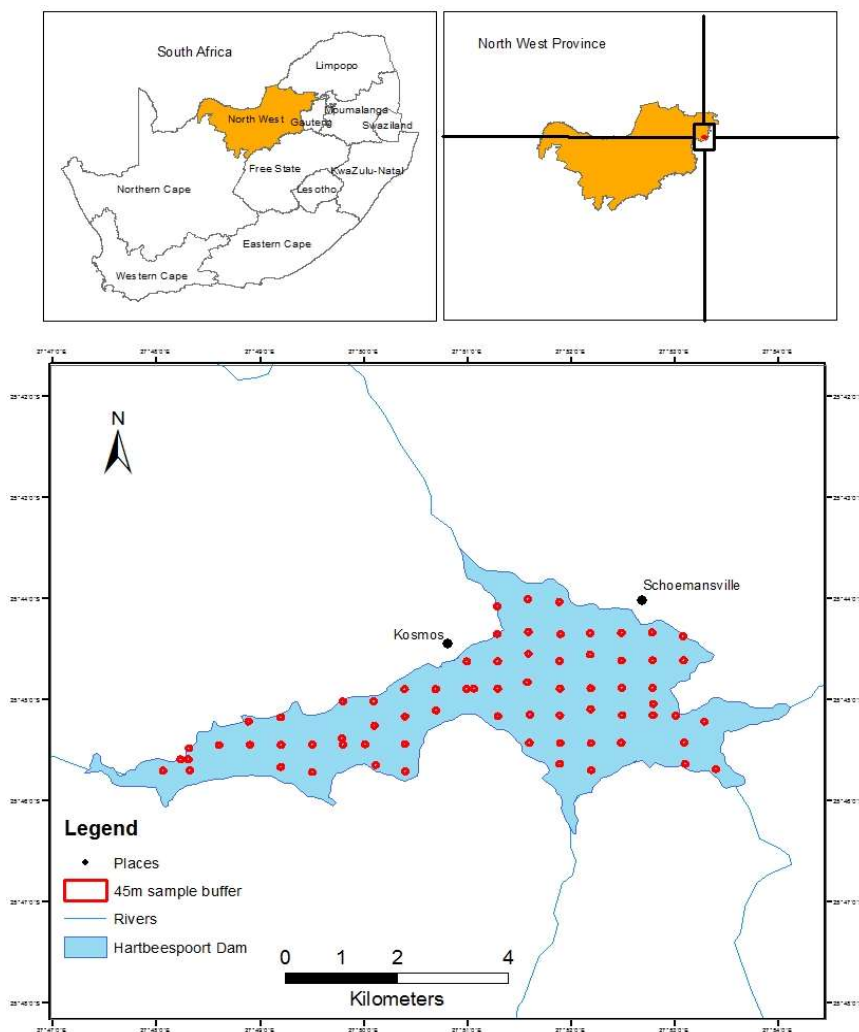


Figure 18.1: Location of the Hartbeespoort Dam and distribution of sampling locations. Note that the sampling locations are given as 45 m buffers symbolized by red colour.

Table 18.1: Summary statistics of chlorophyll-a ($\mu\text{g/L}$) and turbidity (NTU) acquired after the field survey and laboratory analysis

Statistics	Chlorophyll-a $\mu\text{g/L}$	Turbidity (NTU)
Minimum	0.5	0.1
Maximum	19199	19.1
Mean	1957.7	3.4
Range	19198.5	19
Standard Deviation	3741.5	5.3
Coefficient of variation (%)	191	156

Remote sensing data

This study utilised a Landsat 8 (Path: 170, Row: 78) image that was acquired on March 24, 2015. The image was downloaded from the United States Geological Survey (USGS) online

portal (<http://earthexplorer.usgs.gov>). The spatial resolution of the image is 30 m in the visible and infrared bands. Temporal coincidence between field measurements and remote sensing acquisition is vital to improving the reliability of estimation when assessing water quality characteristics (Bonansea *et al.* 2015). For this reason, an image acquired on March 24, 2015 was the best fit for the study. The image had zero percent cloud cover and therefore atmospheric correction was deemed unnecessary. The individual bands were converted from DN's to Top Of Atmosphere (TOA) reflectance using calibration factors given with the data. Subsequently, NDVI was quantified using Equation 1 (Tucker *et al.* 1979).

$$NDVI = \frac{NIR-RED}{NIR+R} \dots \dots \dots \text{Equation 1}$$

where *NIR* and *RED* are the TOA reflectance of the near-infrared and red bands, respectively. NDVI values range from -1 to +1, where values approaching +1 correlate with dense vegetation. Water typically has an NDVI value of less than zero.

The NDWI was developed by Mcfeeters (1996). NDWI is a function of strong absorption by water in the short visible wavelengths and low reflectance in the longer visible and near infrared wavelengths. Low NDWI values are associated with low water content features including vegetation and soil particles (Rokni *et al.* 2014). In general, NDWI value for green vegetation is positive due to the weak water absorption near 1.24 μm (Zhang *et al.* 2008). Soils and soil particles are typically represented by negative NDWI values; this is because reflectance at 1.24 μm for wet and dry soils are greater than those at 0.86 μm (Xu, 2006). An NDWI image of the study was produced using Equation 2 to evaluate the capability of NDWI in detecting and quantifying water constituents.

$$NDWI = \frac{NIR-GREEN}{NIR+GREEN} \dots \dots \dots \text{Equation 2}$$

where *GREEN* is the TOA green light reflectance and *NIR* is the TOA near-infrared (NIR) reflectance. NDWI value ranges from -1 to +1, where, as values increase above 0, they indicate the presence of extensive deep water bodies while values less than 0 represent features with low water content (Mcfeeters, 1996).

Developing and testing models

In this study, a 45 m buffer around each sample point was used as a zone to compute summary statistics of reflectance (minimum, maximum, mean and standard deviation) of all nine bands as well as the NDVI and NDWI images. Preliminary analysis showed that the mean spectral values were most suitable for this analysis; therefore they were chosen for further statistical analysis. The zonal mean of each sample was registered with the corresponding observed turbidity and chlorophyll-a values. This was done to allow efficient data handling and for the creation of a single, complete and organised dataset that can be used in a statistical analysis.

Least squares regression models were produced to investigate the relationships between field measurements of the selected water quality variables and mean values of upwelling reflectance in the individual bands, NDVI and NDWI. Natural logarithm was used to transform the laboratory measured chlorophyll-a concentrations, since this was found to be better correlated with Landsat data (e.g. Sriwongsitanon *et al.* 2011; Bonansea *et al.* 2015). The goodness-of-fit was measured using the coefficient of determination (R^2) statistic. Root Mean Square Error (RMSE) was used to measure the difference between values predicted by the predictive models and the observed data (Equation 3).

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (y_i - x_i)^2}{n}} \dots\dots\dots\text{Equation 3}$$

where y_i is the field-observed value and x_i is the modeled value, consistent with a specific sample location.

Results

Preliminary analysis revealed that models developed using bands 5, 6, 7, NDVI and NDWI were the best performing models in estimating the selected water quality parameters. Therefore the results reported here focus on these models. Table 18.2 shows the predictive models for ln(chlorophyll-a) and turbidity. The R^2 for chlorophyll-a ranged from 0.14 (red band (band 4)) to 0.908 (NDVI). Note that the red band (band 4) is among the weak models that were excluded after the preliminary analysis; it is mentioned here for the purpose of comparison only. The strongest correlation between chlorophyll-a and individual bands was found for the near-infrared band ($R^2 = 0.64$; $RMSE = 1.33$). Weak relationships were seen in the shortwave infrared bands ($R^2 = 0.28$, $RMSE = 9.67$ and $R^2 = 0.25$; $RMSE = 1.92$). NDVI ($R^2 = 0.91$; $RMSE = 0.67$) performed better than NDWI ($R^2 = 0.85$; $RMSE = 0.85$) in estimating chlorophyll-a. All the models based on individual bands as well as indices were significant ($p < 0.001$). Figure 18.2 shows scatter plots of observed ln(chlorophyll-a) and Landsat-estimated chlorophyll-a. Maps of the spatial distribution of the estimated chlorophyll-a by the five models are shown in Figure 18.4. The R^2 for turbidity ranged from 0.09 (Green band) to 0.60 (NDWI). It should be noted that the green band (band 4) is mentioned for the purpose of comparison only. The near-infrared Band 5 ($R^2 = 0.48$; $RMSE = 3.8$) showed the strongest correlation compared to the shortwave infrared bands (band 6: $R^2 = 0.27$, $RMSE = 6.25$, band 7: $R^2 = 0.25$, $RMSE = 4.64$). Turbidity prediction capability was strongest with NDWI compared to prediction with NDVI ($R^2 = 0.60$ vs. 0.57 and an $RMSE$ of 3.44 vs. 3.57). A significance level of $p < 0.001$ was observed across all models between observed turbidity and Landsat products. The scatter plots produced from the regression analysis of observed turbidity and Landsat-estimated turbidity are shown in Figure 18.3. The spatial distribution of turbidity estimated by the presented models is shown in Figure 18.5.

Table 18.2: Statistical results of correlation analysis of ln(chlorophyll-a) and turbidity for the best performing Landsat 8 products. p at a confidence level of 95%.

Chlorophyll-a					
	Band 5	Band 6	Band 7	NDVI	NDWI
p	<0.001	<0.001	<0.001	<0.001	<0.001
R^2	0.64	0.28	0.25	0.91	0.85
RMSE	1.33	9.67	1.92	0.67	0.85
Turbidity					
	Band 5	Band 6	Band 7	NDVI	NDWI
p	<0.001	<0.001	<0.001	<0.001	<0.001
R^2	0.48	0.27	0.25	0.57	0.60
RMSE	3.81	6.25	4.64	3.57	3.44

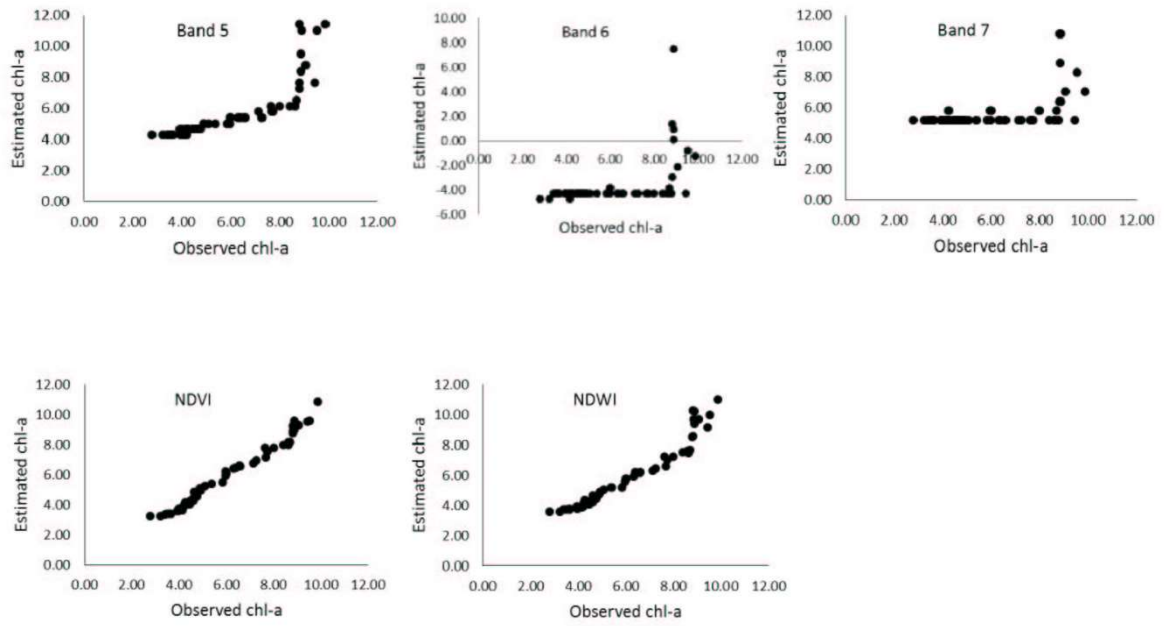


Figure 18.2: Best performing ln(chlorophyll) models using band 5, band 6, band 7, NDVI and NDWI

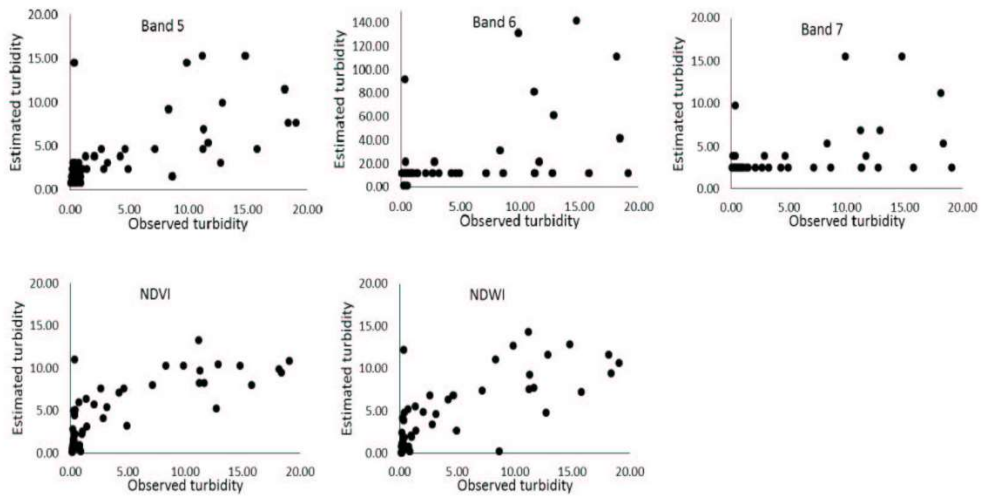


Figure 18.3: Best performing turbidity models using band 5, band 6, band 7, NDVI and NDWI

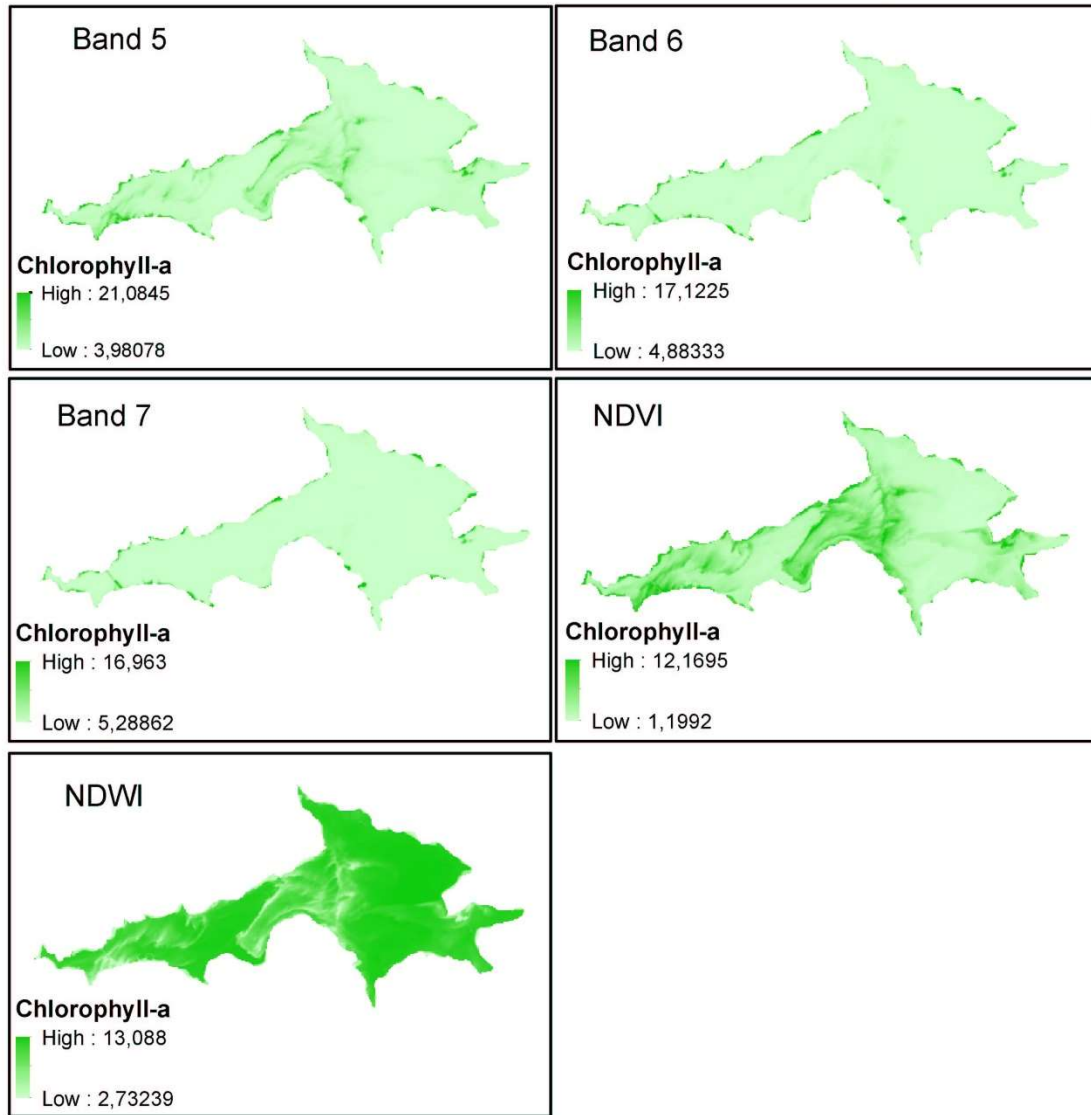
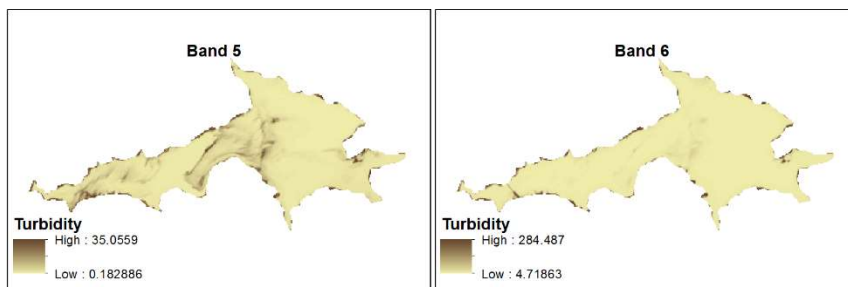


Figure 18.4: Spatial distribution of chlorophyll-a in the Hartbeespoort Dam



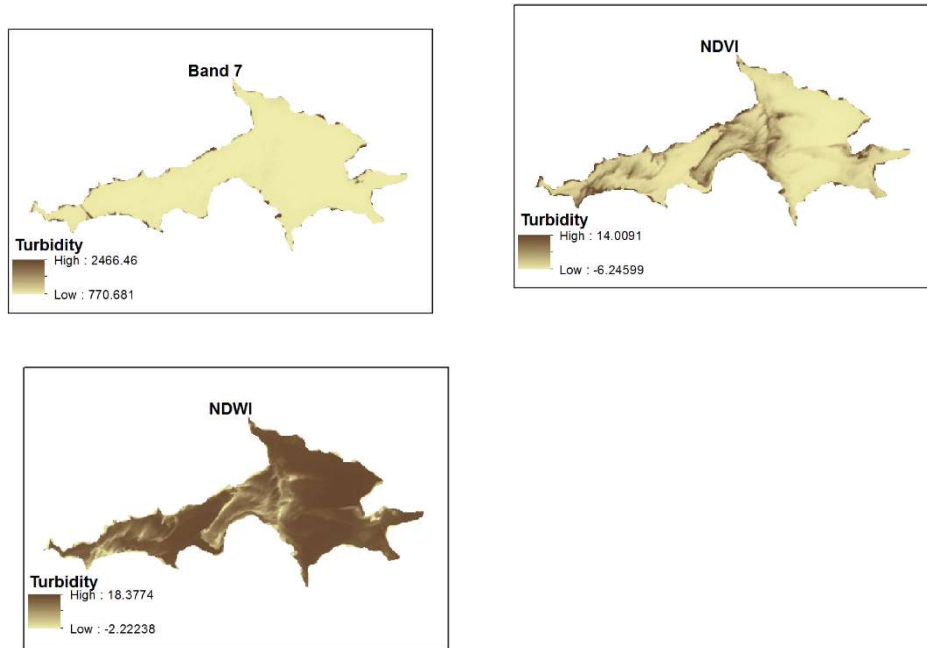


Figure 18.5: Spatial distribution of turbidity in the Hartbeespoort Dam

Discussion

The results confirm that there is a relationship between the selected water quality indicators (chlorophyll-a and turbidity) and Landsat 8 bands 5, 6 and 7 as well as NDVI and NDWI. The results obtained in this study showed that both chlorophyll-a and turbidity can be estimated using Landsat 8 bands 5, 6 and 7 as well as NDVI and NDWI. These results were comparable with those found by other studies such as Bonansea *et al.* (2015) who used Landsat 8 data to estimate chlorophyll-a and Secchi disk transparency in an inland lake.

This study also found that the long wavelength (near-infrared to thermal-infrared) bands as well as NDVI and NDWI were most suitable for estimating the selected water quality parameters. The near-infrared band displayed the strongest correlation with the selected water quality parameters compared to other individual Landsat 8 bands. NDWI performed better than NDVI in estimating the concentrations of water quality parameters. The low correlations observed between shortwave-infrared 1 and shortwave-infrared 2 with chlorophyll-a is a result of the low depth penetration in water-bodies of mid-infrared wavelength radiations (Allan *et al.* 2011). Infrared light is absorbed by water, and any upwelling reflectance indicates the presence of constituents. Chlorophyll-a fluorescence increases in the near-infrared wavelengths, making the wavelength suitable for the discrimination of chlorophyll-a. The long wavelength of infrared electromagnetic radiation is less affected by Rayleigh scattering than other short wavelength electromagnetic radiations are (Xing *et al.* 2007). It is noteworthy that the model using Near infrared band estimated $\ln(\text{chlorophyll-a})$ concentrations accurately up to approximately $9 \mu\text{g/l}$ (Figure 18.4).

The relationship between turbidity and upwelling radiation is determined by the size and colour of particles in the water. Low-to-moderate levels of turbidity can be discriminated using shorter wavelength products (Ritchie *et al.* 1983). Wang *et al.* (2007) found that low concentrations of suspended sediments can be discriminated using wavelengths between 430–835 nm (coastal to near-infrared bands). Zhou *et al.* (2006) found that the performance of bands

green to near-infrared is weaker when predicting turbidity in waters with a high variation in suspended sediments concentration in eutrophic to hypertrophic conditions. Turbid water-bodies exhibit higher reflectance especially at higher wavelengths (Torbick *et al.* 2008). Reliable estimates of turbidity can be produced by contrasting between the red and near-infrared wavelengths. Bottom (floor) reflectance from shallow waters which are common along dam banks and docks hamper the retrieval of accurate turbidity estimations using NDVI (Kleynhans *et al.* 2011).

In conclusion, the study reported here demonstrated that medium resolution satellite imagery provides an empirical method of retrieving information on the status and dynamics of water quality in inland lakes. The key advantages of medium resolution satellite imagery in water quality assessments highlighted in this study are the ability to retrieve the variation in water quality parameters. These capabilities provide an alternative to *in situ* water quality assessments that require large financial investments, are labour intensive and provide incomplete information on the status and dynamics of water quality. The combination for Landsat imagery and statistical modelling proves to be a valuable tool that can be applied in water quality monitoring in inland lakes.

Acknowledgements

This study was funded by the University of Johannesburg. We thank the Zoology Department (University of Johannesburg) for helping us in the field surveys and laboratory analysis of the data. Our deepest appreciations go to the Harties Boat Company for helping in the collection of water samples by providing us with boat cruise services at no cost. We also thank Mr Teboho Anthony Makhubu for the help he lent during the sampling campaign.

References

- Akpanyung, E.O., Akanemesang, U.M., Akpakpan, E.I. and Anodoze, N.O. 2014. Levels of heavy metals in fish obtained from two fishing sites in Akwa Ibom State, Nigeria. *African Journal of Environmental Science and Technology*, 8, pp. 416-421.
- Allan, M.G., Hamilton, D.P., Hicks, B.J. and Brabyn, L. 2011. Landsat remote sensing of chlorophyll a concentrations in central North Island lakes of New Zealand. *International Journal of Remote Sensing*, 32, pp. 2037-2055.
- Ashton, P.J., Chutter, P.M., Cochrane, K.L., De Moor, F.C., Hely-Hutchinson, J.R., Jarvis, A.C., Robarts, R.D., Scott, W.E., Thornton, J.A., Twinch, A.J. and Zohary, T., 1985. *Limnology of hartbeespoort dam*. National Scientific Programmes Unit: CSIR.
- Bonansea, M. and Fernandez, R.L. 2013. Remote sensing of suspended solids concentration in a reservoir with frequent wildland fires on its watershed. *Water Science and Technology*, 67, pp. 217-223.
- Bonansea, M., Rodriguez, M.C., Pinotti, L. and Ferrero, S., 2015. Using multi-temporal Landsat imagery and linear mixed models for assessing water quality parameters in Río Tercero reservoir (Argentina). *Remote Sensing of Environment*, 158, pp. 28-41.
- Carpenter, S.R., Stanley, E.H. and Vander Zanden, M.J., 2011. State of the world's freshwater ecosystems: physical, chemical, and biological changes. *Annual Review of Environment and Resources*, 36, pp. 75-99.
- Dekker, A.G., Brando, V.E., Anstee, J.M., Pinnel, N., Kutser, T., Hoogenboom, E.J., Peters, S., Pasterkamp, R., Vos, R., Olbert, C. and Malthus, T.J. 2002. Imaging spectrometry of water. In *Imaging spectrometry* (pp. 307-359). Springer Netherlands.
- Ding, H. and Elmore, A.J. 2015. Spatio-temporal patterns in water surface temperature from Landsat time series data in the Chesapeake Bay, USA. *Remote Sensing of*

- Environment*, 168, pp. 335-348.
- Dörnhöfer, K. and Oppelt, N. 2016. Remote sensing for lake research and monitoring—Recent advances. *Ecological Indicators*, 64, pp. 105-122.
- Giardino, C., Bresciani, M., Valentini, E., Gasperini, L., Bolpagni, R. and Brando, V.E., 2015. Airborne hyperspectral data to assess suspended particulate matter and aquatic vegetation in a shallow and turbid lake. *Remote Sensing of Environment*, 157, pp. 48-57.
- Gordon, H.R. and Morel, A.Y. 2012. *Remote assessment of ocean color for interpretation of satellite visible imagery: A review* (Vol. 4). Springer Science & Business Media.
- Harding, W.R. 2015. Living with eutrophication in South Africa: a review of realities and challenges. *Transactions of the Royal Society of South Africa*, 70, pp. 155-171.
- Holm-Hansen, O. and Riemann, B. 1978. Chlorophyll a determination: improvements in methodology. *Oikos*, pp. 438-447.
- Keith, D.J., Milstead, B., Walker, H., Snook, H., Szykman, J., Wusk, M., Kagey, L., Howell, C., Mellanson, C. and Druke, C. 2012. Trophic status, ecological condition, and cyanobacteria risk of New England lakes and ponds based on aircraft remote sensing. *Journal of Applied Remote Sensing*, 6, pp. 063577-1.
- Kleynhans, W., Olivier, J.C., Wessels, K.J., Salmon, B.P., Van den Bergh, F. and Steenkamp, K., 2011. Detecting land cover change using an extended Kalman filter on MODIS NDVI time-series data. *IEEE Geoscience and Remote Sensing Letters*, 8, pp. 507-511.
- Lau, S.S.S. and Lane, S.N. 2001. Continuity and change in environmental systems: the case of shallow lake ecosystems. *Progress in physical geography*, 25, pp. 178-202.
- Matthews, M.W. 2014. Eutrophication and cyanobacterial blooms in South African inland waters: 10 years of MERIS observations. *Remote Sensing of Environment*, 155, pp. 161-177.
- McFeeters, S.K. 1996. The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *International journal of remote sensing*, 17, pp. 1425-1432.
- Moss, B. 2012. Cogs in the endless machine: lakes, climate change and nutrient cycles: a review. *Science of the Total Environment*, 434, pp. 130-142.
- Munyati, C. 2015. A spatial analysis of eutrophication in dam reservoir water on the Molopo River at Mafikeng, South Africa. *Sustainability of Water Quality and Ecology*, 6, pp. 31-39.
- Nazeer, M. and Nichol, J.E. 2016. Development and application of a remote sensing-based Chlorophyll-a concentration prediction model for complex coastal waters of Hong Kong. *Journal of Hydrology*, 532, pp. 80-89.
- Oberholster, P.J. Botha, A.M. and Grobbelaar, J.U. 2004. Microcystis aeruginosa: source of toxic microcystins in drinking water. *African Journal of Biotechnology*, 3, pp. 159-168.
- O'Reilly, J.E., Maritorena, S., Siegel, D.A., O'Brien, M.C., Toole, D., Mitchell, B.G., Kahru, M., Chavez, F.P., Strutton, P., Cota, G.F. and Hooker, S.B. 2000. Ocean color chlorophyll a algorithms for SeaWiFS, OC2, and OC4: Version 4. *SeaWiFS postlaunch calibration and validation analyses, Part, 3*, pp. 9-23.
- Reinart, A. and Kutser, T. 2006. Comparison of different satellite sensors in detecting cyanobacterial bloom events in the Baltic Sea. *Remote Sensing of Environment*, 102, pp. 74-85.
- Ritchie, J.C., Schiebe, F.R. and Cooper, C.M. 1983. Spectral measurements of surface

- suspended matter in an oxbow lake in the lower Mississippi Valley. *Journal of Freshwater Ecology*, 2, pp. 175-181.
- Rokni, K., Ahmad, A., Selamat, A. and Hazini, S. 2014. Water feature extraction and change detection using multitemporal Landsat imagery. *Remote Sensing*, 6, pp. 4173-4189.
- Schroeter, L. and Gläßer, C. 2011. Analyses and monitoring of lignite mining lakes in Eastern Germany with spectral signatures of Landsat TM satellite data. *International Journal of Coal Geology*, 86, pp. 27-39.
- Shekede, M.D., Kusangaya, S. and Schmidt, K. 2008. Spatio-temporal variations of aquatic weeds abundance and coverage in Lake Chivero, Zimbabwe. *Physics and Chemistry of the Earth, Parts A/B/C*, 33, pp. 714-721.
- Siri, G.P., Sithebe, N.P. and Ateba, C.N. 2011. Identification of Klebsiella species isolated from Modimola dam (Mafikeng) North West Province South Africa. *African Journal of Microbiology Research*, 5, pp. 3958-3963.
- Sriwongsitanon, N., Surakit, K. and Thianpopirug, S. 2011. Influence of atmospheric correction and number of sampling points on the accuracy of water clarity assessment using remote sensing application. *Journal of Hydrology*, 401, pp. 203-220.
- Theologou, I., Patelaki, M. and Karantzalos, K. 2015. Can single empirical algorithms accurately predict inland shallow water quality status from high resolution, multi-sensor, multi-temporal satellite data? *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 40, pp. 1511-1516.
- Torbick, N., Hu, F., Zhang, J., Qi, J., Zhang, H. and Becker, B. 2008. Mapping chlorophyll-a concentrations in West Lake, China using Landsat 7 ETM+. *Journal of Great Lakes Research*, 34, pp. 559-565.
- Tucker, C.J. 1979. Red and photographic infrared linear combinations for monitoring vegetation. *Remote sensing of Environment*, 8, pp. 127-150.
- Wang, Y., Yan, F., Zhang, P. and Dong, W. 2007. Experimental research on quantitative inversion models of suspended sediment concentration using remote sensing technology. *Chinese geographical science*, 17, pp. 243-249.
- Xing, X.G., Zhao, D.Z., Liu, Y.G., Yang, J.H., Xiu, P. and Wang, L. 2007. An overview of remote sensing of chlorophyll fluorescence. *Ocean Science Journal*, 42, pp. 49-59.
- Xu, H. 2006. Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. *International Journal of Remote Sensing*, 27, pp. 3025-3033.
- Zhang, W., Lu, Q., Gao, Z. and Peng, J. 2008. Response of remotely sensed normalized difference water deviation index to the 2006 drought of eastern Sichuan Basin. *Science in China Series D: Earth Sciences*, 51, pp. 748-758.
- Zhou, W., Wang, S., Zhou, Y. and Troy, A. 2006. Mapping the concentrations of total suspended matter in Lake Taihu, China, using Landsat-5 TM data. *International Journal of Remote Sensing*, 27, pp. 1177-1191.
- Zohary, T. and Breen, C.M. 1989. Environmental factors favouring the formation of *Microcystis aeruginosa* hyperscums in a hypertrophic lake. *Hydrobiologia*, 178, pp. 179-192.

Chapter 19: Assessing seasonal changes in waterbodies within wetlands using Landsat imagery: The case of southern Johannesburg

Lutendo Zwedzi¹ and Solomon G. Tesfamichael^{1*}

¹Department of Geography, Environmental Management, and Energy Studies,
University of Johannesburg

*Corresponding author: sgtesfamichael@uj.ac.za

Abstract

In South Africa, water is a scarce resource that needs efficient management supported by accurate monitoring. This study focuses on assessing the extent of waterbodies within wetlands along the Klip River in the south of Johannesburg. Maximum likelihood supervised classification method was performed in four seasons (summer, autumn, winter, spring) to determine how best the classification can discriminate waterbodies from other land cover types in the wetlands. Five classes were created in the classifications: waterbodies, trees, grass, bare and wetland vegetation. Waterbodies were then extracted from the five classes and compared with reference data obtained from the South African National Biodiversity Institute (SANBI) and Google EarthTM. Results indicated overall classification accuracies in all seasons ($\geq 70\%$). The study also found the variation in the number of waterbodies identified through classification across seasons. This study demonstrated the utility of Landsat data to monitor the seasonal dynamics of waterbodies in wetland systems.

Keywords: Waterbodies, wetlands, seasonal changes, Landsat, image classification

Introduction

Wetlands provide important ecosystem services such as habitat to different flora and fauna, water for domestic consumption and agricultural activities, and purifiers of polluted water (Vermaak, 2009; Zeleke *et al.* 2015, Hu *et al.* 2017; Woldemariam *et al.* 2018). Due to human activities, mining activities and agricultural purposes, wetlands have been under threat, resulting in deterioration of their ecological services (McCarthy and Venter, 2006). Wetlands in the Klip River system have been drained and converted to farmland for cultivation (www.nda.agric.za, 2008). In addition, contamination related to acid mine drainage (AMD) released from mining activities is compounding the problems (Humphries *et al.* 2017). Due to these activities, waterbodies within wetlands are under severe stress with likely impacts on both their quality and quantity.

It is therefore essential for monitoring waterbodies within wetlands on a regular basis. Traditional methods of monitoring wetlands in general include assessment of nutrient conditions (Chen *et al.* 2019), soil characterisation (Chen *et al.* 2019) and vegetation sampling (Thomas *et al.* 2015). Such methods are however labour-intensive, time-consuming, relatively expensive and unable to cover large spatial areas in a short period of time (van Deventer *et al.* 2018). Remote sensing offers efficient tools for extracting and monitoring changes of waterbodies and wetlands over time. Essentially, remote sensing assists in wetland characterisation by allowing for a wide spatial coverage and repeated monitoring schemes in a

cost effective manner (Jensen, 2005; Jones *et al.* 2009; van Deventer *et al.* 2018). As a result, it is becoming a standard tool in the assessment of wetland ecosystems. For example, across India, wetlands were delineated in various districts using IRS-1A/B LISS I/II data in a study by Garg *et al.* (1998). Lucas and Milne (2016) used different sensors (MODIS, SAR, Optical remote sensing) to classify wetland types as well as understanding their dynamics and pressures in different seasons in Botswana, South Sudan and Australia. In another study, Landsat 8 was used to monitor unsustainable wetlands in south eastern Iran (Maleki *et al.* 2018). These studies in general have demonstrated the capability of remote sensing in mapping the characteristics of wetlands and/or associated waterbodies. Studies or management-oriented projects have also been undertaken to map wetlands in South Africa (e.g. Mbona *et al.* 2015; Schael *et al.* 2015; Fisher *et al.* 2017; Grundling *et al.* 2017; Rebelo *et al.* 2017). In a review of the South African Inventory of Inland Aquatic Systems, van Deventer *et al.* (2018) highlighted the shortage of mapping at fine spatial scales (such as sub-quaternary catchment) in South Africa. There is, therefore, a need to utilise commonly used remotely sensed data to map water bodies that vary greatly in size within the urban environment. This study aims to identify waterbodies with widely varying spatial extents (68 – 285227 m²) within wetland systems using Landsat imagery. In addition, the study will investigate the accuracy of identifying waterbodies in different seasons. This objective is important in that it indicates if waterbodies can be mapped at any time of the year, and by doing so, it informs the question whether or not the potential exists to monitor waterbodies throughout the year. It should be noted that the seasonal comparison is made based on a single image per season due to inconsistent data availability throughout each season.

Methods

Study area

The study area covers ground south of Johannesburg (Figure 19.1) and is traversed by the Klip River system that contains numerous wetlands. These wetlands host waterbodies and other land cover types. Temperatures in the area are warm to hot in summer (January) and cool to cold in winter (July) and include dry winters in autumn (May) (South African Weather Services, 2018). The geology of the study areas includes permian sandstones and the vegetation of the Klip River consists of grasslands and bushlands (Mucina and Rutherford, 2006). The wetlands and waterbodies in the area are located within or near formal and informal settlements, which in turn affect the wetlands. Furthermore, water discharges associated with mining activities in the Central Rand Goldfield drain pollutants into the wetlands of the study area (Humphries *et al.* 2017). Efficient monitoring of the waterbodies (and wetlands) in the study area is useful not only to mitigate the impacts of pollution but also to improve ecosystem services within an urban environment (Wang and Zhu, 2011).

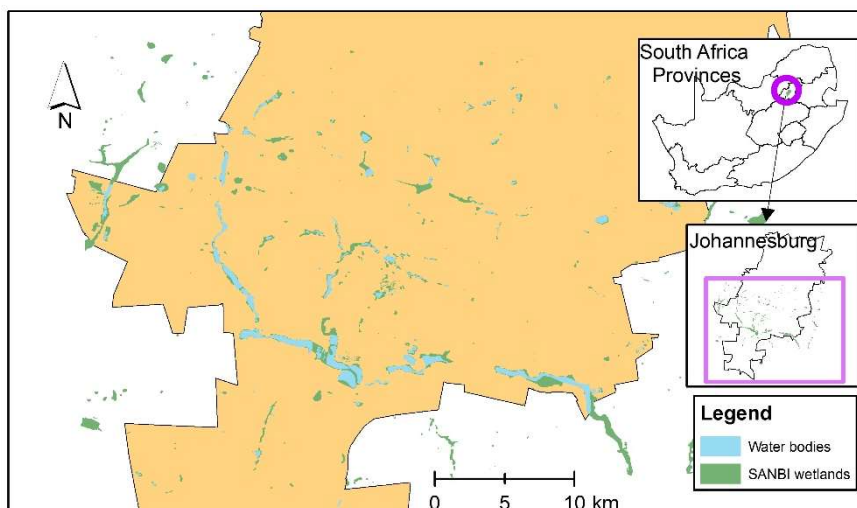


Figure 19.1: Study area showing waterbodies and wetlands, south of Johannesburg

Landsat data

Landsat Operational Land Imager (OLI) 8 was downloaded from the United States Geological Survey (USGS) Earth Explorer. Landsat OLI images consist of 11 bands (Table 19.1) with a 30 meter (m) spatial resolution for the visible and infrared portions of the electromagnetic energy. Four images were downloaded for the study for the year 2016. These images represented summer (December – February), autumn (March – May), winter (June – August) and spring (September – November) seasons in the area (South African Weather Services, 2018). Ideally, multiple images acquired within a season should be used to have reliable representation. This, however, can be achieved in the case of uninterrupted data availability such as for the coarse spatial resolution Moderate Resolution Imaging Spectroradiometer (MODIS) data. Several Landsat images were missing in the study area for all seasons; as a result we opted to utilise a single image that was deemed representative of a calendar season. It should be acknowledged that the calendar season may deviate from the long-term seasonal behaviour, and therefore future studies must take this into consideration. These included one per season; 05 January (summer), 27 May (autumn), 06 July (winter) and 02 November (spring). A multispectral image was created by combining the visible and infrared bands for each season and subsequently the image with the study areas coverage was extracted for further analysis.

Table 19.1: Landsat OLI bands used to create multispectral image per season in this study (data source: <https://earthexplorer.usgs.gov/>)

Band name	Band width (micrometer)	Spatial resolution
Coastal/Aerosol	0.435 – 0.451	30 m
Blue	0.452 – 0.512	30 m
Green	0.533 – 0.590	30 m
Red	0.636 – 0.673	30 m
NIR	0.851 – 0.879	30 m
SWIR-1	1.566 – 1.651	30 m
Pan	0.503 – 0.676	15 m

Image classification and accuracy assessment

Maximum likelihood supervised classification was performed to identify waterbodies in this study, since this method allows for a great deal of control on the classification process and the resultant map. In supervised classification, the analyst should have prior knowledge of the study area's geography and have an idea of the spectral properties of each land cover class (Jensen, 2005). This knowledge is used to train the land cover types by relating them to spectral (reflectance) information at selected sampling locations. A two-step classification was employed in the study. The first step generated trained and generated five land cover classes including water, grass, trees, wetland vegetation and bare land, although the focus of the classification was identifying waterbodies. This step was implemented to avoid the potential of mixing certain land cover types such as between waterbodies and wetland vegetation. The second step involved combining the non-water bodies resulting in a binary map showing water and non-water bodies. Training data were created by manually digitising polygons representing the five land cover types. These training data were subsequently used as inputs in the maximum likelihood supervised classification to classify the entire study area.

Accuracy was assessed by using randomly generated sample points on the classified waterbodies and non-waterbody categories. We sought to achieve two goals in deciding the sample size: firstly we decided to have a sample size that is believed to be representative of the classified number of waterbodies. Secondly, we used an equal number of samples across seasons in order to standardise the accuracy assessment. Accordingly, a total of 40 points were generated for each season and overlaid on the two classes; this sample size represented at least 20% of waterbodies per season. These points were then overlaid on Google Earth™ which served as reference data in the study. Accuracy was then assessed using a confusion matrix which compares the level of agreement between reference and classified samples (Congalton, 2001; Congalton and Green, 2009). The evaluation uses three metrics, including overall accuracy, producer's accuracy and user's accuracy. Overall accuracy quantifies the total number of correctly classified samples for all classes and is computed using Equation 1. Producer's accuracy measures the level of accuracy of a class relative to the class in the reference data; this accuracy indirectly measures how much of the samples of a class in the reference data set is missed (omitted). Producer's accuracy is calculated using Equation 2. User's accuracy compares the degree of accurate identification of samples of a class with the number of samples assigned to that class by the classification process. As such this statistic may incorrectly allocate samples of a class to another class, resulting in an error commonly referred to as commission error. The user's accuracy is calculated using Equation 3.

$$\text{Overall accuracy (\%)} = \frac{\text{Sum of correctly classified samples}}{\text{Total number of samples}} \times 100 \quad \text{Equation 1}$$

$$\text{Producer's accuracy (\%)} = \frac{\text{Number of correctly classified samples in a class}}{\text{Total number of reference samples in that class}} \times 100$$

Equation 2

$$\text{User's accuracy (\%)} = \frac{\text{Number of correctly classified samples in a class}}{\text{Total number of classified samples in that class}} \times 100$$

Equation 3

Results and discussion

Statistics relating to the classification accuracies for all seasons are presented in Table 19.2. The best overall classification accuracies were obtained in summer and winter (98%), while spring had the lowest accuracy at 70%. The producer's accuracies for water are similar to the overall accuracy in terms of ranking in which summer and winter had the best accuracies. The user's accuracies for water bodies were the best in summer, autumn and winter (100%), although this accuracy was also high for spring.

Seasons	Producer's accuracy (%)	User's accuracy (%)	Overall accuracy (%)
Summer	Water=95 Non-water=100	Water=100 Non-water=95	0.98
Autumn	Water=100 Non-water=95	Water=95 Non-water=100	0.88
Winter	Water=95 Non-water=100	Water=100 Non-water=95	0.98
Spring	Water=45 Non-water=95	Water=90 Non-water=34	0.70

Figure 19.2 shows the classified water body maps of the four seasons, while Table 19.3 summarises the number and areas of classified waterbodies. The number of waterbodies in summer was 34 while this number increased to 98 in autumn, decreased to 42 in winter and finally peaked at 293 in spring (Table 19.3). Areas for each season were also calculated with spring having the largest area of waterbodies mapped and summer having the smallest area of the waterbodies (Table 19.3).

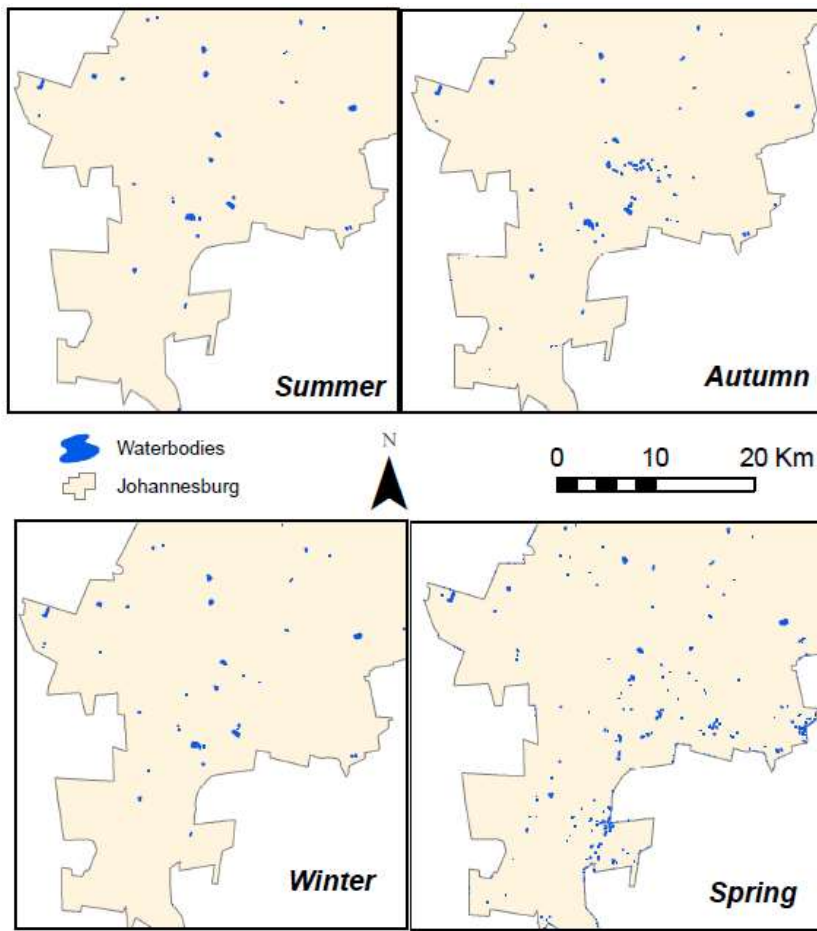


Figure 19.2: Waterbodies identified using maximum likelihood classification in January, May, July and November 2015

Table 19.3: Number of waterbodies and area identified by the maximum likelihood classification in the study

Seasons	Number of water bodies	Total area (m ²)
Summer	34	2630985
Autumn	98	3719906
Winter	42	2804705
Spring	239	4558635

The results of this study generally showed good accuracy. Overall accuracy of water vs. non-water accuracy were quite high in all seasons except spring, which has 70% accuracy (Table 19.2). Of relevance to the purpose of this study, the water class was estimated at high producer’s accuracy in all seasons but spring. On the other hand, the user’s accuracy was high for all seasons ($\geq 90\%$). The number of waterbodies identified per season (Table 19.3) should not be viewed as a contradiction to the accuracy matrix presented in Table 19.2, since the accuracy assessment samples do not include all waterbodies that were created by the classification. The high accuracy found in this study compares well with previous works elsewhere. Ko *et al.* (2015), for example, used Landsat 8, TM and ETM+ to identify which sensor provides the best classification of waterbodies and achieved overall accuracy of Landsat

8 OLI to be 0.99. Similarly, Jakovljević *et al.* (2019) also mapped waterbodies using SVM, Rapid-Eye and Sentinel-2 to compare the different sensors and achieved overall accuracy between 0.88 and 0.94. Szabó *et al.* (2019) also used multispectral remote sensing for land cover mapping in wetlands to compare the differences between hyperspectral aerial and Landsat images. They achieved overall accuracies between 0.80 and 0.90. Studies have also delineated waterbodies within wetlands using Light Detection And Ranging (LiDAR) remote sensing systems successfully (e.g. Wu and Lane, 2016); such an approach can be powerful; however, data availability or cost should be taken into account. Our study used Landsat data to identify a variety of waterbodies within wetlands, achieving accuracies over 0.70. The study also showed the variation in the number of waterbodies across seasons. The summer season classification resulted in a low number of waterbodies; this could be attributed to the amount of vegetation that covers most of the area in the season. Similarly, winter has a low number of waterbodies, as can be expected in a season when there is low rainfall and a high loss of water, that result in the reduced extent of waterbodies or the drying of certain waterbodies.

Conclusion

In this paper, Landsat 8 OLI was tested for identifying waterbodies that have a large variation in spatial coverage within wetlands. Maximum likelihood supervised classification was used to map waterbodies in the four seasons. The results showed high levels of accuracy in mapping the waterbodies, based on overall, producer's and user's accuracies. The only exception could be the spring season, when producer's accuracy was low in comparison to other seasons. The study also established the potential effect of season on the amount of waterbodies that can be identified through image interpretation. This finding justifies the reason we should encourage the use of remote sensing that gives users a rapid method of accounting waterbodies in different seasons. The finding also shows the importance of taking vegetation into consideration for accurate mapping of waterbodies, particularly in vegetation growing seasons. Overall, this study strengthens previous findings on the utility of Landsat in mapping and monitoring waterbodies of different sizes. It is important to note that our study focusing on seasonal comparison relied on a single image per season and therefore the conclusion should only be accepted as a crude indicator. Further studies are encouraged to use multitemporal images per season such as in the case of time-series analysis, although this strategy may require data availability at regular time intervals, which could not be satisfied for the Landsat data used in the present study.

Acknowledgments

The University of Johannesburg provided the necessary infrastructure to collect and analyse the data for the research. One of the authors of the research was funded by the National Research Foundation (NRF) Master's Scholarship programme.

References

- Chen, W., Cao, C., Liu, D., Tian, R., Wu, C., Wang, Y., Qian, Y., Ma, G., Bao, D. 2019. A valuating system for wetland ecological health: Case study on nineteen major wetlands in Beijing-Tianjin-Hebei region, China. *Science of the Total Environment*, 666: 1080–1088.
- Congalton, R. G. 2001, Accuracy assessment and validation of remotely sensed and other spatial information. *International Journal of Wildland Fire*, 10: 321–328.
- Congalton, R.G., Green, K. 2009. Assessing the accuracy of remotely sensed data. 2nd ed.

- Boca Raton: CRC Press.
- Fisher, R.C., Gouws, J., Niewoudt, H., Adams, T. A., Ebrahim, Z. 2017, Wetland groundtruthing for catchment SQ4 ID 9433 on the Agulhas Plain. Wetlands data set compiled by the South African National Parks: Scientific Services, Cape Research Centre. SANParks, Cape Town.
- Garg, J.K., Singh, T. S., Murthy, T.V.R. 1998, Wetlands of India. Scientific Note: RSAM/SAC/RESA/PR/01/98. Space Applications Centre, Ahmedabad, India.
- Ghosh, S., Thakur, P. K., Sharma, R., Nandy, S., Garg, V., Amarnath, G., Bhattacharyya, S. 2017, The potential applications of satellite altimetry with SaRAL/altiKa for Indian inland waters, Proceedings of National Academy of Sciences, India Section A Physical Sciences, 87: 661–677.
- Grundling, P., Grundling, A. T., Pretorius L., Mulders, J., Mitchell, S. 2017, South African peatlands: ecohydrological characteristics and socio-economic value. WRC Report No. 2346/1/17. Water Research Commission, Pretoria.
- Hu, S., Niu, Z., Chen, Y., Li, L., Zhang, H. 2017, Global wetlands: Potential distribution, wetland loss and status. *Science of the Total Environment*, 586: 319–327.
- Humphries, M. S., McCarthy, T. S., Pillay, L. 2017, Attenuation of pollution arising from acid mine drainage by a natural wetland on the Witwatersrand, *South African Journal of Science*, 2017; 113(1/2), <http://dx.doi.org/10.17159/sajs.2017/20160237>.
- Jakovljević, G., Govedarica, M., Álvarez-Taboada, F. 2019, Waterbody mapping: a comparison of remotely sensed and GIS open data sources, *International Journal of Remote Sensing*, 40: 2936–2964.
- Jensen, J.R. 2005, *Introductory digital image processing* (3rd edition). City: Prentice Hall.
- Jones, K., Lanthiera, Y., van der Voetb, P. *et al.* 2009, Monitoring and assessment of wetlands using earth observation: the Glob-Wetland project. *Journal of Environmental Management*, 90: 2154–2169.
- Ko, B. C., Kim, H. H., Nam, Y. J. 2015, Classification of potential waterbodies using Landsat 8 OLI and a combination of two boosted Random Forest classifiers. *Sensors*, 15: 13763–13777.
- Lucas, R., Milne, T. 2016, Remote sensing of wetland types: semiarid wetlands of Southern Hemisphere. In: Finlayson C. *et al.* (eds), *The wetland book*. Springer, Dordrecht. pp. 1–7.
- Maleki, S., Soffianian, A., Koupaei, S.S., Saachi, S., Pourmanafi, S. 2018, Application of remote sensing in monitoring Unsustainable wetlands: case study Hamun wetland. *Journal of the Indian Society of Remote Sensing*, 46: 1871–1879.
- Mbona, N., Job, N., Smith J., Nel, J., Holness, S., Memani, S. Dini, J. 2015, Supporting better decision-making around coal mining in the Mpumalanga Highveld through the development of mapping tools and refinement of spatial data on wetlands. WRC Report No. TT614/14. Water Research Commission, Pretoria.
- McCarthy, T.S., Venter, J. S. 2006, Increasing pollution levels on the Witwatersrand recorded in the peat deposits of the Klip River Wetland. *South African Journal of Science*, 102: 27–34.
- Mucina, L., Rutherford, M. C. 2006, *The vegetation of South Africa, Lesotho and Swaziland*. Publishers: South African National Biodiversity Institute, 807.
- Rebelo, A.J., Scheunders, P., Esler, K. J., Meire, P. 2017, Detecting, mapping and classifying wetland fragments at a landscape scale. *Remote Sensing Applications: Society and Environment*, 8: 212–223.

- Schael, D. M., Gama, P. T., Melly, B. L. 2015. Ephemeral wetlands of the Nelson Mandela Bay Metropolitan Area: Classification, biodiversity and management implications. (WRC) Report No. 2181/1/15. Water Research Commission, Pretoria.
- South Africa Weather Service (2018). How are the dates of the four seasons worked out? <http://www2.weathersa.co.za/learning/weather-questions/82-how-are-the-dates-of-the-four-seasons-worked-out>. Accessed on May 16, 2019.
- Szabó, L., Burai, P., Deák, B., Dyke, G. J., Szabó, S. 2019, Assessing the efficiency of multispectral satellite and airborne hyperspectral images for land cover mapping in an aquatic environment with emphasis on the water caltrop (*Trapa natans*). *International Journal of Remote Sensing*, 40: 5192–5215.
- Thomas, R. F., Kingsford, R. T., Lu, Y., Cox, S. J., Sims, N. C., Hunter, S. J. 2015, Mapping inundation in the heterogeneous floodplain wetlands of the Macquarie Marshes, using Landsat Thematic Mapper. *Journal of Hydrology*, 524: 194–213.
- Van Deventer, H., Smith-Adao, L., Petersen, C., Mbona, N., Skowno, A. and Nel, J. L. 2018. Review of available data for a South African Inventory of Inland Aquatic Ecosystems (SAIIAE). *Water SA*, 44: 184–199.
- Vermaak, V. 2009, A geomorphological investigation of the Klip River wetland, south of Johannesburg, M.Sc. in Environmental Sciences, University of the Witwatersrand.
- Wang, C.-y., Zhu, W.-p. 2011. Analysis of the Impact of Urban Wetland on Urban Temperature Based on Remote Sensing Technology. *Procedia Environmental Sciences*, 10: 1546–1552.
- Woldemariam, W., Mekonnen, T., Morrison, K., Aticho, A. 2018, Assessment of wetland flora and avifauna species diversity in Kafa Zone, Southwestern Ethiopia. *Journal of Asia-Pacific Biodiversity*, 11: 494–502.
- Wu, Q., Lane, C. R. 2016, Delineation and quantification of wetland depressions in the Prairie pothole region of North Dakota. *Wetlands*, 36: 215–227.
- Zelege A., Gadisa, T., Gebremichael, G. 2015, Diversity and relative abundance of bird species of Sheko District, Bench Maji zone, Southwest Ethiopia. *International Journal of Development & Research*, 5: 3975–3979.

Chapter 20: Hydrological modelling through regionalisation of parameters: A case of Mazowe Dam Catchment

Ellen Nhedzi Gozo

Department of Rural and Urban Development, Great Zimbabwe University,
P.O. Box 1235, Masvingo, Zimbabwe
gozoellen@gmail.com, enhedzi@yahoo.com

Abstract

Understanding catchment hydrology is key to water resource management, hence; hydro-meteorological data forms the basis for carrying out water resources assessments. This data can be obtained through direct measurements at hydro-meteorological stations or can be derived from remotely sensed data. However, inhibiting factors such as rugged terrain, inaccessibility of areas, lack of measuring infrastructure and lack of remote sensing information at appropriate temporal and spatial resolution can hinder the collection and availability of this information. In hydrology, regionalisation then comes into play to assign basic data to ungauged catchments. Regionalisation is best achieved through modelling. The Hydrologiska Byråns Vattenbalansavdelning (HBV) rainfall-runoff model was used to model two gauged sub-catchments of Mazowe Dam Catchment and parameters were transferred to the remaining two ungauged sub-catchments using the spatial proximity regionalisation method. Modelling was done for periods where there was complete hydro-meteorological data for the gauged catchments. The regionalisation parameters were tested on the gauged catchments and they showed high regression coefficients between the simulated and observed runoff. Therefore, the regionalisation parameters can be applied successfully in the assessment of water resources in these ungauged sub-catchments of Mazowe Dam.

Keywords: catchment; water resources management; regionalisation; HBV Model; hydrological modelling;

Introduction

Water resources management plays a central role in ensuring adequate supply of water for both humankind and biodiversity. The process however requires in-depth knowledge about the distribution and state of available water resources to ensure optimum development and utilisation of the resource. In this case, hydro-meteorological data such as precipitation, evaporation, discharge, transpiration and infiltration is required for the analysis of catchment dynamics in the plight of several natural and human induced changes in the catchments. The effects of water resource use, land use and climate change on water resources availability can only be assessed when the catchment hydrology is fully understood. This therefore calls for understanding catchment hydrology as a means to improve water resource use and management. However, the analysis of catchment hydrology is heavily dependent upon hydro-meteorological data.

The availability of hydrological-meteorological data is restricted in both temporal and spatial respects. Therefore, for many practical problems extension of existing data is an important task in hydrology (Seibert, 1999). Predicting hydrological variables in ungauged

catchments is one of the major issues in the hydrological sciences. According to Goswami, O'Connor *et al.* (2007), flow simulation in ungauged catchments is presently regarded as one of the most challenging tasks in surface water hydrology. Many of the ungauged catchments are located in the headwaters of rivers, in mountainous regions of the world having enormous potential for sustainable water resource development. However, due to inaccessibility, rugged and inhospitable terrain, and historical lack of foresight concerning the need to have these headwaters adequately gauged, their potential is not readily realizable. Hydrological regionalization, a process of transferring information from neighbouring catchments to the catchment of interest, is normally used to predict variables in ungauged catchments. The regression method and the spatial proximity method are the most widely used regionalisation techniques.

Catchment characteristics

There are four main tributaries in the catchment. Only one river used to be a perennial river but it has since seized to flow year all round due to reasons that are yet to be established. There are two runoff stations in the catchment that record flow from two of the four tributaries. The mean annual rainfall is 883mm. The annual evapotranspiration for the area is generally taken to vary from 1200mm to about 1500mm. There are mainly three types of soil in the catchment which are locally classified under the Zimbabwean Soil classification system as the Fersiallitic soils (Harare 5E heavy clays), Paraferallitic (sandy loams) and Lithosols which are sandy loams. The catchment is largely underlain by andesitic and dacitic metavolcanics and granitic rocks with a variable potential for groundwater occurrences depending on depth and spatial extend of both fracturing and secondary weathering. The land use in the area is mainly irrigated and rain fed agriculture (crop production). Crops grown are wheat, maize, citrus fruits, soya beans, barley and peas. Some areas are well vegetated with indigenous trees. The forests are dominated by the brachstegia species. Some patches of exotic trees such as gum trees and pine trees also appear in the basin. Figure 20.1 below shows the Mazowe Dam Catchment.

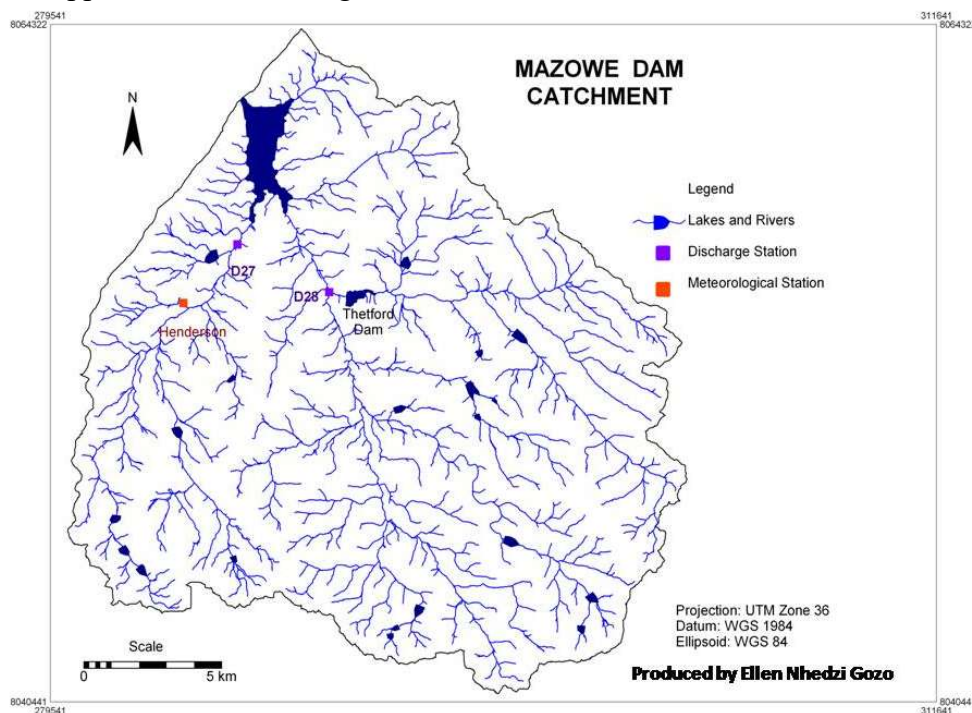


Figure. 20.1: Map showing the Mazowe Dam Catchment

Materials and methods

The main purpose of this study is to determine runoff from the ungauged catchments through a process of parameter transfer from the gauged catchments to ungauged catchments. A range of rainfall runoff models has been used in regionalisation studies (Lee, McIntyre *et al.* 2005). Commonly used models include the HBV model [Merz and Blöschl (2004), Gotzinger and Bardossy (2007), Parajka, Merz and Blöschl (2005), Seibert (1999), Hundecha and Bardossy (2004) and Booij (2005)], the IHACRES model (Croke, Merritt *et al.* 2004), and the Probability Distributed Model (Young 2006). Of these three, the HBV model was chosen because it has been applied in many model parameter transfer studies successfully and it was also applied in Ruwa, a catchment closer to the Mazowe Catchment by Liden and Harlin (2000) and they found it applicable. R Lidén, J Harlin *et al.* (2001) again applied the HBV in the hydrological modelling of fine sediments in a Zimbabwean River, the Odzi River. The HBV model was also applied in the stream flow of the Pungwe Project in the Manicaland province of Zimbabwe (SHMI 2003).

There are water abstractions points and small inland lakes along rivers that affect the runoff measured at the gauging stations. These abstractions and the effect of inland lakes need to be taken into account during the modelling process. According to the SMHI (2006) HBV manual, the HBV model can model abstractions from rivers as well as from lakes.

The HBV model

The HBV model is a semi-distributed conceptual rainfall-runoff model, which includes conceptual numerical descriptions of hydrological processes at catchment scale. It was originally developed at the Swedish Meteorological and Hydrological Institute (SMHI) in the early 70s to assist hydropower operations and it was named after the abbreviation of Hydrologiska Byråns Vattenbalans-avdelning (Hydrological Bureau Water Balance-section). It has been applied to different countries with different climatic conditions and amongst these are Sweden, Zimbabwe, India and Colombia.

Model setup

The model simulates daily discharge using daily rainfall, temperature and potential evaporation as input. Precipitation is simulated to be either snow or rain depending on whether the temperature is above or below a threshold temperature. Runoff record is required for calibration. The model uses sub-basins as primary hydrological units and within these an area elevation distribution and a simple classification of land use is made (Rientjes 2007). The classes are forest, open cover and lakes.

The general water balance can be described as:

$$P - E - Q = \frac{d}{dt} [SP + SM + UZ + LZ + Lakes]$$

Where: P = precipitation (mm); E = evapotranspiration (mm); Q = runoff (m^3s^{-1}); SP = snow pack (mm); SM = soil moisture (mm); UZ = upper groundwater zone (mm); LZ = lower groundwater zone (mm); Lakes = lake volume (m^3)

The model consists of subroutines for snow accumulation and melt, a soil moisture accounting procedure, routines for runoff generation and finally, a simple routing procedure between sub-basins and in lakes. It is possible to run the model separately for several sub-basins and then add the contributions from all sub-basins.

The regionalisation method

As noted by Beskow *et al.* (2016b) cited in Cassalho *et al.* (2017), hydrological regionalisation

can be applied on gauged sites, in order to add information to the existing series, as well as to transfer them to ungauged locations for the sake of meeting data demands. In this study the spatial proximity (nearest neighbour) regionalization method is used. Parameters from the neighbouring sub-basins are transferred to the ungauged catchments. This nearest neighbour approach is appropriate when very few catchments in a homogeneous region in the neighbourhood of an ungauged catchment are gauged. In this study two gauged sub-basins are present. The calibrated parameter sets are retained as single entities that are indexed using suitable catchment characteristics, thus addressing one of the major criticisms of regression-based approaches (Merz and Blöschl 2004). The rationale behind this method is that these are nested catchments therefore one would expect the parameters to be similar. With reference to a study by Merz and Blöschl (2004) of comparing different regionalization methods in 459 catchments of Australia, they found out that the regionalization method that used parameters from neighbouring catchments performed best on most scores. They found that the methods based on spatial proximity performed better than any of the regression methods that are based on catchment attributes. For regression methods, the regressions are not always straightforward to interpret (Parajka, Merz *et al.* 2005). For the Mazowe catchment, only two gauged catchments are available therefore making the regression analysis unreliable to use as the Nash-Sutcliffe coefficient (R^2) of the parameter against the catchment attribute is always 1 (one). However, the question of whether or not homogeneous catchments tend to occur in close proximity to each other has been the subject of significant debate over the years (Parajka, Merz *et al.* 2005).

Regardless of which method is used, the problems in regionalization of rainfall-runoff models are manifold. Reliability of methods of flow assessment in ungauged catchments by parameter transferring from gauged areas depends on type, quantity and quality of available data at gauged sites in the region, and the degree of similarity of the gauged and the ungauged sites. Parameters of a calibrated model are a function of the model structure, model input data including the errors contained within the data series, catchment characteristics and the calibration scheme including the selection of objective functions. Hence, model parameters may have little physical relevance (Merz and Blöschl 2004). Figure 20.2 below shows the sub-basins created for the modelling purpose.

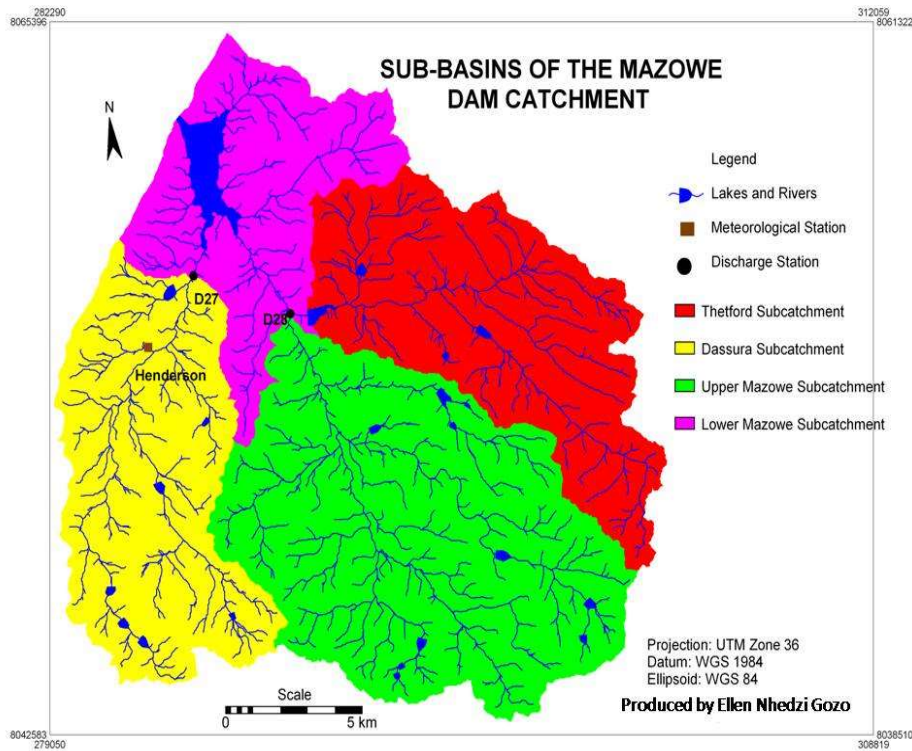


Figure 20.2: A map showing the four created sub-basins of the Mazowe Dam catchment.

Modelling

Modelling was done for the gauged sub-basins using the HBV model. These sub-basins were named the Dassura and Upper Mazowe. Parameters for these sub-basins were determined and used in the regionalisation method for modelling of the ungauged sub-basins.

Computation

Each district had one sub-basin therefore these sub-basins, the Dassura and Upper Mazowe sub-basins, were selected as the principal and presentation basins. The start time for computation was set to 10 October 1988. The model warm up was done by running the model for a period of one year then runoff was computed for the whole period of 10 October 1988 to 31 December 2005.

HBV Model Calibration

After running the model with the initial input data, it was observed that the hydrographs of the simulated flows were not matching that of the observed runoff. This is because a hydrologic model is a simplified representation of a complex hydrological system and therefore may not reflect the real world with enough accuracy. A hydrologic model therefore requires fine tuning of the model parameters to improve the reliability of the model

An important part of the modelling process is to establish that the results simulated by the model are consistent with that of the physical system it represents. Hydrological models are calibrated in order to get a good fit between observed and simulated variables. A model can only be applied with confidence once the model output has been tested for accuracy and correctness, i.e. verified, against observed data and where no observed data are available, to

ensure that sensible values are generated. (Jewitt, Garratt *et al.* 2004). In HBV model, it is recommended that calibration be done with ten years of data. Optimisation of model parameters is done following a calibration procedure specified in the SMHI manual. Parameters are calibrated following a certain order. This order ought to be the following; Firstly, the volume parameters. Secondly, snow parameters. Thirdly, soil parameters, followed by response parameters and lastly, damping parameters

The catchment does not experience snow therefore snow parameters were not dealt with in this study. The set of the modelling period was divided into two parts, the first ten years, 1988 to 1998 for model calibration and the remaining part from 1999 to 2005 for model validation. Table 20.1 shows the combination of optimum parameter values obtained during the calibration process.

Sub-basin	Dassura	Upper Mazowe
Alfa	1.1	1.1
Athorn	0	0
Beta	1	1
Cflux	0.1	0.1
Fc	1500	896
k4	0.001	0.001
Khq	0.2	0.2
Lp	0.1	0.1
Maxbas	1	2
Perc	0.01	0.01

The performance of these parameters was assessed using visual interpretation of the hydrographs and the objective functions that are available in HBV model. These objective functions are the Nash-Sutcliffe coefficient (R^2), the accumulated difference (Accdiff), relative accumulated difference, and the mean error. The Nash-Sutcliffe model efficiency coefficient is used to assess the predictive power of hydrological models. An efficiency of $R^2 = 1$ corresponds to a perfect match of modeled discharge to the observed data. An efficiency of $R^2 = 0$ indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero ($-\infty < R^2 < 0$) occurs when the observed mean is a better predictor than the model. The smaller the accumulated difference, the better the model performs. The Relative volume error can vary between ∞ and $-\infty$. The model performs best when the value of zero is attained. Table 20.2 shows the error analysis values attained during the calibration process for the Dassura and Upper Mazowe sub-basins.

Sub-basin	Dassura	Upper Mazowe
R2	0.86121	0.80389
Accumulated difference	0.63527	0.69675
Relative accumulated difference	0.03951	0.00062
Mean error	0.35181	0.38236

HBV model validation

Validation is a process of demonstrating that a given site-specific model is capable of making accurate predictions for periods outside a calibration period (Refsgaard J. C and Knudsen 1996). Simple model structures, calibrated over a certain period, are influenced by the rainfall-runoff sequence specific to that period (Lee, McIntyre *et al.* 2005) therefore in order to prove validity of a model, the model should be tested against a second, independent set of stress conditions. In the Mazowe Catchment model, the data series were divided into two sets. The first set of ten years for calibration and the remaining set were used for validation. Validation was done for the two gauged sub-basins with data from 1999 to 2005. The objective functions available in HBV model were used for testing the validity of modelling the Mazowe Catchment with the HBV model. The objective functions used to measure the reliability of the model are the mean error, the relative accumulated difference, the accumulated difference between the measured and calculated runoff and the Nash-Sutcliffe coefficient (R^2). The results of the model validation are shown in Table 20.3.

Sub-basin	Dassura	Upper Mazowe
R^2	0.70776	0.71271
Accumulated Difference	30.82709	25.2138
Relative Accumulated Difference	0.07678	0.02658
Mean Error	0.43912	0.50151

Results and discussion

Modelling was performed successfully to model runoff from the two gauged sub-basins. Both calibration and validation results show a strong relationship between the simulated and observed runoff from the two gauged catchments. Best results (with best R^2) were attained during the calibration period than the validation period for both sub-basins. These R^2 values are shown in Table 20.2 and Table 20.3. There was a high correlation between observed and simulated runoff of $R^2 = 0.93$ during the calibration period and $R^2 = 0.91$ during the validation period for Dassura sub-basin and $R^2 = 0.90$ during the calibration period and $R^2 = 0.80$ during the validation period for Upper Mazowe sub-basin. This was assessed by forming a regression analysis between the observed and the simulated runoff for the two stations. Figure 20.3, Figure 20.4, Figure 20.5 and Figure 20.6 show the regression between observed and simulated runoff for Dassura and Upper Mazowe sub-basins during calibration and validation periods. That equally good model simulation was obtained using the HBV model is not surprising. Corresponding results has been reported by other researchers for example in Ruwa catchment of Zimbabwe (Liden and Harlin 2000) and in the Odzi river catchment of Zimbabwe (Lidén, Harlin *et al.* 2001).

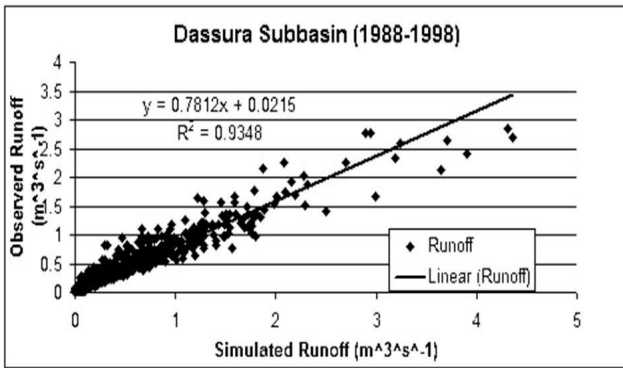


Figure 20.3: Relationship between Observed and Simulated Runoff for Dassura Sub-basin during the calibration period (1988-1998)

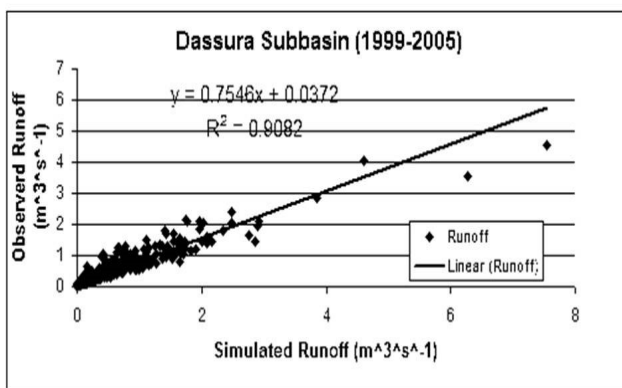


Figure 20.4. : Relationship between Observed and Simulated Runoff for Dassura Sub-basin during the validation period (1999-2005).

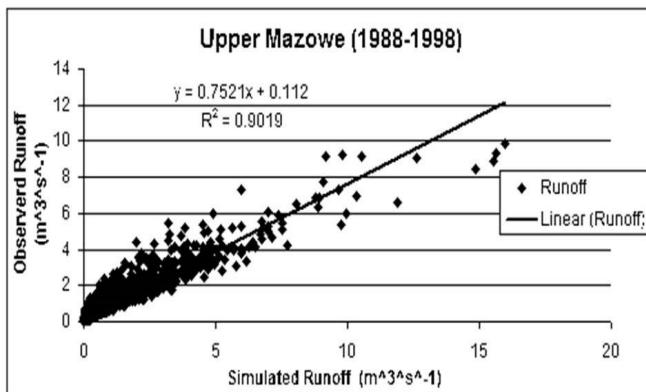


Figure. 20.5 :Relationship between Observed and Simulated Runoff for Upper Mazowe Sub-basin during the calibration period (1988-1998)

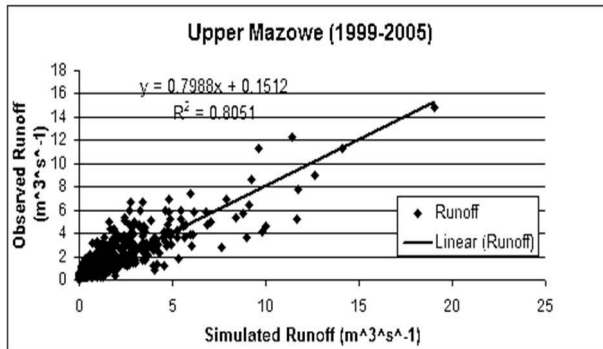


Figure 20.6: Relationship between Observed and Simulated Runoff for Upper Mazowe Sub-basin during the validation period (1999-2005)

From the model output, it is observed that the model consistently overestimated extreme events of peak runoff. The model has also been seen to inconsistently overestimate or underestimate base flow during the offset of the wet season. For illustration, hydrographs for the period 2000 to 2003 for Dassura and Upper Mazowe Sub-basins were extracted and are shown in Figure 20.7 and Figure 20.8. The rain period of year 2000 to 2001 is one of the wettest periods and 2002 is one of the driest years during the modelling period. From the 2000 and 2001 hydrograph it can be observed that the model overestimated the peak runoff. During some drier years the model underestimated runoff.

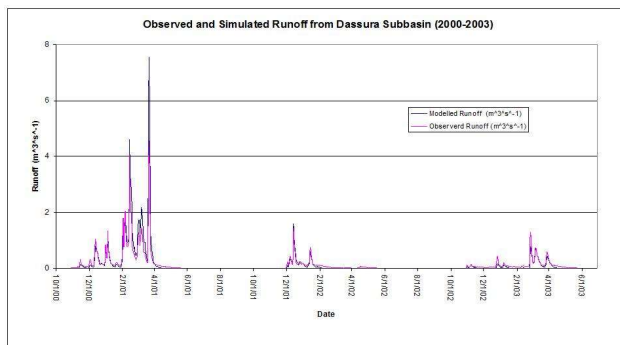


Figure 20.7: Observed and simulated runoff for Dassura sub-basin in the years 2000 – 2003

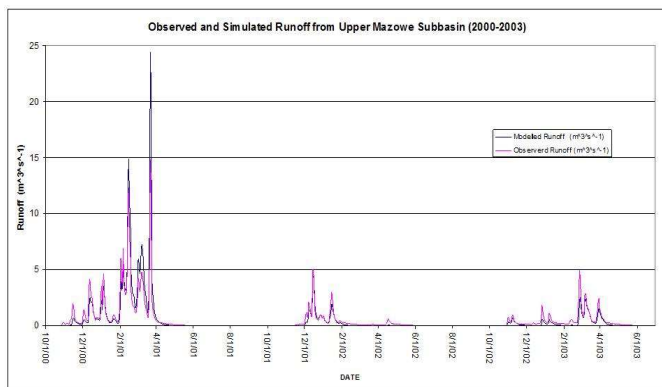


Figure 20.8: Observed and simulated runoff for Upper Mazowe sub-basin in the years 2000 – 2003

The simulated runoff could not match the observed runoff due to a number of possible factors. There are a number of small lakes, borehole abstractions and surface abstractions along the streams in the catchment which could not be accounted for in the model, therefore free model parameters were tuned to reduce total runoff from these catchments. These parameters could not adequately account for that water going out of the system. Some input data brought with them errors as well. Aerial rainfall for the catchment was obtained using a Thiessen polygon interpolation method using rainfall records from one meteorological station. Overestimation or underestimation of rainfall from one point to the other is most probable. Evapotranspiration was calculated from daily temperatures and therefore errors could have also been encountered during the conversion of water particles into vapour by the formula since other factors such as that of wind were not taken into account. Also interpolation of this evapotranspiration over the entire area can also cause some disparities. Finally, hydrological modelling on its own is a simplified representation of the physical hydrological processes of the earth therefore some imperfections can be encountered.

Table 20.4: Parameter transfer to ungauged sub-basins

Sub-basin	Upper Mazowe	Upper Mazowe	Dassura	Dassura
Parameter	Calibration	Regionalisation	Calibration	Regionalisation
Period of simulation	1989-2005	1989-2005	1989-2005	1989-2005
R2	0.76995	0.62818	0.80393	0.63249

Accumulated Difference	0.32355	96.12275	25.37983	134.6584
Relative Accumulated Difference	0.00014	0.10131	0.02945	0.15624
Mean Error	0.3996	0.54112	0.36929	0.46671

Calibrated parameters were transferred to the ungauged catchment through the proximity (nearest neighbour) method. The ungauged and gauged catchments uses climatic variables from one gauging station therefore rainfall, temperature and potential evaporation variables are considered to be the same for the four sub-basins. Calibrated parameters from the two gauged catchments are the same for alfa, athorn, beta, cflux, k4, perc, lp and khq. These parameters are transferred as they are to the ungauged sub-basins. There was a difference in the calibrated values of maxbas and fc therefore averaged values for the two gauged catchments were used in the two ungauged sub-basins. Table 20.4 contains the parameters that were transferred to Thetford and Lower Mazowe sub-basins.

Table 20.5: Model parameters transferred from Dassura and Upper Mazowe sub-basins to Thetford and Lower Mazowe sub-basins		
Sub-basin	Thetford	Lower Mazowe
Alfa	1.1	1.1
Athorn	0	0
Beta	1	1
Cflux	0.1	0.1
Fc	1200	1200
k4	0.001	0.001
Khq	0.2	0.2
Lp	0.1	0.1
Maxbas	1.5	1.5
Perc	0.01	0.01

The performance of these regionalised values in the catchment was tested by applying them to both gauged catchments, the Dassura and Upper Mazowe sub-basins and compared the simulation results attained by regionalisation with that attained by calibration parameters.

For catchments without stream flow observations, parameters have to be estimated from other sources of information such as neighbouring sub-basins, literature or assumed based on expert judgement. However, there is lack of calibration data from these ungauged sub-basins. This lack of calibration data can make the model perform poorer than in gauged sub-basins. It can be observed that the regionalisation parameters did not perform as good as modelling with the calibration parameters. Although the accuracy was lower than that of the calibration values, the results from regionalisation has a high R^2 of 0.632 and 0.628 for Dassura and Upper Mazowe Sub-basins respectively implying that these regionalisation parameters can successfully be applied to these ungauged catchments. Merz and Bloschl (2004) examined eight regionalisation methods in Austria and found that the methods based on spatial proximity alone performed better than any of the regression methods based on catchment attributes. Figures 20.9 to 20.12 show the regression between runoff simulated by calibration and

regionalisation parameters against observed runoff. As illustrated by the values of the objective functions in **Error! Reference source not found.5**, the simulated runoff by calibration parameters for both gauged sub-basins show a higher regression coefficient with the observed runoff than the simulated runoff with regionalisation parameters.

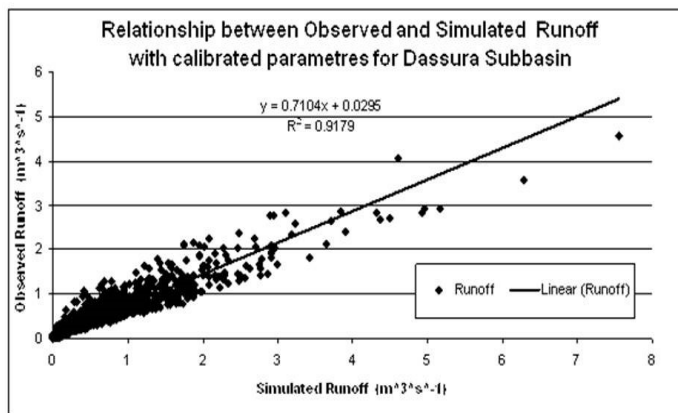


Figure 20.9: Relationship between observed runoff and simulated runoff by calibration parameters for Dassura sub-basin (1989-2005)

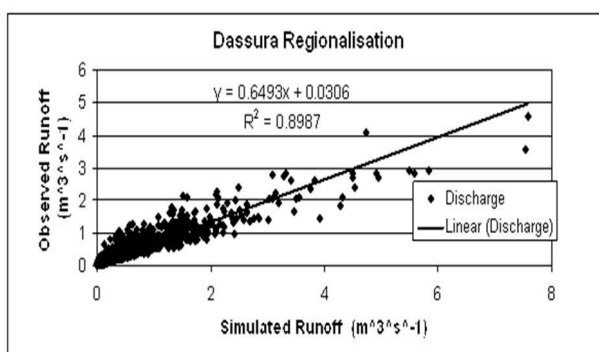


Figure 20.10: Relationship between observed runoff and simulated runoff by regionalization for Dassura sub-basin (1989-2005)

From the modelling results of the two ungauged sub-basins; the Thetford and Lower Mazowe sub-basins, it was observed that during the dry periods, as opposed to the two gauged sub-basins, there is no flow from these sub-basins. This can however be the real scenario on the ground with the Lower Mazowe sub-basin as there are only intermittent streams in the sub-basin. Runoff is mainly in terms of rills and sheet erosion and this is the reason why this catchment is not gauged. For the Thetford sub-basin this may not be the case as there is one of the main tributary to the Mazowe River. However this tributary is also not a perennial river therefore the modelling results can be closer to the truth during dry periods. For the wet seasons, for both sub-basins, there is much uncertainty as there is no data for calibration. Figure 20.13 and 20.**Error! Reference source not found.14** show the hydrographs of simulated runoff for the Thetford and Lower Mazowe sub-basins during the 2000 to 2003 period.

Conclusion

The science and art of water resources management requires that the managers have the knowledge of where, in what quantity and quality water resources. The assessment relies on the identification of water resources, the quantification and qualification of water resources

through the components and processes of the hydrological cycle. Some processes such as losses through evapotranspiration and conversion of rainfall to runoff are best explained through the use of hydrological models. These models make use of hydrometeorological data to transform the processes of the hydrological cycle into meaningful hydrological information that can be used for water resources management issues. Many parts of the world lack this data and methods have to be devised to assign data to areas where there is no information to enable water resources managers to account for all the water resources in their areas of jurisdiction. Regionalisation is one of the ways that can be used.

Beck *et al.* (2016) note that HBV can arguably be considered to be of average complexity and thus fairly representative of a “typical” hydrologic model. The HBV model was used to analyse the hydrological processes of Mazowe dam catchment with great success as evidenced by high correlation co-efficiencies between the simulated and the observed data for the two gauged stations in the catchment. The nearest neighbor method was then used to transfer parameters to the ungauged sub-catchments and the results can also be applied with success. However, as pointed out by Anees *et al.* (2017), river and floodplain modelling are characterized by uncertainties in input and model parameters, model structures and model calibration. Some errors were encountered because the whole process involves simulation of the real world process and there are lots of simplifications in the model structure and errors from several sources such as measurement errors that are involved hence no model can ever be perfect. It can be concluded that with the availability and use of hydrological models and regionalisation methods, data can be made available where measurements are not possible or yield unreliable data. The analysis of the effects our actions and natural phenomena on water resources can therefore be analysed and well understood with the availability of adequate information about our water resources.

Acknowledgements

My appreciation goes to ITC- The Netherlands, Mazowe Citrus Company, Zimbabwe National Water Authority – Mazowe Catchment ad Data & Research, Meteorological department, AGRITEX, Mazowe Catchment farmers, colleagues and family members for logistics, financial, technical and moral support.

References

- Anees T.M, K. Abdullah *et al.* 2017. One- and Two-Dimensional Hydrological Modelling and Their Uncertainties, Flood Risk Management, Theodore Hromadka and Prasada Rao, IntechOpen, DOI: 10.5772/intechopen.68924. Available from:
<https://www.intechopen.com/books/flood-risk-management/one-and-two-dimensional-hydrological-modelling-and-their-uncertainties>
- Beck H.E., van Dijk A. I. J. M. *et al.* 2016 “Global-scale regionalization of hydrologic model parameters” *Water Resources Research*, Volume 52, Issue 5
- Bergström, S. 1991. "The HBV Story In Sweden" Swedish Meteorological and Hydrological Institute Norrköping, Sweden "
- Booij, M. J. 2005. "Impact of climate change on river flooding assessed with different spatial model resolutions." *Journal of Hydrology* 303(1-4): 176-198.
- Beskow, S.; L.C.Timm, *et al.* 2016a."Potential of the LASH model for water resources management in data-scarce basins: a case study of Fragata River Basin, Southern Brazil." *Hydrological Sciences Journal*, v. 61, n. 14, p. 2567-2578,
<http://dx.doi.org/10.1080/02626667.2015.1133912>.
- Bosch, J. M. and J. D. Hewlett 1982. "A review of watershed experiments to determine the

- effect of vegetation changes on water yield and evapotranspiration, *Journal of Hydrology* 55 (1982), pp. 3–23."
- Cassalho F., S. Beskow, *et al.* 2017 "Hydrological regionalization of maximum stream flows using an approach based on L-moments." RBRH vol.22 Porto Alegre, <http://dx.doi.org/10.1590/2318-0331.021720160064>
- Croke, B. F. W., W. S. Merritt, *et al.* 2004. "A dynamic model for predicting hydrologic response to land cover changes in gauged and ungauged catchments " *Journal of Hydrology* 291(1-2):
- Goswami, M., K. M. O'Connor, *et al.* 2007. "Development of regionalisation procedures using a multi-model approach for flow simulation in an ungauged catchment." *Journal of Hydrology* 333(2-4): 517-531.
- Gotzinger, J. and A. Bardossy 2007. "Comparison of four regionalisation methods for a distributed hydrological model." *Journal of Hydrology* 333(2-4): 374-384.
- Hundecha, Y. and A. Bardossy 2004. "Modeling of the effect of land use changes on the runoff generation of a river basin through parameter regionalization of a watershed model." *Journal of Hydrology* 292(1-4): 281-295.
- Jewitt, G. P. W., J. A. Garratt, *et al.* 2004. "Water resources planning and modelling tools for the assessment of land use change in the Luvuvhu Catchment, South Africa." *Physics and Chemistry of the Earth, Parts A/B/C* 29(15-18): 1233-1241.
- Lee, H., N. McIntyre, *et al.* 2005. "Selection of conceptual models for regionalisation of the rainfall-runoff relationship." *Journal of Hydrology* 312(1-4): 125-147.
- Liden, R. and J. Harlin 2000. "Analysis of conceptual rainfall-runoff modelling performance in different climates." *Journal of Hydrology* 238(3-4): 231-247.
- Lidén, R., J. Harlin, *et al.* 2001. "Hydrological modelling of fine sediments in the Odzi River, Zimbabwe." *Water SA* Vol. 27(No. 3).
- Merz, R. and G. Bloschl 2004. "Regionalisation of catchment model parameters." *Journal of Hydrology* 287(1-4): 95-123.
- Parajka, J., R. Merz, *et al.* 2005. "A comparison of regionalisation methods for catchment model parameters."
- Refsgaard J. C and J. Knudsen 1996. "Operational validation and intercomparison of different types of hydrological models." *Water Resources Research* 32(7): 2189-2202.
- Rientjes, T. H. M. 2007. *Modelling in Hydrology*. Department of Water Resources, ITC, Enschede.
- Rosenberry, D. O., T. C. Winter, *et al.* 2007. "Comparison of 15 evaporation methods applied to a small mountain lake in the northeastern USA." *Journal of Hydrology* 340(3-4): 149-166.
- Seibert, J. 1999. "Regionalisation of parameters for a conceptual rainfall-runoff model." *Agricultural and Forest Meteorology* 98-99: 279-293.
- SHMI 2003. "www.smhi.se/foretag/m/hbv_demo/html/consulting.html , 12/02/08."
- SMHI 2006. "Intergrated Hydrological Modelling System Manual. Version 5.10."
- Young, A. R. 2006. "Stream flow simulation within UK ungauged catchments using a daily rainfall-runoff model." *Journal of Hydrology* 320(1-2): 155-172.

Chapter 21: Water management in the wildlife lodge industry: A southern African perspective

Jacobus Grobler and Kevin Mearns

University of South Africa, Department of Environmental Sciences
Private Bag X6, Florida 1710, South Africa
mearnkf@unisa.ac.za

Abstract

The tourism industry across the world requires water for basic human consumption, irrigation of gardens and golf courses, preparation of food and drinks, making snow for winter sports and general water activities such as swimming or motorised water sports (Gössling et al. 2012). Tourism and more specifically wildlife tourism is a major source of income and livelihood for many rural communities across southern Africa. Many wildlife tourism lodges across southern Africa are in remote locations where little or no infrastructure exists. These lodges are dependent on natural water sources such as rivers, dams and boreholes to provide their water needs. The staff employed at these wildlife lodges often reside on the properties and as a result of the lack of nearby housing, roads and public transportation must be accommodated by the tourism ventures. Lodges as a result make allowance not only for the tourism venture operations but for the domestic water use of staff members. Lodge managers must make sure that enough water is available at an acceptable water quality to meet these needs of both guests and staff. This paper investigated water quantity use at 31 wildlife lodges across southern Africa ; this paper also provided water quantity use baselines and proposes water use benchmarks for the wildlife lodge industry in southern Africa.

Keywords: Tourism, water quantity use, water quantity baselines and benchmarks

Introduction and literature review

The tourism industry across the world requires water for basic human consumption, landscape irrigation, preparation of food and beverages and for a number of water sport activities (Gössling *et al.* 2012). As a result of the importance of this critical resource for tourism, it is of critical importance that tourism ventures improve their water management and reduce their consumption of water. The wildlife lodge industry in southern Africa is no different and depends on water for its very existence. Owing to their rural location many wildlife lodges are dependent on natural water sources to supply their water use demands. The rural location of these wildlife lodges also results in the consequence that staff that are employed at these lodges have to reside on these premises of the lodge as little or no transport and housing infrastructure exists elsewhere near the lodges. The accommodated staff add to the strain on water resources, especially in water-scarce areas such as the Namib and Kalahari deserts. Managers therefore need to ensure that sufficient water at an acceptable quality is available for both guests and staff.

Water management in the wildlife lodge industry is a very important management aspect that should be carefully managed. Water management in the wildlife lodge industry involves all the processes and procedures from the abstraction point to discharging back into

the environment. This paper specifically investigates the volumes of water that are used by wildlife tourism lodges across three southern African countries, namely Namibia, Botswana and South Africa. Tourism activities contribute to water consumption and can be partially responsible for depleting water sources. It is thus of the utmost importance that tourism ventures apply sustainable water utilisation and preserve good quality freshwater as the well-being of staff and guests depend on the availability of good quality freshwater. Since the wildlife lodge industry depend on wildlife and ecosystems for their existence, it is important that water courses and their quantity are managed to prevent them from losing their tourist attractions.

In some areas, tourism may compete for water directly with local communities for domestic use or with local farmers for agricultural use. In Fiji and Sri Lanka tourism water usage is 8.5 times more per person per night than that of the local community (Becken, 2014). In Zanzibar, Tanzania, the average use *per capita* of freshwater for tourists is 15 times higher than local residents (Gössling, 2001). Such imbalances could lead to water conflict situations, and tourism ventures must integrate their needs with local communities to obtain the best outcomes for businesses, tourists, communities and the environment (Becken, 2014). Many lodges share their water source with local communities and depleting or degrading these resources could cause conflict with local communities which are also dependent on the same water resources.

Gössling *et al.* (2015) and Mearns and Grobler (2016) stipulated the importance of baselines and benchmarks to improve water use management and to assist tourism ventures to use water sustainably. International guidelines and benchmarks of sustainable water use and consumption quantities cannot be applied to the wildlife lodge industry due to difference in nature of the tourism sector and the fact that staff reside on the properties at wildlife lodges in southern Africa, while international benchmarks take cognisance only of guest water use while staff members in the international benchmarks return home daily (Baker & Mearns, 2015; Mearns & Grobler, 2016; Baker & Mearns 2017). Therefore, the researchers found it necessary to investigate water quantity consumption in the wildlife lodge industry in South Africa, Namibia and Botswana. This study could assist in providing some baselines of water consumption and assist in developing locally relevant and realistic water use benchmarks for the southern African wildlife lodge industry. Two of the major organisations in the wildlife lodge industry in South Africa were approached for this study, namely andBeyond and Wilderness Safaris. Both organisations have lodges in the three selected countries in this study and agreed to the study. An overview of the two companies follows.

andBeyond

andBeyond was established in 1991 (itw as then called Conservation Corporation Africa or CC Africa) due to the rising international demand for ecotourism and wildlife experiences. The organisation is a progression of the model originally established over 30 years ago at Londolozi Private Game Reserve. This model demonstrated that, by harnessing international financial capital through low-impact, high-yield tourism, conservation land could prove its economic viability whilst affording rural communities a meaningful share of the benefits. The spirit and effectiveness of this model led to the company's core ethic of "Care of the Land, Care of the Wildlife, Care of the People" (andBeyond, 2018). andBeyond began in the early 1990s at Phinda Private Nature Reserve in KwaZulu-Natal, South Africa. With its vast involvement in the local community, andBeyond established the Rural Investment Fund, now known as the Africa Foundation. The Africa Foundation focuses on rural development around andBeyond

lodges and reserves, and facilitates international financial support for responsible, consultative community projects in rural Africa (andBeyond, 2018). Since 1995 andBeyond continued to expand its portfolio of superior safari lodges and moved into Kenya, Zimbabwe and Tanzania, and later Botswana and Namibia. In February 2000, andBeyond merged with two other travel outfits (Afro Ventures and Into Africa) to form one of Africa's most comprehensive tourism companies, combining the strength of its lodge portfolio with a large tour operating division, destination management, group travel and mobile safari specialist operation. andBeyond now offers personalised, luxury tours in 12 African countries (andBeyond, 2018). In 2006 andBeyond extended into India, Sri Lanka, Bhutan and Nepal. This expansion resulted in the name change, in 2008, from CC Africa to andBeyond to reflect the company's extended footprint beyond Africa. South America was added to the portfolio in 2015, adding Chile, Argentina, Peru and Ecuador to andBeyond's experiential travel offering (andBeyond, 2018).

Wilderness Safaris

Wilderness Safaris was founded in Botswana in 1983. It started off as a mobile tented safari that hosted tourists in and around the Okavango Delta. Today Wilderness Safaris offers private access to 2.5 million hectares of Africa's finest wildlife and wilderness areas. The company owns and manages 40 luxury camps in Africa and offers safaris across eight African countries: Botswana, Kenya, Namibia, Rwanda, Seychelles, South Africa, Zambia and Zimbabwe (Wilderness Safaris, 2017). Like andBeyond, Wilderness Safaris designed their vision based on what the company call the 4C's: Commerce, Conservation, Community and Culture. Commerce deals with the ecotourism offerings and products and is regarded by the organisation as the most critical element to sustainability in the modern world. It also focuses on creating life-changing experiences for clients and guests, while working closely with local governments, community shareholders and stakeholders to ensure a sustainable business. The conservation vision aims to maximise positive impacts of their operations on biodiversity and to minimise negative impacts. This is divided into two sections. Environmental Management Systems (EMS) deal with how the organisation build and manage their camps in the eco-friendliest way possible. The biodiversity conservation element covers the understanding, management and protection of wildlife and ecosystems. The Community vision includes staff, partners in the travel industry, guests and communities in or adjacent to operation areas. The organisation believes in honest, mutually beneficial and dignified relationships with their community partners. Culture aims to promote the unique Wilderness culture across the globe to respect and care for the environment. Other initiatives include the Wilderness Wildlife trust and the Children in Wilderness programme (Wilderness Safaris, 2017). Apart from their primary aim of sharing Africa's wonderful places with guests, the organisation states that their ultimate goal is to make a difference in Africa, to its people and its wildlife (Wilderness Safaris, 2017).

Water quantity management

Water consumption can be measured by concentrating on water throughput (Styles *et al.* 2015). This method focused on the total volume consumed divided by the number of guest nights at a hotel or resort. This calculation would state the volume, usually in litres, per person per night or litre per guest-night. These measurements are the standard today; however Gössling *et al.* (2015) stated that water consumption is much more sophisticated when considering all the water that is required to sustain the tourism system. Gössling *et al.* (2015) differentiated water into three major components: direct water use, indirect water use and systematic water use.

- **Direct water use** is water that is directly consumed by the hotel, resort or lodge. This will include all water that is consumed by rooms (toilets, taps and showers), irrigation (gardens, golf courses and lawns), laundry and cleaning, wash bays, kitchens (guest and staff), swimming pools (initial filling, filter backwash, evaporation) and staff quarters.
- **Indirect water use** is water that is consumed to provide services to the establishments. This would include water used in the construction phase of the hotel, resort or lodge, energy production, fuel production and food and beverage production.
- **Systematic water use** is all water consumed coupled with activities, shopping and services in transit to or in the destination. This will often entail other infrastructure such as railways, roads, airports and harbours, all of which involve water use. Water use embodied in these properties has not yet been studied.

In this study the authors focus on the direct water use at the lodges in the wildlife industry and present the results as per the standard, namely, litre per guest-night. When direct water use is calculated, it is important that measuring and data collection is done frequently and accurately. Water flow meters and equipment must be in proper working order and the data must be recorded as accurately as possible. Another important aspect is that the flow meters are installed at the correct locations in the system. When water is measured before water is stored and dispensed, it can impact on the data and can result in unreliable results. When other equipment such as flow switches or automated systems are faulty, it can lead to storage units overflowing, making results inaccurate. It is therefore important to ensure that all meters and equipment are in good working order and that water meters are installed in the correct locations.

Developing baselines and benchmarks

A baseline assessment is the collecting and processing of data to establish a baseline result. The purpose of establishing baselines is to provide a starting point from which future measurements and predictions can be calculated. It can aid in forecasting water use based on the number of expected arrivals and can aid managers in better water use forecasting and management. Baseline assessments are not standardised, and many different formats can be used in different situations. With regard to water quantity in the tourism sector, the baseline water consumption would be the volume that is consumed per guest per day or per room per day. The baseline can be exclusive to a specific destination, region, province, country, industry or market segment. Table 21.1 states baselines for specific countries and regions from previous studies.

Country	Accommodation type	Water use per guest per night
Mediterranean	Mostly hotels	250 L
Mediterranean	Campsites	145 L
Mediterranean	All accommodation	440 – 880 L
Benidorm, Spain	Campsites	84 L
Benidorm, Spain	1 Star hotel	174 L
Benidorm, Spain	2 Star hotel	194 L
Benidorm, Spain	3 Star hotel	287 L
Benidorm, Spain	4 Star hotel	361 L
Greece	5 Star hotel	675 L
Greece	4 Star hotel	234 L

Tunisia	Hotels	466 L
Morocco	Apartments	180 L
Morocco	3 Star or villa	300 L
Morocco	4 Star hotel	400 L
Morocco	5 Star hotel	500 L
Morocco	Luxury 5 Star hotel	600 L
Sarigerme, Turkey	4 Star hotel	400 – 1000+ L
Sharm El Sheikh, Egypt	Hotels	< 500 L (per bed)
Sharm El Sheikh, Egypt	5 Star hotels	1410 – 2190 L (per room)
Zanzibar, Tanzania	Guesthouses	248 L
Zanzibar, Tanzania	Hotels	931 L
Zanzibar, Tanzania	Hotels and guesthouse (average)	685 L
Jamaica	Unspecified	527 – 1596 L
Jamaica	Average	980 L
Thailand		913 – 3423 L (per room)
Philippines	4 Star hotel	1802 L (per room)
Hong Kong	Hotels	336 – 3198 L (per room)
Australia	Hotels	750 L (per room)
Australia	Large hotels	300 L (per room)
Melbourne, Australia	Various	227 – 435 L
USA	Unspecified	382 – 787 L (per room)
Las Vegas, USA	Hotels / resorts	303 L
Seattle, USA	Hotels	378 – 1514 L (per room)
Germany	Unspecified	90 – 900 L
Germany	Average	340 L
Scandinavia	Hilton chain	516 L
Scandinavia	Scandic chain	216 L
Coastal Normandy, France	Campsite	92 L
Coastal Normandy, France	Hotel restaurant	259 L
Coastal Normandy, France	Hotel	175 L
Coastal Normandy, France	Other	115 L

(Gössling *et al.* 2015)

Benchmarking is a comparative management tool that is widely used all over the world. The aim of benchmarking is for continuous improvement in performance and best practice of an organisation. The process involves measuring one's own performance and evaluating it against the best in its class or similar organisations (Saagi *et al.* 2017). The four main types of benchmarking are:

- **Internal benchmarking** is a comparison of a business process to a similar process inside the organisation, for example a company such as Wilderness Safaris comparing water use of one of their lodges to another. This method is fairly cost efficient and access to information is easily obtainable. It can however be influenced by internal bias and may not yield the best in class comparison (Córcoles *et al.* 2010).
- **Competitive benchmarking** is the comparison of a product, service, process, or method against direct competitors, for example Wilderness Safaris comparing their performance against andBeyond's. Competitors may have similar regulatory issues and competitive benchmarking could lead to possible partnerships. Some disadvantages of this method are that competitors might provide misleading information, exploiting your

weaknesses and this could lead to minimum performance improvement (Córcoles *et al.* 2010).

- **Functional benchmarking** is a comparison to similar or identical practices within the same or similar functions outside the immediate industry, for example andBeyond comparing their wastewater works with industrial wastewater works. Although this can result in a better improvement rate, it is more time-consuming and involves adaptation of best practices (Córcoles *et al.* 2010).
- **Generic benchmarking** broadly conceptualises unrelated business processes or functions that can be practised in the same or similar ways regardless of the industry. Some advantages of this method include that it is non-competitive, innovative and examines multiple industries; however, it can be difficult to identify the best in its class and can be very time-consuming (Córcoles *et al.* 2010).

As mentioned earlier, baseline assessments can be used as benchmarks. By having a multiple set of baselines, the best in a class can be set as the benchmark for the others. In this study the authors will make use of competitive benchmarks, comparing the baselines from two wildlife lodge industry operators, Wilderness Safaris and andBeyond. Another way of laying down a benchmark is to determine the average of multiple baselines and aim for a target improvement, in this case a 20% reduction on the average. In this study the authors will only produce one benchmark, which will be the best-in-class benchmark. The target-based benchmark was not used in this study as the authors could not establish an achievable and reasonable percentage reduction from the two companies concerned at this early stage in the research.

The purpose of monitoring a water management system is to identify gaps in the system and strive for continuous improvement. The most common form of monitoring a management system is by conducting audits (Gössling *et al.* 2015). Audits are carried out against a pre-determined set of criteria which will indicate whether the management system complies with company, legal or other statutory requirements. Audit results will indicate if the desired objectives have been met or not and will indicate areas which require attention and improvement. The baselines and benchmarks forthcoming from this research will provide guidance against which the auditing of used water quantities can be compared.

Research design and methodology

The authors partnered with two of the leading wildlife lodge industry operators in southern Africa, andBeyond and Wilderness Safaris, for this study. Across South Africa, Namibia and Botswana, 31 lodges were selected to participate in this study. The locations and geography from the lodges differed vastly, from desert to permanent swampland. The multiple case study used an empirical design and consisted of a quantitative secondary data analysis. The secondary data was obtained from the two research partners during the specified 24-month period from March 2015 to February 2017. All the lodge names have been changed to codes to ensure anonymity as per agreement with the research partners. The first letter in the code refers to the country in which the lodge is situated, whereas the number at the end was the number that the researchers allocated to a specific lodge for identification, for example B3 will mean the third of the lodges whose data was analysed by the authors in Botswana. The majority of the lodges had complete records of water consumption for the 24-month period. Missing data was excluded from the analysis and conclusions. The authors also visited 12 lodges to verify that the information provided by the company representatives was accurate and reliably collected.

Discussion of results and analysis

The authors presented, discussed and analysed the water quantity results from the data

obtained. The water consumption baseline will refer to the average of the lodges analysed as specified. The benchmark that the authors had used was the “best in class” method and will be the lowest water consumption *per capita* for the lodges as specified. The authors first present the results for all three countries combined before separating the countries.

The authors used the international standard of litre per guest per night (l/g/n) as well as the recommendations made by Mearns and Grobler (2016) to include staff. The guest and staff usage is presented as litre per bed per night (l/b/n). The international standard should not be applicable for the wildlife lodge industry in South Africa, Namibia and Botswana due to the major role staff play in water consumption, as well as the difference in characteristics of the specific tourism sector, especially with regard to staff living on the premises.

The average water consumption from all three countries, both in l/g/n and l/b/n, was used to create a general baseline for the wildlife lodge industry in South Africa, Namibia and Botswana. The authors then calculated the averages for each country individually and used the country’s average, both in l/g/n and l/b/n, as the baseline for the specific country. The authors used the best-in-class method to provide a benchmark for each country as well as all three countries together. The lodge that had the least water consumption *per capita*, considering both l/g/n and l/b/n, was used as the best-in-class benchmark for the specified country. The final baselines and benchmarks were then stated as per the international standard of litre per guest per night (l/g/n) as well as the inclusion of staff of litre per bed per night (l/b/n).

Figure 21.1 indicates the l/g/n per lodge in all three countries. The water quantity records for the two years under investigation were used and the total water consumption for the 24 months was divided by the total number of guest nights over the same period to provide a two-year average at each lodge. Lodges with blue values represent lodges from Botswana. Lodges with green values represent lodges from South Africa, whereas lodges with a yellow value represent lodges from Namibia.

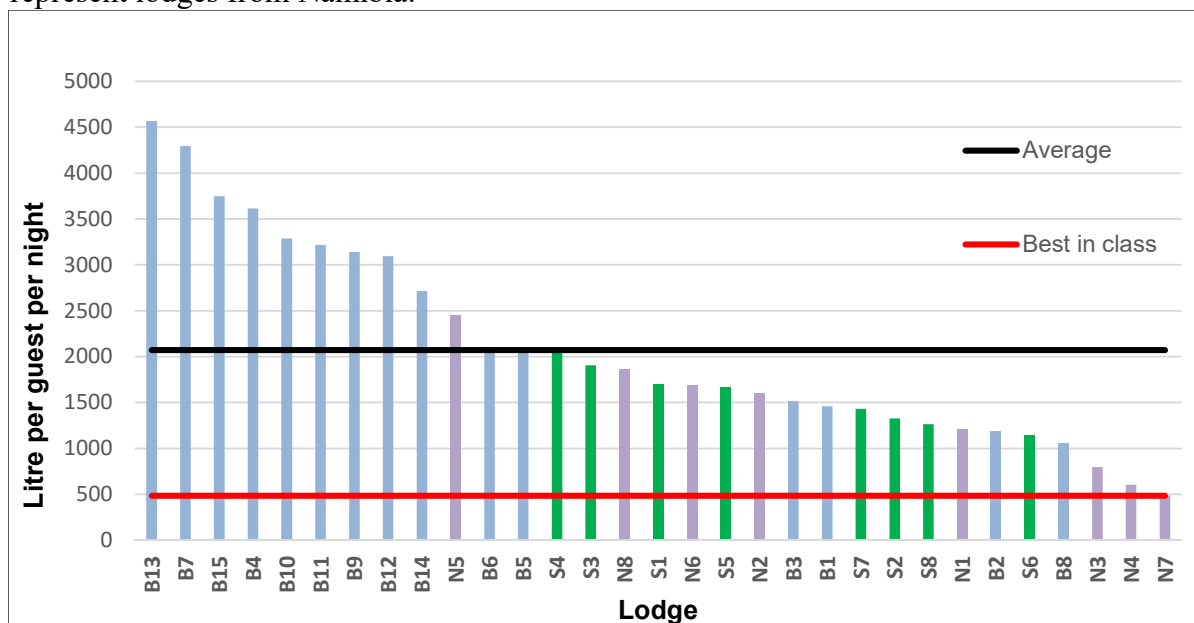


Figure 21.1: Average litre per guest night for all the lodges included in the study within South Africa, Namibia and Botswana

The average consumption across the three countries was 2073 l/g/n. According to Table 21.1 the average consumption for 5-star hotels in Greece and Morocco is 675 l/g/n and 500 l/g/n respectively. The average consumption for all types of accommodation in the Mediterranean

range between 440 – 880 l/g/n, while the average consumption for hotels in Zanzibar is 931 l/g/n. The results indicate that the average consumption across South Africa, Namibia and Botswana is in some instances three to four times more than other countries across the globe. Table 21.1 states that countries such as the Philippines, Thailand and Hong Kong use up 3 198 litre per room. The average for South Africa, Namibia and Botswana is the highest of all the countries for which baselines are available.

Nine of the 10 highest water consuming lodges were in Botswana. The three lowest water consuming lodges were all located in Namibia. The highest usage from all the lodges was lodge B13 with 4567 l/g/n. The lowest water consumption was at lodge N7 with only 485 l/g/n, which also was the best in class from the lodges presented in Figure 21.1. Figure 21.2 illustrates the water consumption per capita when staff nights were included. The results were presented as l/b/n.

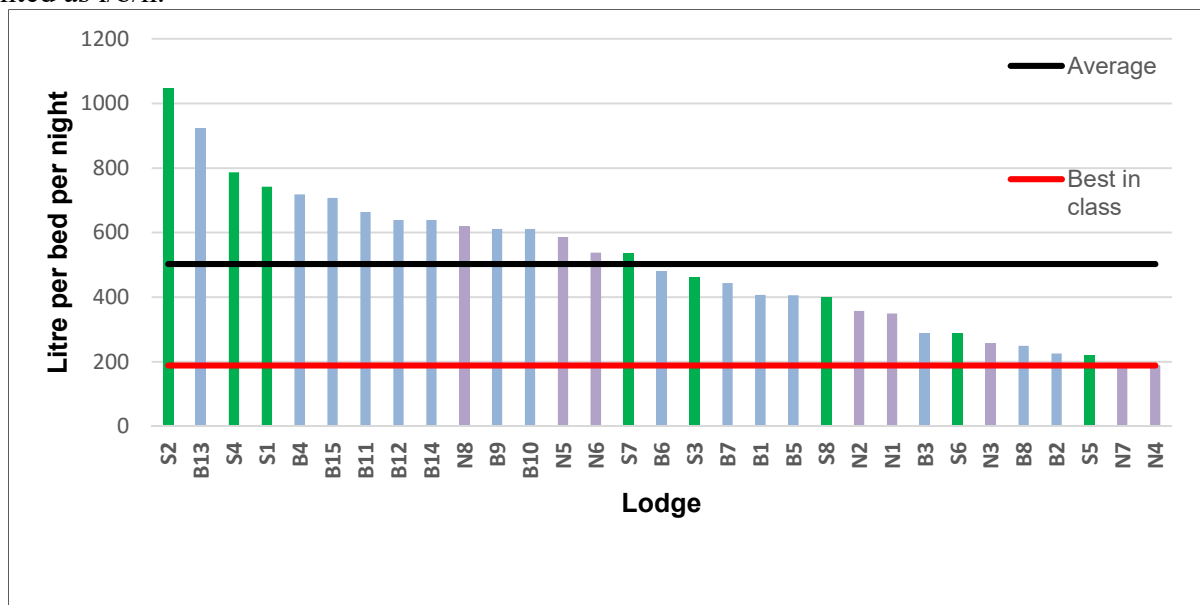


Figure 21.2: Average litre per bed night from all the lodges

Figure 21.2 indicates that the average water consumption *per capita* was 503 l/b/n when staff were included in the calculations. According to Table 21.1 this baseline is similar to hotels across the globe. This means that when staff consumption is included in total consumption, the water usage is not as outrageously high as is suggested above when only guest consumption is used. These averages compare favourably to 5-star hotels in Greece and Morocco and are less than hotels in Zanzibar, Thailand, Hong Kong and the Philippines.

Three of the top five water consumers came from lodges located in South Africa. Six of the 10 highest water consumers came from lodges in Botswana. The two lodges with the lowest water consumption were both lodges situated in Namibia. The highest water usage was lodge S2 with 1048 l/b/n. The lowest water consumption *per capita* was lodge N4 with only 188 l/b/n, which was the best in class from all the lodges. The average consumption from all 31 lodges across all three countries was 503 l/b/n. Figure 21.3 illustrates the results from the eight lodges in South Africa with regard to the international standard of l/g/n.

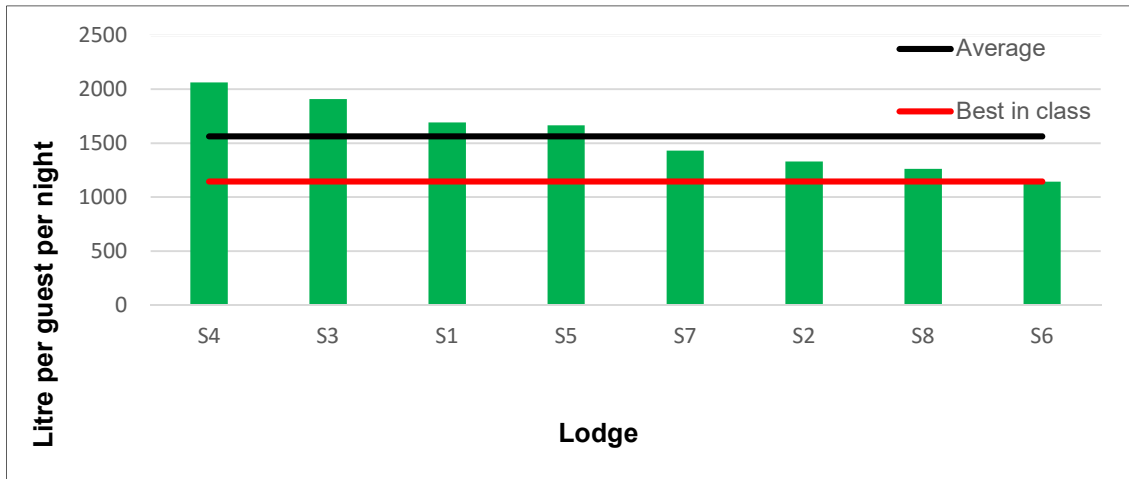


Figure 21.3: Average litre per guest per night from the eight lodges in South Africa

Figure 21.3 indicates the same scenario as previously mentioned when only guest consumption is considered. The average of 1 562 l/g/n in South Africa is well above the majority of hotels listed in Table 21.1. The results indicate that the lodge with the highest water consumption *per capita* was lodge S4 with 2063 l/g/n. The lodge with the lowest water consumption *per capita* was lodge S6 with 1144 l/g/n, also the best in class from all the lodges in South Africa. Figure 21.4 illustrates the results when staff were included in the calculations for South Africa.

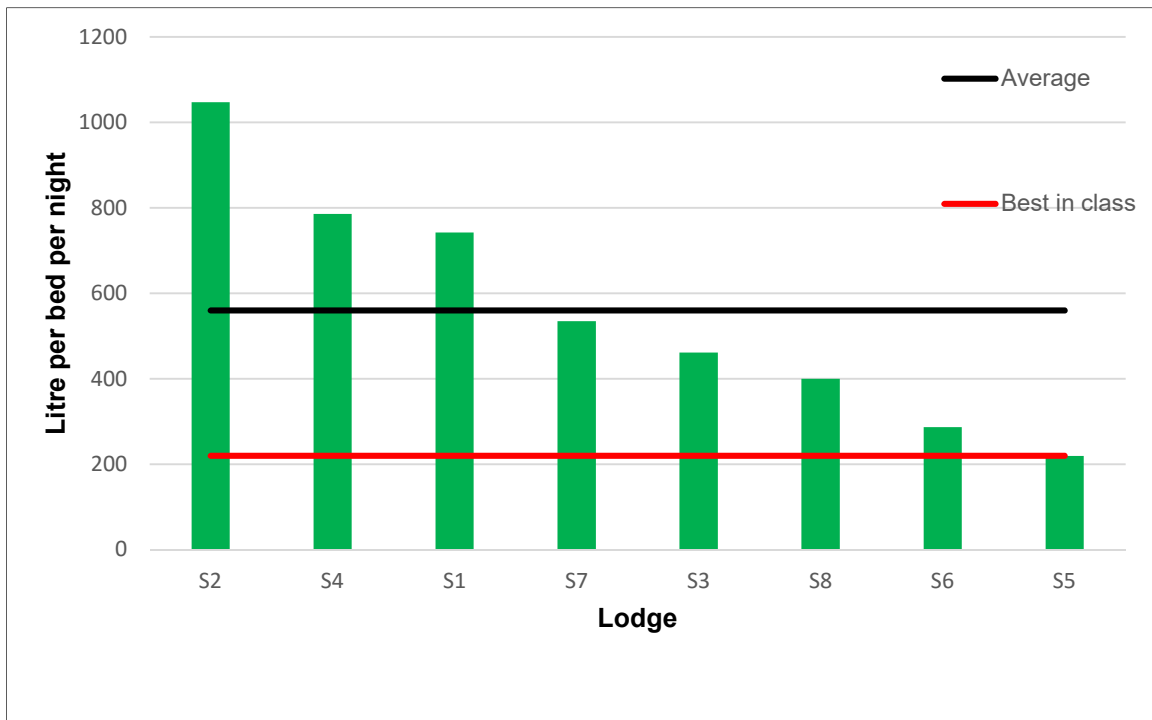


Figure 21.4: Average litre per bed night from the eight lodges in South Africa

Figure 21.4 illustrates the average water consumption *per capita* in South Africa, of 560 l/b/n, when staff is included in the calculations. This compares well to hotels and tourism establishments across the globe. The results indicate that the lodge with the highest water consumption *per capita* was lodge S2 with 1048 l/b/n. The lodge with the lowest water consumption *per capita* was lodge S5 with 220 l/b/n, also the best in class from all the lodges

in South Africa. The main reason the consumption at lodge S2 is considerably higher than the rest of the lodges in South Africa, is because only a small percentage of the staff reside on the property. Staff commuting from the local community to the lodge consume water during their work shift, but because they are not staying on the property their consumption is not calculated into the bed nights. Figure 21.5 illustrates the water consumption from the eight lodges in Namibia with regard to international standard l/g/n.



Figure 21.5: Average litre per guest per night from the eight lodges in Namibia

Figure 21.5 illustrates similar findings : when only guest consumption is considered the average water consumption per capita in Namibia of 1 337 l/g/n is well above the baselines from hotels in other countries across the globe. The lodge with the highest water consumption *per capita* was lodge N5 with 2450 l/g/n. The lodge with the lowest water consumption *per capita* was lodge N7 with 485 l/g/n, also the best in class from all the lodges in Namibia. Figure 21.6 illustrates the results when staff were included in the data analysis.

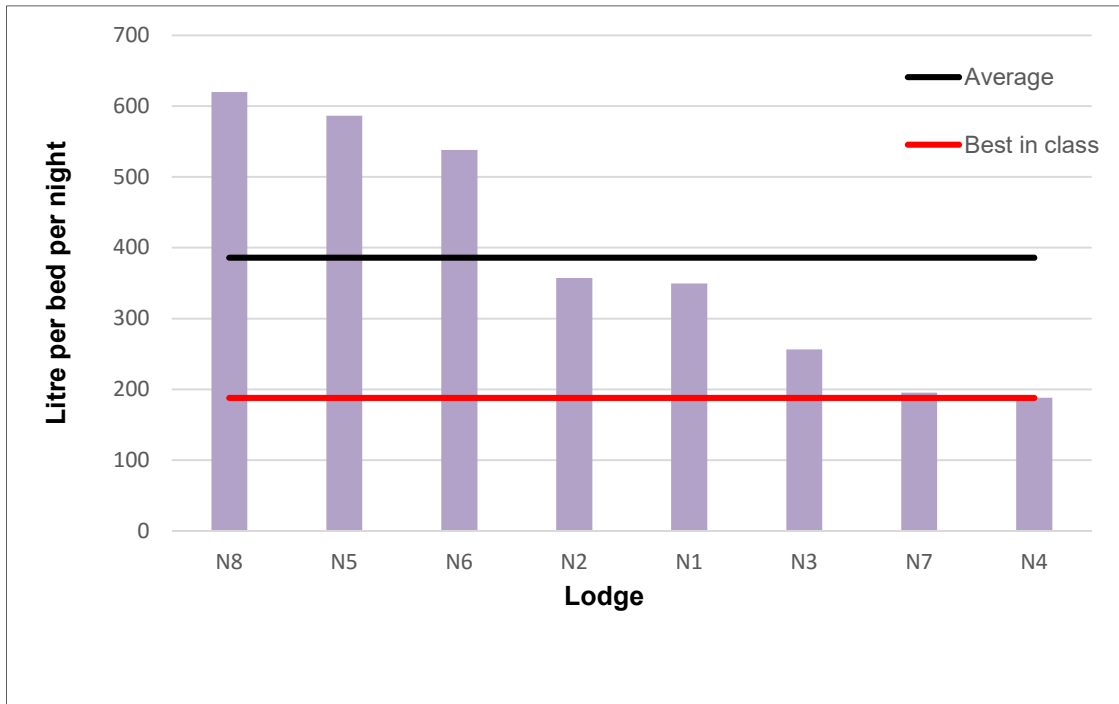


Figure 21.6: Average litre per bed night from the eight lodges in Namibia

Figure 21.6 illustrates that the average water consumption *per capita* in Namibia of 386 l/b/n also compares well to hotels and tourism establishments across the globe when staff is included in the calculations. The lodge with the highest water consumption *per capita* was lodge N8 with 620 l/b/n. The lodge with the lowest water consumption *per capita* was lodge N4 with 188 l/b/n, also the best in class from all the lodges in Namibia. Figure 21.7 illustrates the water consumption from the 15 lodges in Botswana with regard to the international standard of l/g/n.

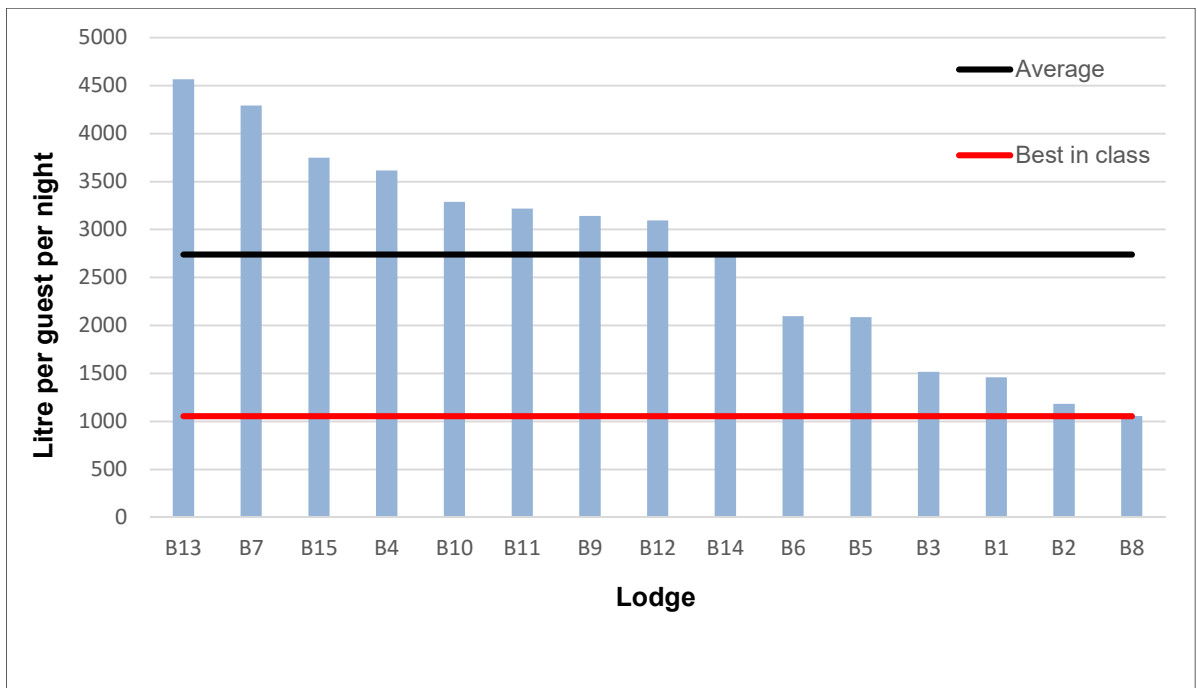


Figure 21.7: Average litre per guest night from the 15 lodges in Botswana

Figure 21.7 illustrates the exact same result as the previous results shown above. When only guest consumption is considered, the average water consumption *per capita* in Botswana of 2 739 l/g/n is well above the baselines from hotels in other countries across the globe. The results indicate that the lodge with the highest water consumption *per capita* was lodge B13 with 4567 l/g/n. The lodge with the lowest water consumption *per capita* was lodge B8 with 1055 l/g/n, also the best in class from all the lodges in Botswana. The average water consumption for lodges located in Botswana was 2739 l/g/n.

Figure 21.8 illustrates that the average water consumption *per capita* in Botswana of 534 l/b/n also compares similarly to hotels and tourism establishments across the globe when staff is included in the calculations. The results indicate that the lodge with the highest water consumption *per capita* was lodge B13 with 923 l/b/n. The lodge with the lowest water consumption *per capita* was lodge B2 with 225 l/b/n, also the best in class from all the lodges in Botswana. The average water consumption with the inclusion of staff for all the lodges located in Botswana was 534 l/b/n.

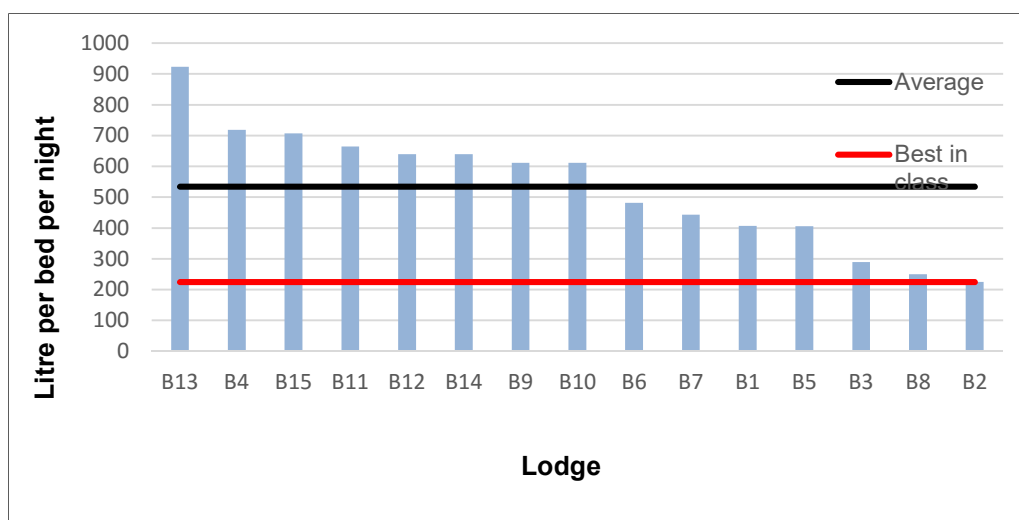


Figure 21.8: Average litre per bed night from the 15 lodges in Botswana

The results clearly indicate that if only guest consumption is considered, the averages in all the calculations were outrageously high compared to countries such as Greece, Morocco, Zanzibar, Germany and the USA. When staff nights were included, the average water consumption is comparable to most other countries around the world. The results indicate that the lodge with the highest consumption in Botswana, when only guests were considered, was more than double than the lodge with the highest consumption in South Africa and more than 2000 l/g/n more than the lodge with the highest consumption in Namibia. The lodges with the lowest consumption, when only guests were considered, were very similar in South Africa and Botswana, but more than double the lodge with the lowest consumption in Namibia. The average consumption in South Africa and Namibia, when only guests were considered, were similar, with averages of 1562 l/g/n and 1337 l/g/n irrespectively, with the lodges in Botswana averaging more than double the lodges in Namibia with an average of 2739 l/g/n.

The results indicate that the lodge with the highest consumption in South Africa, when guests and staff were considered, was similar to the lodge with the highest consumption in Botswana. The Namibian lodge with the highest consumption was 300 l/b/n less than the lodge with the highest consumption in Botswana. The lodges with the lowest consumption, when guests and staff were considered, were very similar in all three countries, ranging from 188

l/b/n to 225 l/g/n. The average consumption in South Africa and Botswana, when only guests were considered, was similar, with averages of 560 l/b/n and 534 l/b/n respectively. The lodges in Namibia had the lowest average of all three countries, averaging only 386 l/b/n.

	All countries	South Africa	Namibia	Botswana
Highest consumption, guests only (l/g/n)	4567	2063	2450	4567
Lowest consumption, guests only (l/g/n)	485	1144	485	1055
Average, guests only (l/g/n)	2073	1562	1337	2739
Highest consumption, guests and staff (l/b/n)	1048	1048	620	923
Lowest consumption, guests and staff (l/b/n)	188	220	188	225
Average, guests and staff (l/b/n)	503	560	386	534

The table indicates that lodges in Botswana use 1402 l/g/n more than Namibia and 1177 l/g/n more than South Africa. Namibia uses 225 l/g/n less than South Africa. It is clear that water consumption in Botswana is significantly higher per capita than in South Africa and Namibia.

Resultant baselines and benchmarks

The baseline water consumption for all three countries as a whole was 2073 l/g/n or 503 l/b/n. Botswana had the highest *per capita* average when only guest consumption was considered with an average of 2739 l/g/n against the 1562 l/g/n of South Africa and the 1337 l/g/n in Namibia. South Africa had the highest average when both staff and guest nights were considered, with an average of 560 l/b/n against the 534 l/b/n of Botswana and the 386 l/b/n of Namibia.

The best in class method was used as the benchmark, which was 485 l/g/n or 188 l/b/n. The water consumption baseline in South Africa was 1562 l/g/n or 560 l/b/n. The benchmark of the best in class was 1144 l/g/n or 220 l/b/n. In Namibia the baseline water consumption was 1337 l/g/n or 386 l/b/n. The best in class benchmark was 485 l/g/n or 188 l/b/n. In Botswana the water consumption baseline was 2739 l/g/n or 534 l/b/n. The best in class benchmark was 1055 l/g/n or 225 l/b/n.

The results indicated that the average water consumption across all three countries was very high compared to other countries when the l/g/n were used for comparisons; however, when the staff nights were included in the consumption figures, the average l/b/n were very similar to countries such as Greece, USA, Germany, Morocco and many other. The average water consumption from the lodges in Namibia, both in l/g/n and l/b/n, was the lowest from all three countries, whereas the average water consumption in Botswana was highest of the three countries.

Conclusion

The wildlife lodge industry is dependent on water for its existence as it serves both its staff and its guests. Staff and guest are encouraged to use water sparingly ; however, the success of the current measures has not been evaluated in this study and requires investigation. Both wildlife lodge companies involved in this study monitor their current systems and are constantly seeking cost effective ways to improve their performance. However, since the cost of water is

minimal, it is hard to earn a return on investment by investing in water saving measures and technologies. Both organisations review their environmental management systems periodically and are continuously looking to improve their environmental performance and water management systems.

Since this was the first study to investigate water quantity management in the wildlife lodge industry in South Africa, Namibia and Botswana, the results and analysis of this study will provide lodges and organisations with valuable information with regard to water quantity use and management in the industry and will aid organisations in their goals of sustainable tourism development. The baselines and benchmarks will also assist in the planning of new developments as they provide information which can help developers to plan their new tourism developments on the quantity of water that can be sustainably sourced from the available water resources.

References

- andBeyond. 2018. *www.andBeyond.com* [accessed 24 November 2018]
- Baker, M. and Mearns, K. 2015. Sustainable tourism indicators to manage scarce water resources. *The Responsible and Sustainable Tourism Handbook. Southern and East Africa*. 3, 51 – 57.
- Baker, M. & Mearns, K. 2017. Applying sustainable tourism indicators to measure the sustainability performance of two tourism lodges in the Namib Desert. *African Journal of Hospitality, Tourism and Leisure*, 6 (2), 1-22.
- Becken, S. 2014. Water equity – Contrasting tourism water use with that of the local community. *Water resources and industry*. 7, 9 – 22.
- Córcoles, J.I., de Juan, J.A., Ortega, J.F., Tarjuelo, J.M. and Moreno, M.A. 2010. Management evaluation of Water Users Associations using benchmarking techniques. *Agricultural Water Management*. 98, 1 – 11.
- Gössling, S. 2001). The consequences of tourism for sustainable water use on a tropical island Zanzibar, Tanzania. *Journal of Environmental Management*. 61(2), 179 – 191.
- Gössling, S., Peeters, P., Hall, C.M., Ceron, J.P., Dubois, G., Lehmann, L.V. and Scot, D. 2012. Tourism and Water use: Supply, Demand and Security. An International Review. *Tourism Management*. 33, 1 – 15.
- Gössling, S., Hall, C.M. and Scott, D. 2015. *Tourism and Water*. Channel View Publications. Ontario.
- Mearns, K. and Grobler, H. 2016. Managing Water for Tourism in the Phinda Private Nature Reserve, KwaZulu-Natal, South Africa, Athens: ATINER'S Conference Paper Series, No: WAT2016-2022. 4th Annual International Forum on Water, Athens, Greece 11 July-14 July 2016, 1-23.
- Saagi, R., Kroll, S., Flores-Alsina, X. and Jeppson, U. 2017. A model library for simulation and benchmarking of integrated urban wastewater systems. *Environmental Modelling and Software*. 93, 282 – 295.
- Styles, D., Schoenberger, H. and Galvez-Martos, J.L. 2015. Water management in the European hospitality sector: Best practice, performance benchmarks and improvement potential. *Tourism Management*. 46, 187 – 202.
- Wilderness Safaris. 2017. *Agents Manual 2017*. Wilderness Safaris, Sandton.

Chapter 22: Household water demand management strategies for sustainable use in Maun, Botswana

Manga Motho*, Oluwatoyin D. Kolawole, Moseki R. Motsholapheko
and Patricia K. Mogomotsi

Okavango Research Institute,
University of Botswana, Bag 285, Maun
*Corresponding author: mmotho@ub.ac.bw

Abstract

The availability of fresh water for human consumption is a crucial issue. On a global scale, water is increasingly becoming a scarce resource due to the increasing demand driven by urbanisation and rapid economic growth, which is further exacerbated by climate change. Although mitigating measures in the form of legislations have been implemented to lessen the demand, empirical evidence shows that 2.4 billion people worldwide experience water shortages. Since water is a vital resource for combating poverty and achieving sustainable development, it needs to be conserved. Thus, water demand management plays a fundamental role in this regard. Like other African countries, Botswana is not an exception as it faces severe water shortages, especially in urban settlements. Hence there is a need for awareness of household water demand management strategies in Botswana. Adopting a case study approach and using social survey and literature review methods to obtain both primary and secondary data, respectively, the neoclassical theory of supply and demand was used to assess household water demand management practices in Maun, Botswana. With the aid of a self-administered questionnaire, data were collected from a sample of 40 respondents comprising household heads and water managers. Descriptive statistics were used to summarise the data. Preliminary findings show that encouraging households to reuse wastewater, harvest rainwater and implement efficient water-saving appliances contributes to water conservation. The majority of households lack understanding of efficient water-using appliances, reading water meters and calculation of monthly bills. Therefore, there is a need for public education and awareness of such issues.

Keywords: Conservation, demand management, household, strategies, sustainable, theory, water

Introduction

Fresh water is vital for human survival and to the functioning of ecosystems (Baron *et al.* 2002; Assessment, 2005). However, the available fresh water resources are expected to decline as a result of rapid population growth, economic expansion, global climate and varying rainfall patterns among other factors (Kenway *et al.* 2015). As population increases, the demand for water is expected to increase, placing pressure on available water resources (Butler & Memon, 2005). Therefore, sustainable management practices have gained attention with the aim of reducing household water consumption (Wong & Brown, 2009). Moreover, water conservation strategies (such as water pricing, water rationing, public education, etc.) have been applied in developed countries to attain sustainable water management (Lee *et al.* 2011). Households can contribute to water demand management by reducing the quantity of water they consume

through conservation practices which include the use of efficient appliances like showers, toilets and washing machines, among others (Kenney *et al.* 2008; Fidar *et al.* 2010; Lee *et al.* 2011).

Botswana, a semi-arid country with limited surface and groundwater sources, has unevenly spread and limited sources of water in both quantity and quality (Botswana National Water Master Plan Review/BNWMMPR, 2006). Consequently, she depends on trans-boundary water sources such as the Okavango, Zambezi and Limpopo rivers (BNWMMPR, 2006). Surface water in the country is sourced from 10 dams, among them being Gaborone, Letsibogo and Lotsane. Despite these dams, the country is unable to meet the demand (Botswana Water Accounting, 2016). This emanates from a rapid population and economic growth as well as climate variability, among others (BNWMMPR, 2006). Estimates are that water demand in Botswana will increase from 193 Mm³/year in 2000 to 335.2 Mm³/year by 2020 (BNWMMPR, 2006). This is a massive increase and will absolutely increase water stress. Furthermore, the rainfall in the country is unreliable and very low with a record of 650mm per year. Consequently, low and unreliable rainfall has a negative impact on the availability of surface water resources. This indicates that there is a need for instant implementation of water demand management strategies for sustainable use of water resources.

The Ngamiland District is equally affected by high water demand. Maun as the main village in the district has very limited water resources (Kujinga *et al.* 2014). This is due to several factors such as population increase and tourism expansion, among other factors (Moffat *et al.* 2011). The main water source in the village is groundwater, which is used for various purposes such as agriculture, industrial and domestic uses. Over the past years, there has been a deterioration of water quality and supply (Moffat *et al.* 2011). This has led to water challenges due to intensive water use by different sectors, households included (Moffat *et al.* 2011). Hence, this research uses Maun as a case study to assess household water demand management strategies and suggest measures for improving them.

Overview of water demand management

Currently, the water crisis is a challenge to both developed and developing countries worldwide. It threatens the economic growth, ecosystems and livelihoods (Baron *et al.* 2002; Assessment, 2005). In a quest to address these challenges, there has been a movement towards integrated water resources management globally ; nations have embarked on improving their water policies in an attempt to achieve sustainable use of water resources. These efforts increased after the Dublin 1992 International Conference on Water and the Environment (ICWE) held in Rio de Janeiro, Brazil. The conference stressed the urgent need for shifting beyond supply management practices of water resources to a new paradigm of integrated water resources management (IWRM) for the advancement of sustainable approaches to water development and management (ICWE, 1992), see Table 22.1.

Table 22.1: The four Dublin principles
1. Water is finite, vulnerable and essential resource which should be managed in an integrated manner.
2. Water resource development and management should be based on participatory approach, involving all relevant stakeholders.
3. Women play a central role in the provision, management and safeguarding of water.
4. Water has an economic value and should be recognised as an economic good, considering affordability and equity criteria.

(Source: ICWE, 1992)

It is progressively being recognised that supply and demand can only be balanced if both concepts are addressed equally (Herbertson *et al.* 2001). Therefore, water demand management is a key mechanism of integrated resource planning, which is a requirement for sustainable water management (Gumbo *et al.* 2003; Odongo, 2014). Water demand management is defined as the “development and implementation of strategies that achieve effective sustainable use of available limited supply” (Savenije & Van der Zaag, 2002). Schuringa (2000) clarifies water demand management as “an approach to improve the efficiency and sustainable use of water resources, considering the economic, social and environmental aspects”. Water demand management aims to reassure the sustainable use of available water resources through economic and efficient management before additional supply (Wegelin-Schuringa, 2000). Water demand management depends on the application of socio-economic measures such as water conservation technologies, public education, economic analysis, reduction of non-revenue water, water recycling and incentives, among others (Nyambe *et al.* 2002; Al-Maskati, 2011).

Water demand management strategies in Botswana

Water access and use in Botswana is governed by the Water Act (1968), National Water Policy (2012), Water Management Plan (2010) and the Botswana Integrated Water Resource Management and Efficiency Plan (2013) and other water-related policies (Gondo & Kolawole, 2016). Botswana like other regional countries faces water challenges (Kujunga *et al.* 2014, Madigele, 2016). Thus, water resources are gradually declining in most areas in Botswana, including the Ngamiland District. For example, in 1962 the quantity of renewable internal freshwater resources in Botswana was 4,364 m³ and three years later the value reduced to 1,643 m³ (Food and Agricultural Organisation/FAO, 2016). The quantity of fresh water further decreased to a minimum value of 1,081 m³ in 2014 (FAO, 2016). This suggests that access to improved water resources has worsened. While Botswana is prone to water scarcity due to limited water resources (Kujunga *et al.* 2014), it is estimated that almost half of the available water is wasted through leakages, lack of effective WDM programs and inefficient management practices (BNWMP, 2006). Hence, there is a need for sustainable water use.

Botswana like other nations has embarked on water resources management. As an approach to address water challenges as well as ensuring efficient and sustainable water management, institutional changes were proposed. Thus, in 2009 the government of Botswana appointed the Water Utilities Corporation (WUC) as the main supplier of freshwater and wastewater management services across the country (Setlhogile & Harvey, 2015). WUC is a government-owned parastatal which was established in 1970 to manage a water supply and distribution project in the Shashe Development area. Previously both the Department of Water Sanitation (DWS) and the district councils provided water while the Department of Waste Management and Pollution Control was responsible for wastewater management services. The DWS was now mandated for water resources planning, development and management of large water infrastructures such as dams (Setlhogile & Harvey, 2015).

Water tariffs are fully controlled by the government in urban and rural areas (National Water Report, 2005). WUC has to recover its full supply costs and subsidisation for customers is provided to ensure sustainability for all (National Water Report, 2005). According to the 8th National Development Plan (Government of Botswana, 1997), urban water pricing depends on the principles of equity and affordability (all citizens should have access to drinkable water to meet their basic needs and water from standpipes is free in rural areas and subject to a minimal monthly flat rate in urban areas). The other principle is efficiency, which implies that water supply should be cost-effective and people should conserve water (Government of Botswana,

1997). Botswana uses the increasing block rate structure (National Water Report, 2005). Unit charges of this structure differ by use band (the higher the use band, the more the unit charges). Other water management strategies applied in Botswana include restrictions of water use, rainwater collection, water loss reduction and use efficiency (Arntzen *et al.* 1999).

Theoretical approach

The theoretical foundation of this study is informed by the neoclassical economic theory of supply and demand as propounded by Alfred Marshall in 1890. The theory states that at higher prices, producers tend to supply more, while consumers would reduce demand. At lower prices, consumers tend to demand more, while producers would reduce supply ; it focuses on the effects of perception of the usefulness of products on market forces (supply and demand) (Nagel, 1963; Marshall, 1982; McCloskey, 1996). According to Marshall, the following are the assumptions of the theory: i) Choices on economic issues are always made rationally, based on complete information about a product or service; ii) Consumers compare goods and make a final decision based on the perceived utility; iii) The consumer's main aim is to capitalise on the satisfaction given by the use of the product; iv) The main aim of producers is to maximise profits; and v) The market equilibrium is attained when both the customer and producers achieve their respective goals.

In the context of this study, the demand for water decreases when suppliers increase its price, all things being equal. Due to the increase in price, water customers would have to reduce water use and change unnecessary water use behaviours. At lower prices of water, people tend to buy and use water in large quantities, but there is a limit on how much water anybody can use. The world population and standard of living continue to increase. As a result, this leads to water shortages to meet various purposes. Therefore, charging prices which reduce consumption may assist in water resource sustainability. It may also encourage people to seek alternative water sources, hence this may contribute to water conservation.

Research methodology

Study area

Maun, a capital of tourism, is situated in the north-western part of Botswana in the Ngamiland District (see Figure 23.1), under the administration of the North-West District Council. It is divided into two sub-district authorities, namely Maun and Okavango sub-District Authorities and are administered from Maun. Maun village is the district headquarters and has a population of 58, 877 (CSO, 2011). Tourism and livestock rearing are some of the main sectors in the district (Motsholapheko *et al.* 2011). People in the Ngamiland District also rely on natural resources for transportation, fishing, handicraft materials, reeds, employment, etc. (Kgomotso & Swatuk, 2006). The ethnic groups found in Maun include the Batawana, Bayei, Hambukushu, Baherero and others. Maun village has been experiencing water shortages over the years (Moffat, 2011). Furthermore, it has the highest level of water demand among large villages in the country, Molepolole ranked first (Botswana Water Statistics, 2009).

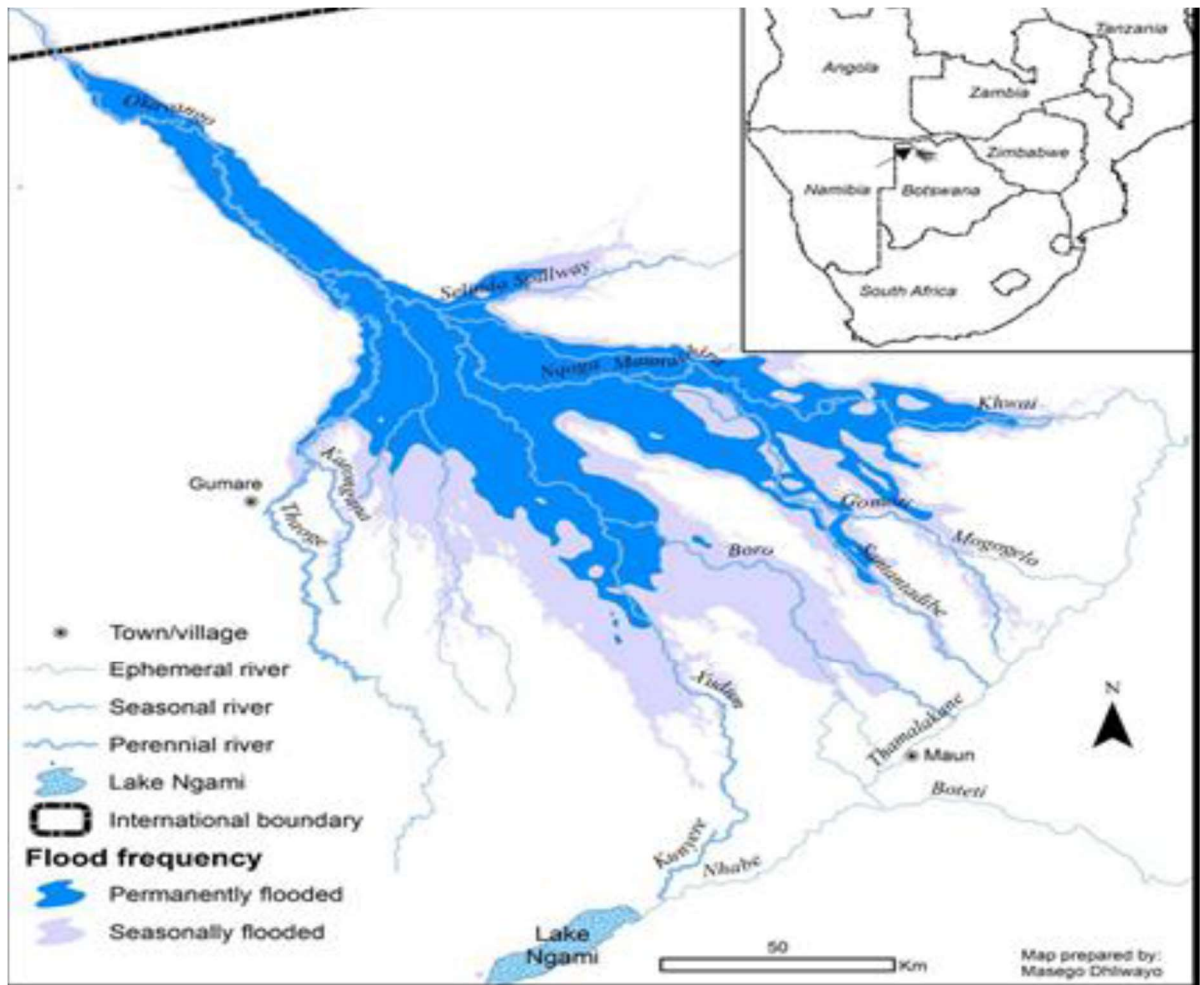


Figure 22.1: Map showing the location of Maun (Source: Okavango Research Institute-GIS, 2018)

The study adopted a case study methodology which included quantitative and qualitative analysis. Primary data were collected using an in-depth structured and unstructured questionnaire targeting households in Disaneng and Boseja wards. The information collected from respondents included demographic and socio-economic factors, household water demand management, the effectiveness of the strategies and perceptions of household on water demand management in Maun. A sample of 40 household heads was selected using a simple random sampling technique. Expert purposive sampling was applied in the selection of key informants from Water Utilities Corporation (WUC). The purpose of these interviews was to get in-depth information on household water demand management strategies. Secondary data were obtained from journal articles, books, reports and newspapers through systematic literature review. Quantitative data obtained through the questionnaire survey was analysed using descriptive statistics (frequency tables, percentages and charts), measures of central tendency (mean) and measure of dispersion (standard deviation). Qualitative data from key informant interviews and documents obtained from the water expert was analysed using thematic and narrative analysis.

Results and discussion of social survey

This section provides the analysis and discussion of the findings of the study. It consists of demographic and socio-economic characteristics of respondents, household water demand

management strategies, effectiveness, benefits and perceptions of household heads on water demand management.

Demographic and socio-economic characteristics of respondents

A total of 40 households were interviewed in the survey. Table 22.2 shows a summary of descriptive data. Findings reveal that the majority (70%) of the household heads were females while (30%) were males. The average age of the household heads was 36.1, with a standard deviation of 10.5. The majority (35%) of the respondents fall within the 30-39 age group. However, a proportion of the household heads (5%) were 60 and above. This analysis shows that most of the household heads were still in the youth stage (20-40 years). Findings of this study show that the average household size of the survey is 4.7 ; it ranges from one up to 13 members. This is somewhat bigger than Botswana’s average household size (3.3 persons per household) (Statistics Botswana, 2017). The average household size of the study has an impact on water consumption. A high number of people in a household leads to high quantities of water consumption.

Findings from this study show that more than half (55%) of the households had tertiary qualifications, either a certificate, diploma or undergraduate and postgraduate degrees. Only 2.5% of the respondents did not have formal education. Generally, most household heads in the study area had acquired formal education. The other socio-economic survey findings indicate the occupation of the household heads. It reveals that the majority (42.5%) owned businesses, 22.5% are employed in private-owned businesses, 5% are employed by the government, 5% are retired and the remaining 25% were unemployed. The data reveal that the majority (62.5%) of the respondents fall within a range of income group of less than P2,000.00 per month (with the mean of P2,797.35 and standard deviation of 3,961.3) (Table 22.2). The large value of the standard deviation may have been influenced by the large variation between the minimum and maximum monthly income of household heads. About 15% of the household heads earned from P5,000.00 and above. A study by Zhang and Brown (2005) reports that households with higher income are associated with a higher level of education and more household water use and consumption. Thus, people in the study area use significant quantities of water.

A research study on the relationship between house ownership and water consumption in Sydney reveals that people who rent houses tend to be reluctant to implement water-saving practices compared to those living in their own houses, and they barely replace inefficient water appliances (Troy & Randolph, 2006). A study by Shan *et al.* (2015) reports that homeowners are more conscious of the changes in the price of water compared to those who rent homes. This may be due to the reason that house owners are responsible for paying the water bills; therefore, people who rent tend not to be aware of the amount of water they use since they do not directly pay for water bills. Findings of this study show that the majority (77.5%) of the household heads fully owned the houses, 17.5% were renting private houses and 5% were renting public (government) houses (see Table 22.1).

Table 22.2: Characteristics of respondents of the survey			
Variable	Frequency	%	N=40
Gender			
Male	12	30	
Female	28	70	

Total	40	100	
Age group			
20-29	13	32.5	Mean=36.1
30-39	14	35	Sta Dev. =10.5
40-49	7	17.5	
50-59	4	10	
60 +	2	5	
Total	40	100	
Educational level			
None	1	2.5	
Primary	4	10	
Secondary	13	32.5	
Tertiary	22	55	
Total	40	100	
Employment			
Employed	27	67.5	
Unemployed	13	32.5	
Total	40	100	
Type of employment			
Civil service	2	5	
Privately owned business	9	22.5	
Owned business	17	42.5	
Retired	2	5	
Not working	10	25	
Total	40	100	
Income group			
Less than P2,000	25	62.5	Mean =P2,797.35
P2,001-P3,000	4	10	Sta Dev.=3961.3
P3,000-P4,000	3	7.5	
P4,001-P5,000	2	5	
P5,0001 +	6	15	
Total	40	100	
Household ownership			
Fully owned	31	77.5	
Renting-private	7	17.5	
Renting-public	2	5	
Total	40	100	

Source: Field survey, April 2019

Household WDM strategies in Maun Village

Water is regarded as an economic resource that should be managed and used sustainably (Al-

Jayyousi, 2003; Madigele, 2016; Gondo & Kolawole 2016). With the crisis of water scarcity, security and demand worldwide, the resource needs to be used wisely. Water demand management has been recognised to be an effective strategy in managing water resources. Household heads were asked if they practise household water demand management strategies. Results show that 77.5% of the household heads were engaged in some form of household water demand management strategies, while 22.5% were not.

Table 22.3 shows different household water demand management strategies identified during the study and their percentages in terms of implementation. Of 40 household heads interviewed, 31 showed that they do apply household WDM strategies, while 9 did not. A total of nine Likert-scale items/statements (Table 22.3) was used to determine the application of household water demand management strategies by household heads. The statements favoured water management and were rated on a 5-point Likert scale, where 1 was the minimum point and 5 was the maximum point for each statement. Ranked on a scale of 1-5 the possible maximum average score for each household head for all the nine statements is thus 45/9, which is 5 points. Therefore, the grand mean score computed for all the household heads was 4.47, with a standard deviation of 1.00. The high score means household heads in Disaneng and Boseja wards apply water demand management strategies. Findings indicate that the majority (61.3%) of the household heads strongly agreed (51.6%) and agreed (9.7%) that they reuse wastewater for other household activities such as watering plants and toilet flushing. While 12.9% were indecisive, 6.5% and 19.3% disagreed and strongly disagreed, saying that they do not reuse waste water. It is not surprising that the majority of people reuse wastewater due to the high demand for water in Maun.

Statement	SA	A	N	D	SD
I reuse wastewater for household activities such as watering plants	16 (51.6)	3 (9.7)	4 (12.9)	2 (6.5)	6 (19.3)
I install efficient water use appliances to regulate water consumption	5 (16.1)	7 (22.6)	3 (9.7)	4 (12.9)	12 (38.7)
I do repair leaking pipes whenever there is a need to do so	21 (67.8)	5 (16.1)	1 (3.2)	1 (3.2)	3 (9.7)
I use a water meter to regulate water consumption	22 (70.9)	2 (6.5)	2 (6.5)	4 (12.9)	1 (3.2)
I harvest rainwater for household water use	18 (58.1)	5 (16.1)	0	2 (6.5)	6 (19.3)
I water plants during the coolest part of the day to conserve water	13 (41.9)	4 (12.9)	5 (16.1)	2 (6.5)	7 (22.6)
I do not fill the bathtub/basin as a way of reducing water use	22 (70.9)	6 (19.3)	1 (3.2)	2 (6.5)	-
I turn off water while brushing teeth to avoid wasting water	25 (80.7)	6 (19.3)	-	-	-
I use a sink/basin plug more often to conserve water	21 (67.8)	5 (16.1)	1 (3.2)	1 (3.2)	3 (9.7)

Percentages in parenthesis ()

Source: Field survey, April 2019

According to Lee *et al.* (2011), household water conservation can be operative from several parts, such as : (i) households account for the majority of the water demand in urban areas, (ii) household appliances such as showers, toilets, washing machines contribute more to the

demand for household water use, and (iii) the possible water savings by water efficiency appliances. Non-efficient water using appliances are identified which waste high quantities of water which could have been used for other purposes. The more efficient the water-using appliance the more water could be saved (Kenney *et al.* 2008; Olmstead & Stavins, 2009; Odongo *et al.* 2014). Findings (see Table 22.3) of this study depict that a few (38.7%) of the household heads strongly agreed (16.1%) and agreed (22.6%) that they install efficient water use appliances. This indicates that there are some people who are aware of water saving appliances. The percentage of household heads who were not sure about the statement was 9.7%. The majority (51.6%) of the household heads disagreed (12.9%) and strongly disagreed (38.7%) with the statement. The survey showed that respondents did not know the differences between efficient and inefficient water use appliances, therefore the researcher had to explain and give examples of them.

Findings show that the majority (83.9%) of the household heads strongly agreed (67.8%) and agreed (16.1%) that they do repair leaking pipes whenever there is need to do so. However, 3.2% were undecided, hence did not reveal whether they install efficient appliances or not. 12.9% disagreed (3.2%) and strongly disagreed (9.7%) with the statement. This indicates a good water conservation practice by household heads. Similar findings by Puust *et al.* (2010) show that leakages in water supply affect both water corporations and their clients.

Water meters are used by various countries across the globe to record water consumption for both the water corporations and their clients (Sonderlund *et al.* 2014). Mostly, water bills are calculated on a monthly basis, based on meter readings. The study shows that the majority (77.4%) of the household heads strongly agreed (70.9%) and agreed (6.5%) that they use a water meter to regulate their household water consumption. 6.5% of the respondents gave a neutral response. Other respondents (16.1%) disagreed and (12.9%) strongly disagreed (3.2%) with the statement. The study found that the majority of those who disagreed did not have taps in their household; they fetch water from neighbours. It was discovered that the majority of people do not know or understand how to read water meters or how monthly water bills are calculated, or do not have knowledge about water tariffs.

Rainwater harvesting is a sustainable option of water supply to combat challenges of water shortage especially in developing countries (Mwamila *et al.* 2016). Rainwater can meet the demand for water depending on rainfall quality and variation (Mwamila *et al.* 2016). The results show that the majority (74.2%) strongly agreed (58.1%) and agreed (16.1%) that they harvest rainwater for household use. 25.8 percent showed that they disagreed (6.5%) and strongly disagreed (19.3%) with the statement. The majority (54.8%) of the household heads strongly agreed (41.9%) and agreed (12.9%) that they water plants during the coolest part of the day (early morning and late afternoon) to conserve water. 16.1% showed a neutral response; they did not show their opinion. The rest of the household heads (29.1%) agreed (6.5%) and strongly disagreed (22.6%) with the statement. Of these responses, the study reveals that some household heads did not have plants and some watered at any time of the day.

The majority (90.2%) of the household heads strongly agreed (70.9%) and agreed (19.3%) that they do not fill the bathtub/container as a practice to reduce water use. The study reveals that the majority of respondents use 9 litre buckets for bathing, this indicates a good water conservation practice as compared to using showers. While 3.2% showed a neutral response, they did not give their opinion on the statement. A few (6.5%) disagreed with the statement. They revealed that they use lots of water for bathing and personal hygiene since they need to maintain healthy lifestyles. For instance, one of the respondents said, "I personally use

more water for bathing because I want to feel that I have bathed well.” This shows that there are people who still care less about water conservation.

All the household heads (100%), strongly agreed (80.7%) and agreed (19.3%) that they turn off water while brushing teeth to avoid wasting water. Most of the respondents revealed that they use cups when brushing teeth to avoid using more water. The majority (83.9%) strongly agreed (67.5%) and agreed (16.1%) that they use a container or sink/basin plug more often when washing dishes to conserve water. 3.2% gave a neutral response; they did not give their opinion on the statement. A few (12.9%) disagreed (3.2%) and strongly disagreed (9.7%) with the statement.

Effectiveness of household WDM strategies

As mentioned earlier, 77.5% of households apply water demand management strategies. Figure 22.1 indicates responses of the respondents on the effectiveness of strategies presented in Table 22.3. The data reveals that the majority (42%) showed that household water demand management strategies were highly effective. The results imply that water demand management is effective in households and therefore beneficial to the entire community in terms of sustainability.

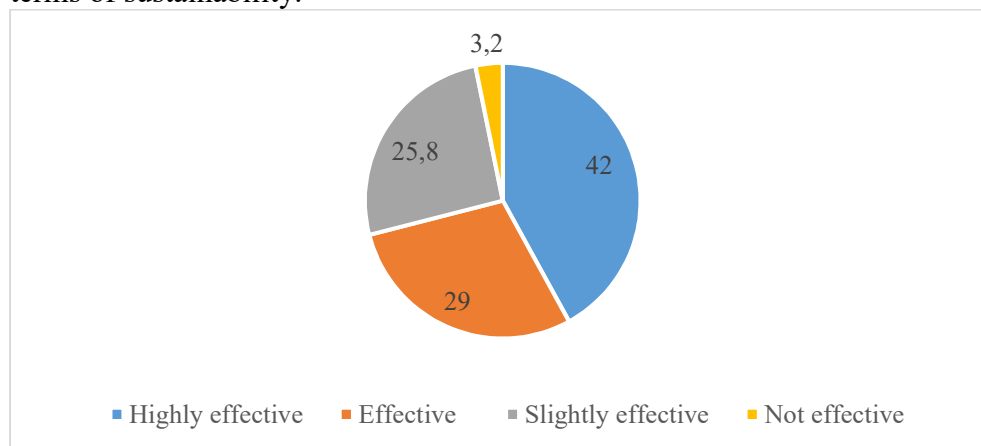


Figure 22.2: Responses on the effectiveness of household WDM strategies. Source: Field survey, April 2019

Benefits of application of household WDM strategies

WDM strategies play a vital role in integrated water resources management (Dziegielewski, 2003). Hence effective demand management is emphasised in water policies internationally (Bryx & Bromberg, 2009). Table 23.4 shows the benefits of applying household water demand management strategies. The findings reveal that the majority (25.8%) of the household heads agreed that the benefits of practising household water demand management strategies are : reduced costs, water usages and leakages/loss. The survey showed that some of the respondents argue that even if they reduce their water consumption, water bills are always high. One of the respondents said: “Even if we conserve water, bills are always high. During previous years when the DWA now known as DWS was responsible for water supply, we never paid high bills and water was available most of the time. With WUC, water is hardly available, and bills are high. WUC also take long to attend to tap leakages and as a result water bills escalate.”

Benefits of applying household WDM strategies	n=31	%
Reduced costs	7	22.6

Reduced water usage	8	25.8
Reduced water leakages/loss	1	3.2
Reduced costs and water usage	5	16.1
Reduced costs and water leakages/loss	2	6.5
Reduced costs, water usage and leakages/loss	8	25.8
Total	31	100

Source: Field survey, April 2019

Perceptions of household heads on WDM

Table 22.5 shows the distribution of household heads by their perceptions on water demand management. Ten Likert-scale items/statements were formed based on communication with residents of Maun village and with reference to literature (Al-Maskati, 2011; Odongo *et al.* 2014). The statements supported water management and were rated on a 5-point Likert scale. The maximum points possible for a household head is 50 and the minimum is 10 points for each statement. Therefore, the calculated mean score for the household heads was 4.36 with a standard deviation of 0.36. The household heads' high value meant that there is a need for implementation of household water demand management strategies in the study area to reduce water consumption.

Perceptions	SA	A	N	D	SD
Maun Village is undergoing shortage of potable water	37 (92.5)	2 (5)	1 (2.5)	-	-
Every household has a responsibility to reduce water consumption	28 (70)	7 (17.5)	4 (10)	-	1 (2.5)
If each household reduces the amount of water it uses just by little, it will make a big difference for the public	32 (80)	7 (17.5)	-	-	1 (2.5)
Compelling households to pay for water reduce water consumption	16 (40)	11 (27.5)	11 (17.5)	2 (5)	4 (10)
Saving water is an indication of good upbringing	29 (72.5)	6 (15)	2 (5)	-	3 (7.5)
My neighbours always practice water conservation	12 (30)	6 (15)	17 (42.5)	3 (7.5)	2 (5)
I always check the water bill regularly to prevent excessive water consumption in our house	17 (42.5)	10 (25)	11 (17.5)	4 (10)	2 (5)
Water Utilities Corporation is responsible for water rationing practices to manage demand	19 (47.5)	17 (42.5)	4 (10)	-	-
Public education encourages households to conserve water	28 (70)	8 (20)	3 (7.5)	1 (2.5)	-
As water is scarce in Maun Village, we need to conserve it	29 (72.5)	10 (25)	1 (2.5)	-	-

Percentages are in parenthesis ()

Information from Table 22.5 shows that the majority (97.5%) strongly agreed (92.5%) and agreed (5%) that Maun village is undergoing a shortage of potable water. Only 2.5% were neutral about the statement. This clearly shows that the village is under water crisis and water

demand management strategies need to be applied by all households to ensure the sustainability of the resource. Moreover, the majority (87.5%) of the household heads strongly agreed (70%) and agreed (17.5%) that every household has a responsibility to reduce water consumption. While 10% were undecided, 2.5% strongly disagreed with the statement. The results indicate that most households are aware of their responsibility to conserve water. The majority (97.5%) strongly agreed (80%) and agreed (17.5%) that if every household could reduce the amount of water it uses only by a little, it will make a difference for the community. 2.5% strongly disagreed with the statement.

Water pricing is a vital water demand management strategy that is used across water corporations to manage water consumption. Price is regarded as an important financial factor influencing household water demand (Arbues *et al.* 2003). It is an effective tool for saving water (Inman & Jeffrey, 2006; Corbella & Pujol, 2009). The logic behind pricing is that high water prices lead to a lower demand for water (Corbella & Pujol, 2009). This follows the economic theory of supply and demand, which states that at lower prices, consumers tend to demand more while producers would reduce supply, and vice versa. Findings show that the majority (67.5%) strongly agreed (40%) and agreed (27.5%) that compelling households to pay water bills monthly reduces consumption. Although 17.5% gave a neutral response, 32.5% disagreed (5%) and strongly disagreed (10%). This study reveals that, although the majority of people in the study area do check and pay for water bills monthly, there are still a significant number of people who do not pay monthly, and some people do not even understand how the water charges are calculated. Hence convincing people to pay their water bill monthly may lead to reduced water consumption in the sense that people would improve their efforts towards household water demand management strategies to avoid paying higher bills. Additionally, data for the study indicates that the majority (87.5%) of household heads strongly agreed (72.5%) and agreed (15%) that saving water is an indication of a good upbringing. 5% were undecided and 7.5% strongly disagreed with the statement. The results mean most people in the study area understand that teaching the young ones about water conservation is a good practice.

The majority (45%) strongly agreed (30%) and agreed (15%) that their neighbours always practise water conservation. 42.5% were not sure whether neighbours practiced conservation or not. A few (12.5%) disagreed (7.5%) and strongly disagreed (5%) with the statement. The majority (67.5%) of the respondents indicated that they strongly agreed (42.5%) and agreed (25%) that they check water bills regularly to prevent excessive water consumption in their households. Although 17.5% were undecided, 15% of the household heads disagreed (10%) and strongly disagreed with the statement. The results show that a significant number of people do check their water bills. A portion of those who do not check may be those who rent houses and those without water connection in their households. The researcher discovered that some of the households in the study area had their water disconnected by WUC due to failure to pay bills.

Household heads were asked to respond to the statement that WUC is responsible for water rationing practices to manage demand. The majority (90%) strongly agreed (47.5%) and agreed (42.5%) with the statement while only 10% showed a neutral response. This means WUC are responsible for ensuring that water is consumed sustainably across the village. One key informant had this to say about water rationing:

Maun Village is undergoing water shortage due to the drying up of the Thamakalane river. The river supplies 60% of all the water in Maun and surrounding areas. Water demand in Maun is 14.7 million litre per day but only 7.5 million is available due to

the drying up of the river. Therefore, the water will be evenly allocated among customers.

That being said, some of the household heads interviewed argued that water rationing is not being done equally, especially people living in Disaneng ward confirmed that they could go up to a week or more without water supply. This meant that water is not being rationed equally among residents of Maun.

Public education and awareness are crucial in water conservation planning and are basic tools that ensure public participation in water demand management and conservation (Emoabino & Alayande, 2008). According to Al-Senaf *et al.* (2008), public awareness is a vital strategy of getting the public to support water conservation efforts by water suppliers. The findings of this study reveal that the majority (90%) of household heads strongly agreed (70%) and agreed (20%) that public education encourages households to conserve water. However, 7.5% were undecided and 2.5% disagreed with the statement. Thus, it shows that there is a need for public education and awareness on household water demand management strategies and other issues related to water in Maun. The majority (97.5%) of the respondents strongly agreed (72.5%) and agreed (25%) that there is a need to conserve water in Maun village because of its scarcity. Only 2.5% gave a neutral response to the statement. The results imply that public information campaign initiatives can also be used to alert customers to water rates and bills, also to teach them sustainable water use practices and about efficient water-using appliances.

Conclusion and recommendations

The study revealed that at present Maun is experiencing a shortage of potable water. This crisis needs households to implement sustainable water demand management strategies to cope with the situation. Reducing water consumption at household level is a way of decreasing water bills and could benefit the environment. Household water demand management strategies such as public education, the installation of efficient water use appliances (showerheads, double-flush toilets and taps), the reuse of wastewater and rainwater harvesting can reduce the demand for water if fully implemented. Rainwater can be used for other household water use activities such as washing clothes, toilet flushing, showering and watering of plants. From the findings of the study it was revealed that the majority of households do not understand metering and how their water bills are calculated. Therefore, there is a need for public education and awareness of such issues. This could help in the reduction of water consumption.

Household awareness on water-efficient appliances needs to be promoted, given that the study shows that the majority of respondents did not know about effective appliances. There is a need for WUC to reinforce its efforts to increase public awareness about water demand management and conservation, the water situation and public participation in decision-making. This will encourage households to act on rules and regulations based on the decision taken by them. Public awareness could be done through mass media and also the establishment of committees of water demand management and conservation that could involve the public. Additionally, water demand management should be included in the school curriculum to promote awareness among school-going children on the water situation in Maun and the importance of conservation. Public awareness could help inducing a behavioural change towards water consumption. Wastewater reuse should be promoted among households, particularly for activities which do not require a high quality of water. WUC should undertake equitable water rationing in Maun to prevent prolonged water shortages.

References

Al-Jayyousi, O.R. 2003. Greywater reuse: towards sustainable water

- management. *Desalination*, 156(1-3), 181- 192.
- Al-Maskati, H. 2011. *Water demand management: a case study of the kingdom of Bahrain* (Doctoral dissertation, © Hana Husain Al-Maskati).
- Al-Senafy, M., Al-Khalid, A., Mukhopadhyay, A. & Al-Fahad, K. 2008, March. Outlines for Water Saving Practices in Kuwait. In *Proc. of the 8th Gulf Water Conference Water in the GCC Towards an Optimal Planning and Economic Perspective*.
- Arbués, F., Garcia-Valiñas, M. Á. & Martinez-Espiñeira, R. 2003. Estimation of residential water demand: a state-of-the-art review. *The Journal of Socio-Economics*, 32(1), 81-102.
- Arntzen, J.W., Kgathi, D. L. & Segosebe, E. 1999. Water demand management: Botswana country study. Report Prepared for the World Conservation Union, IUCN Regional Programme Office for Southern Africa, Harare, Zimbabwe.
- Arouna, A. & Dabbert, S. 2010. Determinants of domestic water use by rural HHs without access to private improved water sources in Benin: A seemingly unrelated Tobit approach. *Water resources management*, 24(7), 1381-1398.
- Assessment, M.E. 2005. *Ecosystems and human well-being* (Vol. 5). Washington, DC: Island press.
- Ballings, R.C., Gober, P. & Jones, N. 2008. Sensitivity of residential water consumption to variations in climate: An intraurban analysis of Phoenix, Arizona. *Water Resources Research*, 44(10).
- Baron, J. S., Poff, N. L., Angermeier, P. L., Dahm, C. N., Gleick, P. H., Hairston Jr, N. G. ... & Steinman, A. D. 2002. Meeting ecological and societal needs for freshwater. *Ecological Applications*, 12(5), 1247-1260.
- BNWMP Review, Botswana national water master plan review, (Department of Water Affairs, Gaborone, Botswana. 2006).
- Botswana National water policy. 2012.
https://www.google.com/search?ei=idDCXNKhIqPIfAPsM6EgAI&q=Botswana+National+water+policy.+%282012%29&oq=Botswana+National+water+policy.+%282012%29&gs_l=psyab.12..33i22i29i30l10.4486926.4488984..4490532...1.0..0.366.366.3-1.....0....1j2..gws-wiz.....6..0i71j35i39.Oz5jb-1mamo. (Accessed 6th April 2019).
- Botswana National Water Report. 2005.
- Botswana Water Accounting Report. 2016. Botswana Water Accounting Report 2014 / 15.
- Bryx, D. & Bromberg, G. 2009. Best practices in domestic water demand management. *Friends of the Earth Middle East FoEME. Tel Aviv*.
- Butler, D. & Memon, F. A. (eds.). 2005. *Water demand management*. Iwa Publishing.
- Corbella, H. M. & Pujol, D. S. 2009. What lies behind domestic water use? a review essay on the drivers of domestic water consumption. *Bulletin of the Association of Spanish Geographers*, (50), 297-314.
- Dziegielewski, B. 2000. Commercial and institutional end uses of water. American Water Works Association.
- Emoabino, I and Alayande A. 2008. Water Demand Management, Problems and Prospect of Implementations in Nigeria.
http://www.dsi.gov.tr/english/congress2007/chapter_3/84.pdf (Accessed 25th April 2019).
- FAO. 2016. WFP 2015, The State of Food Insecurity in the World 2015. Meeting the 2015 international hunger targets: taking stock of uneven progress. Food and Agriculture Organization Publications, Rome.

- Fidar, A., Memon, F.A. & Butler, D. 2010. Environmental implications of water efficient micro components in residential buildings. *Science of the total environment*, 408(23), 5828-5835.
- Gondo, R. & Kolawole, O.D. 2016. Institutions and transboundary water resources management in southern Africa. Proceedings of the Sixth IASTED International conference, *Environmental and Water Resource Management (AfricaEWRM 2016)*. Gaborone, Botswana.
- Gumbo, B., Mlilo, S., Broome, J. & Lumbroso, D. 2003. Industrial water demand management and cleaner production potential: a case of three industries in Bulawayo, Zimbabwe. *Physics and chemistry of the earth, parts a/b/c*, 28(20-27), 797-804.
- Hanke, S. H. & Mare, L.D. 1982. Residential water demand: a pooled, time series, cross section study of Malmö, Sweden. *Journal of the American Water Resources Association*, 18(4), 621-626.
- Herbertson, P. W. & Tate, E. L. 2001. *Tools for water use and demand management in South Africa*. Secretariat of the World Meteorological Organization.
- Howarth, D. & Butler, S. 2004. Communicating water conservation: How can the public be engaged? *Water science and technology: water supply*, 4(3), 33-44.
- ICWE. 1992. The Dublin Statement and Report of the Conference. International Conference on Water and the Environment: Development Issues for the 21st century. 26–31 January. Dublin.
- Inman, D. & Jeffrey, P. 2006. A review of residential water conservation tool performance and influences on implementation effectiveness. *Urban Water Journal*, 3(3), 127-143.
- Kenney, D. S., Goemans, C., Klein, R., Lowrey, J. & Reidy, K. 2008. Residential water demand management: lessons from Aurora, Colorado 1. *JAWRA Journal of the American Water Resources Association*, 44(1), 192-207.
- Kenway, S.J., Binks, A., Lane, J., Lant, P. A., Lam, K. L. & Simms, A. 2015. A systemic framework and analysis of urban water energy. *Environmental Modelling & Software*, 73, 272-285.
- Keshavarzi, A. R., Sharifzadeh, M., Haghghi, A. K., Amin, S., Keshtkar, S. & Bamdad, A. 2006. Rural domestic water consumption behavior: A case study in Ramjerd area, Fars province, IR Iran. *Water research*, 40(6), 1173-1178.
- Kgomotso, P.K. & Swatuk, L.A. 2006. Access to water and related resources in Ngamiland, Botswana: Toward a more critical perspective and sustainable approach. *Physics and Chemistry of the Earth, Parts A/B/C*, 31(15-16), 659-668.
- Kollmuss, A. & Agyeman, J. 2002. Mind the gap: why do people act environmentally and what are the barriers to pro-environmental behaviour? *Environmental education research*, 8(3), 239-260.
- Kujinga, K. Vanderpost, C., Mmopelwa, G. & Wolski, P. 2014. An analysis of factors contributing to household water security problems and threats in different settlement categories of Ngamiland, Botswana. *Physics and Chemistry of the Earth, Parts A/B/C*, 67, 187-201.
- Lee, M., Tansel, B. & Balbin, M. 2011. Influence of residential water use efficiency measures on household water demand: A four-year longitudinal study. *Resources, Conservation and Recycling*, 56(1), 1-6.
- Madigele, P. K. 2016. The complexity of the economic conception of water: revisiting water resources management in developing countries. Proceedings of the Sixth IASTED International conference, *Environmental and Water Resource Management*

- (AfricaEWRM 2016). Gaborone, Botswana.
- Marshall, A. 1892. *Elements of economics of industry* (Vol. 1). Macmillan.
- McCloskey, D. N. 1996. The economics of choice. *Economics and the Historian*, 122-158.
- Meijerink, G. W. & Ruijs, A. J. W. 2003. *Water as an economic good; Points of interest for policy*. LEI.
- Moffat, B., Motlaleng, G.R. & Thukuza, A. 2011. HHs willingness to pay for improved water quality and reliability of supply in Chobe ward, Maun. *Botswana Journal of Economics*, 8(12), 45-61.
- Motsholapheko, M. R., Kgathi, D. L. & Vanderpost, C. 2011. Rural livelihoods and household adaptation to extreme flooding in the Okavango Delta, Botswana. *Physics and Chemistry of the Earth, Parts A/B/C*, 36(14-15), 984-995.
- Mwamila, T.B., Han, M.Y. & Kum, S. 2016. Sustainability evaluation of a primary school rainwater demonstration project in Tanzania. *Journal of Water, Sanitation and Hygiene for Development*, 6(3), 447-455.
- Mwamila, Tulinave Burton, Zacharia Katambara, and Moo Young Han. "Strategies for household water supply improvement with rainwater harvesting." *Journal of Geoscience and Environment Protection* 4.09 (2016): 146.
- Nagel, E. 1963. Assumptions in economic theory. *The American Economic Review*, 53(2), 211-219.
- Nyambe, I., Mwasambili, R., Mate, L., Lungu, C., Kambole, M., Maseka, C. 2002. Water demand management in Zambia: Towards promotion and adoption. Final Country Study Report, IUCN (World Conservation Union) Southern Africa, Water Demand Management Phase II Project Pretoria.
- Odongo, B. J., Mutinda, J. S., Ombongi, G., Kaloki, N. N., Bosire, M. M., Muhani, D. A., ... & Kiara, F. K. 2014. Assessing water supply and demand management in industries and commercial enterprises in Athi River town, Machakos County.
- Olmstead, S. M. & Stavins, R. N. 2009. Comparing price and nonprice approaches to urban water conservation. *Water Resources Research*, 45(4).
- Puust, R., Kapelan, Z., Savic, D. A. & Koppel, T. 2010. A review of methods for leakage management in pipe networks. *Urban Water Journal*, 7(1), 25-45.
- Savenije, H. H. & Van Der Zaag, P. 2002. Water as an economic good and demand management paradigm with pitfalls. *Water international*, 27(1), 98-104.
- Shan, Y., Yang, L., Perren, K. & Zhang, Y. 2015. Household water consumption: insight from a survey in Greece and Poland. *Procedia Engineering*, 119, 1409-1418.
- Schleich, J. & Hillenbrand, T. 2009. Determinants of residential water demand in Germany. *Ecological economics*, 68(6), 1756-1769.
- Setlhogile, T. & Harvey, R. 2015. Water Governance in Botswana.
- Sonderlund, A. L., Smith, J. R., Hutton, C. & Kapelan, Z. 2014. Using smart meters for household water consumption feedback: knowns and unknowns. *Procedia Engineering*, 89, 990-997.
- Statistics Botswana. Botswana Demographic Survey Report, 2017.
<http://www.statsbots.org.bw/sites/default/files/Botswana%20Demographic%20Survey%20Report%202017.pdf>
- Syme, G.J., Shao, Q., Po, M. & Campbell, E. 2004. Predicting and understanding home garden water use. *Landscape and Urban Planning*, 68(1), 121-128.
- Troy, P.N. & Randolph, B. 2006. *Water consumption and the built environment: a social and behavioural analysis*. Sydney, New South Wales, Australia: City Futures Research

Centre.

Vörösmarty, C.J., Green, P., Salisbury, J. & Lammers, R.B. 2000. Global water resources: vulnerability from climate change and population growth. *science*, 289(5477), 284-288.

Wong, T.H. & Brown, R.R. 2009. The water sensitive city: principles for practice. *Water science and technology*, 60(3), 673-682.

Zhang, H.H. & Brown, D.F. 2005. Understanding urban residential water use in Beijing and Tianjin, China. *Habitat International*, 29(3), 469-491.

Chapter 23: An analysis of sector-based water supply and demand: Mapping the possible water development and management ways for Sanyati catchment, Zimbabwe

¹Kusena Winmore, ²Nojiyeza Innocent Simphiwe and ³Debwe Thomas

¹University of Johannesburg; ²University of Zululand; ³Midlands State University

Abstract

Water is one resource that is spatially unevenly distributed and yet overwhelmingly in demand the world over. However, the demand for water is relatively higher for poor communities in developing countries due to a low investment capacity. The Sanyati catchment has relatively more towns and is home to several activities that directly rely on water for survival. This study sought to assess sector-based current water use levels in Sanyati catchment; assess a possibility of new ways of managing the catchment water using Inter-basin Transfer Systems; and future water demands projection using the WEAP model. The study was both quantitative and qualitative in nature. Interviews and observations were the main instruments for primary data collection. Several secondary data sources were used for WEAP model input and ArcMap 10.5 IBTS routes mapping. The findings showed that the main sectors and institutions that utilised water in the catchment were mining, agriculture, the manufacturing industry and local authorities. It was revealed that towns through local authorities and farming sectors were the major users of water. WEAP model results showed a steady increase in demand for water as a result of both population growth and agricultural activities' water demand. It was revealed that of the 10 sub-catchment councils in Sanyati catchment, water sources were not evenly distributed. On the one hand, this created areas of water deficit within the catchment, yet on the other hand, brought surplus and untapped water sources. The study mapped possible inter-basin transfer routes and recommends water harvesting as part of development and management in the Sanyati catchment to address the problem of water shortage.

Keywords: water use, Sanyati catchment; Inter-basin Transfer, water demand.

Introduction

The global consumption of water is doubling every 20 years, more than twice the rate of human population growth (United Nations 2011). If the current trend persists, by 2025 the demand for fresh water is expected to rise by 56 percent more than is currently available. Water as a natural resource is scarce and requires integrated approaches in its management. The supply of water is limited but the demand for water is increasing rapidly on a global scale. The imbalance between water supply and demand is expected to greatly expand as water demand inevitably increases. With respect to total water demand, agricultural demand is the largest globally, whereas demand in the municipal and industrial sectors is increasing significantly (Shiklomanov, 2000). Almost 70% of the extracted fresh water is utilised for crop-raising activities globally (FAO, 2013), and more water is required in order to produce more food in the future. It is believed that if water is utilised effectively in agriculture, it will not be a bottleneck for future food production (De Fraiture and Wichelns, 2010). The demand for

municipal and industrial uses is expected to increase rapidly in the near future due to burgeoning urbanisation and industrialisation. More specifically, the increases between 2000 and 2050 will mainly come from manufacturing (400%), electricity (144%), and domestic uses (127%) (Leflaive *et al.* 2012).

Water scarcity has been a critical issue for many regions and has caused numerous conflicts. In southern Africa, water is the key to winning the battle against poverty and its scarcity could be a limiting factor to growth. Southern Africa's water sector is already being affected by unsustainable water and land use practices, overpumping, flooding, watershed degradation, wetland loss, the proliferation of aquatic weeds, sedimentation, and climate variability. No socio-economic development can take place without water. Zimbabwe's water resources are indeed limited and scarce. The situation is worsened by the occurrence of droughts and the increasing demand associated with population growth and a developing economy. Zimbabwe is an atypical sub-tropical country with one rainy season (November to March). The country's average rainfall is 657 mm/annum and varies spatially from the eastern highlands (1,000mm) to low-lying areas such as valleys (400 mm) in the southern part of the country. Specifically, agriculture normally requires a sizeable amount of water during the crop growing season, and much less water during the other months of the year. The improvement in water use efficiency and productivity is widely considered as the best solution to ensure that future water demand does not exceed water availability, and this requires special attention on the demand side.

Kjeldsen *et al.* (2009) argue that in the last 20 years Zimbabwe has experienced periods of severe drought, increasing the pressure on available freshwater resources and enhancing the occurrence of conflicts between water users. Unreliability of precipitation for the past decades in Zimbabwe has seen many problems arising in water supply for both rural and urban users (Chigumira and Mujere 2015). The Sanyati catchment runs through four different natural regions (1-4) with varying average rainfall amounts; hence the water demand levels are different and must be managed accordingly. The Sanyati catchment receives its rainfall in the upper reaches of the catchment, rainfall decreasing gradually towards the west. Surface water availability follows the same trend, with the upper catchment having almost a perennial flow. Rivers such as the Munyati and Mupfure in the Sanyati catchment are perennial but in dry years these rivers dry up during August to November (Kjeldsen *et al.* 2009).

Rivers in the lower catchment flow during the rainy season and dry up in early winter. Surface water decline in Zimbabwe will most likely affect development in the affected catchments as it provides most of the domestic water in rural areas, supports poverty reduction through irrigation, and reliance on it is likely to increase as rainfall becomes more variable and demand for water becomes greater (Chikodzi 2013). The agricultural sector (which dominates the Sanyati catchment area) plays a very important role in both economic and social terms and therefore sufficient water supply plays a crucial role in everyday life (Nhapi 2015). Climate change will invariably affect water withdrawals especially against the predicted decreasing precipitation trend (1mm to almost 15 mm per decade) and the 2°C and 3°C increase in temperature which will also mean higher crop evaporative demand (Gumbo 2006). According to Makurira and Viriri (2017), sub-catchment council offices are under-funded and this in turn affects other important activities such as monitoring. To manage water resources effectively, current and future water demand and use for all sectors should be estimated as accurately as possible. Therefore, this study seeks to identify surface water sources and users in the catchment; establish current level of the use of water per activity within the catchment; map

the possible inter-basin transfer routes in the catchment, and forecast future water demands for major water users in the catchment for the next 10 years.

Study area

The Sanyati catchment is one of the seven catchments of Zimbabwe (Figure 23.1). The catchment lies between latitudes 16° 16' and 19° 30' south and longitudes 27° 45' to 31° 16' east. The Sanyati river system covers areas drained by the Kwekwe, Zivagwe, Munyati, Mupfure, Sengwa, Ume and Nyaodza rivers. There are 15 hydrological sub-zones, with areas varying from 2527 to 11427km². These hydrological sub-zones form the ten (10) sub-catchments, namely: Sengwa, Nyaodza, Zivagwe, Upper Munyati, Muzvezve, Lower Munyati, Upper Mupfure, Upper Middle Mupfure, Lower Middle Mupfure and Lower Mupfure.

The catchment constitutes a combination of four natural climatic regions and each region has its specific climate characteristics. These are regions ranged from 2 to 5 as shown in Table 23.1:

Region	Rainfall
Region II	750-1000mm
Region III	650-800mm
Region IV	450-650mm
Region V	Below 650mm

The topography of the Sanyati catchment is sloping towards the northwest, as evidenced by the direction of rivers that flow into the Kariba Dam. The catchment constitutes an upland area with an altitude of above 1200m, covering approximately 21527km² of the catchment. The areas like the Mashaba Mountains in the upper Munyati sub-catchment form much of the watershed and the source of the Sanyati River. The upper reaches of the catchment are generally flat and gently undulating until it intersects the Great Dyke. The middle part of the catchment has an altitude of above 900m extending northeast and northwest. The topography is generally flat and undulating with ridges and hills that are as follows : the Mafungautsi plateau with an altitude of 1192m in the Lower Munyati sub-catchment. Its main land use is for recreational parks and forestland. The other plateaus are Kwavanyangau (1181) and Chikurukwe (1385m) in the Sengwa and Nyaodza sub-catchment; the land is classified as communal land. The low-lying areas are at an altitude of more than 300m. Ridges of 1000m and above are found in the Nyaodza, Ume, Sanyati and Sengwa river basins. Basically these are the areas along the Zambezi valley and have a ridged terrain with isolated hills, for example the Chizarira hills (1433m) in the Sengwa sub-catchment, the Mapongola (1100m) and Whamira (1336) hills in Sengwa and Nyaodza sub-catchment ; the land use is for national parks and wildlife management. Charara and Chirisa are classified as safari areas in the Nyaodza and Sengwa sub-catchments (Sanyati River System Outline Plan, 2009).

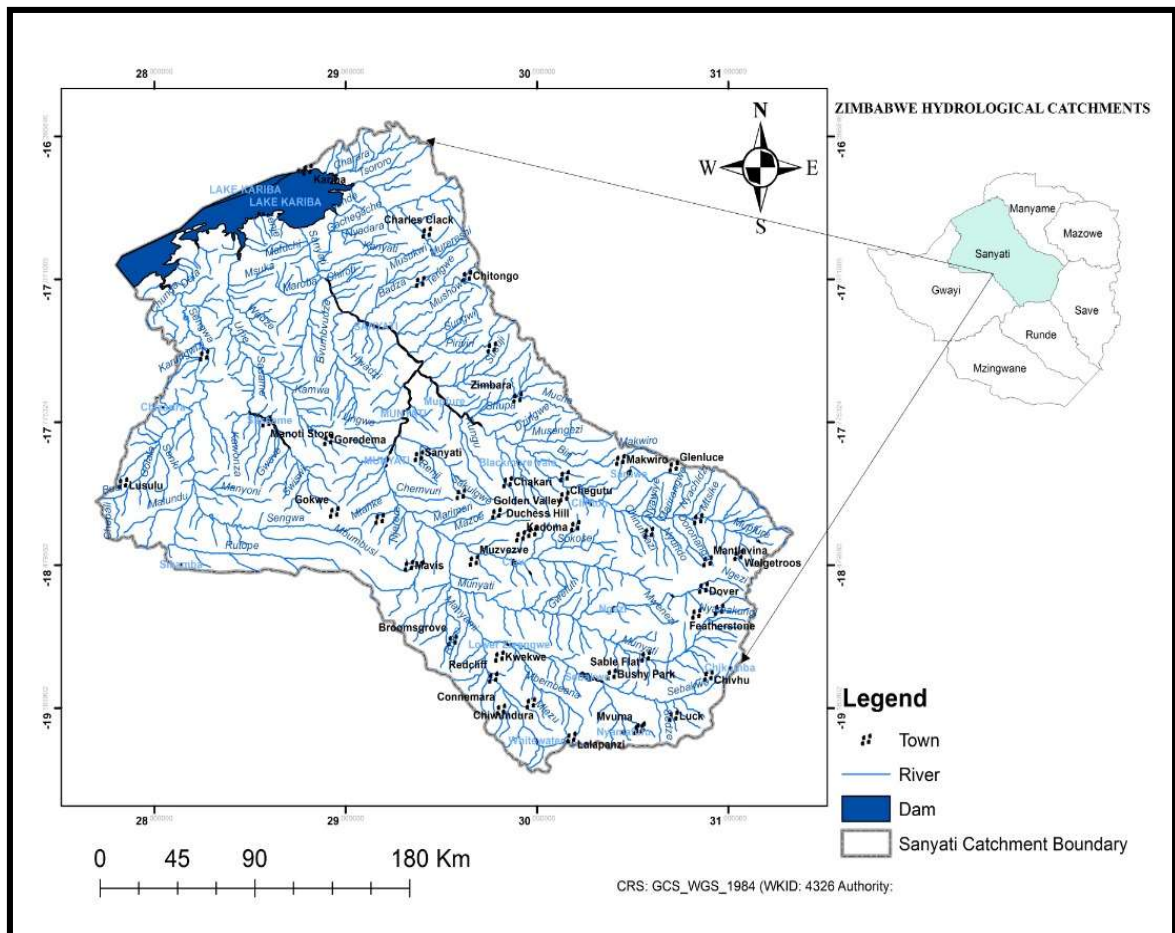


Figure 23.1: Map Showing the study area

Methodology

A case study approach was used for this study because it enables researchers to closely examine data within a specified context. Hence, the Sanyati catchment was purposely chosen as a case study for assessing water demand levels and uses because it presents a cross-section of the whole country in terms of climatic characteristics. A case study was preferred because it gives an intensive description and analysis of the current water demand situation and the concerns for future water requirements. The study targeted key informants from the ZINWA and Sanyati Catchment Council. Through interviews, the key informants provided insight on issues to do with water demand levels. These key people included catchment hydrologists, an inspector, and a planning engineer. The Sanyati raw water users in the ZINWA agreements and permits database and Agritex personnel were also part of the target population (Irrigation Engineer). The reason for targeting the Agritex personnel was to do with the expert knowledge on irrigation rates.

This study used all identified raw water users in the catchment as per ZINWA water agreements and permits to determine clearly the levels of usage of water per activity. However, for forecasting water requirements, the Muzvezve sub-catchment was chosen as a reference study area within the catchment. Purposive sampling based on the availability of flow data was considered among other factors such as river shape and size. Therefore, in terms of monthly

flow data consistence, the Muzvezve River in the Muzvezve sub-catchment was used for 10-year future water demand forecasting using the WEAP model.

The WEAP model is computer-based software which stands for Water Evaluation and Planning System; it was used to project future water requirements amongst the major users within the Sanyati catchment using a single sub-catchment for simulation purposes. The model uses scenario-based analysis for simulating reference years. Various models can be used to forecast different economic variables on a short, mid and long-term basis. Long-term projections are usually done at global level or regional levels. Secondary data for simulation was obtained from the River System Outline Plan (RSOP) and ZINWA annual reports from the Hydrology and Raw Water Engineering department. Monthly flow data were obtained from the hydrological department, consumption rates and annual total volumes of water demand per sector was obtained from the Sanyati Catchment Raw Water Engineering department.

Annual rainfall data was obtained from the CHIRPS online data portal on the website <http://chg.geog.ucsb.edu/data/chirps/> and exported in ArcMap 10.5. DEM was obtained from <https://gisgeography.com/free-global-dem-data-sources/> for analysis with a spatial resolution of 1 arc-second (30 meters). This high-resolution terrain data set was opted for due to its level of accuracy. The obtained slope information was in the form of raster and it was later put into a GIS environment for processing and analysis. Population statistics for Kadoma obtained from the 2012 census together with the associated population growth rates (ZIMSTATS 2012) information was used in the modelling of water demand for Kadoma City as a major demand site.

Data from the secondary sources was mainly analysed through Microsoft Excel while content analysis was used for key informant interviews and field observations results. ArcGIS 10.5 software was used for mapping possible IBTS routes for Sanyati based on slopes and rainfall. However, the model's shortfall is that it did not include other factors such as settlement and geology for IBTS mapping.

The WEAP model was run under two scenarios which projected irrigation increase and population projections within the catchment based on an arithmetic growth rate of 2.01%. The WEAP model for water allocation was run using C87 gauge station flow data from ZINWA. For the best results in running the model, the climatic data, soil, geology and other parameters are needed to closely imitate the reality of the Sanyati catchment.

Results and discussion

Water sources in the catchment

The main sources of raw water in the Sanyati catchment consist of rivers and dams. Rivers draining Sanyati are both perennial and non-perennial. Perennial rivers are mainly found on the upper reaches of the catchment whilst it is the opposite on the western side of the study area. One of the reasons for this is that the Sanyati catchment receives its highest rainfall in the upper reaches of the catchment, rainfall decreasing gradually towards the west. Sanyati catchment has three major rivers, namely Sengwa, Ume and Sanyati, and these feed the Zambezi trans-boundary rivers. However, other small rivers also drain the catchment. For example, in total there are 6680 basins in the study area supplying its different consumers. Table 23.2 shows the major rivers in the catchment.

Sub-catchment	Catchment Area (km ²)	Major River
Lower Mupfure	4 062	Mupfure
Lower Middle Mupfure	2 666	Mupfure
Upper Middle Mupfure	2 527	Mupfure
Upper Mupfure	2 871	Mupfure
Lower Munyati	7 297	Munyati
Upper Munyati	7 776	Munyati and Ngezi
Zivagwe	6 896	Sebakwe
Muzvezve	3 271	Muzvezve
Nyaodza	14 028	Sanyati and Nyaodza
Sengwa	18 660	Sengwa and Ume
TOTAL AREA	70 054	

The major rivers shown in Table 23.2 replenish dams that happen to be the major sources of water for most water users in the catchment. These dams also provide socio-economic development benefits to the catchment water users. Table 23.3 shows the dams that are found in the Sanyati catchment and their capacities.

Name of dam	Full Capacity (10 ⁶ m ³)	Level	Volume as at 31 December 2017 (10 ⁶ m ³)	Volume as at 31 January (10 ⁶ m ³)	% full	Change (10 ⁶ m ³)	% Change
		(m)					
Cactus Poort	3	100.1	2.067	3.086	102.87	1.019	33.97
Chikomba	5.46	98.99	3.974	4.179	76.54	0.205	3.75
Claw	65.46	105.12	45.598	58.923	90.01	13.325	20.36
Clifton	10.87	98.24	7.153	7.565	69.60	0.412	3.79
L/Sebakwe	6.99	99.94	6.858	6.877	98.38	0.019	0.27
Dziva	2.88	100.01	2.868	2.886	100.21	0.018	0.63
Mamina	11.36	98.06	6.846	7.044	62.01	0.198	1.74
Ngezi	22.63	97.5	10.591	11.452	50.61	0.861	3.80
Ngondoma	7.49	99.93	3.029	7.339	97.98	4.310	57.54
Nyamafufu	9.11	98.95	7.075	6.947	76.26	-0.128	-1.41
Padre's pool	2.99	96.99	1.464	1.448	48.43	-0.016	-0.54
Sebakwe	265.73	96.05	193.571	186.278	70.10	-7.293	-2.74
Suri Suri	9.97	95.4	2.654	2.467	24.74	-0.187	-1.88
White Waters	4.9	99.13	3.792	3.705	75.61	-0.087	-1.78
Mahusekwa	2.992	99.2	2.232	2.51	83.89	0.278	9.29

An interview with ZINWA River Inspector revealed that these dams drive the livelihoods of many water users in the catchment. This is mainly because all water users benefit in terms of water supply from these dams. The interview also revealed that some water users applied for permission to build their own dams in order to meet the demand. Some of the dams included the Upper Mupfure OX-West dam, Donnington dam (5.0 10⁶m³), Selusi dam (13.5 10⁶m³) and

Burgan dam ($5.0 \times 10^6 \text{m}^3$).

Sanyati water users

The ZINWA database on raw water users in the catchment reveal six categories of water users. The categories of users are Agriculture A2, Agriculture A1, Agriculture Communal, Industry, Local Authority and Mining. Agriculture A2 consists of large commercial farms mainly focusing on food cash crops such as maize and wheat ; these are 320 hectares on average. Local Authorities were also a major water user in the catchment; and these are different municipalities that draw water from the catchment’s major dams. Table 23.4 shows the number of raw water clients/users in the catchment by category.

Category	Number of clients
Industry	18
Mining	16
Local authorities	8
Agriculture A2	237
Agriculture A1	46
Agriculture communal	11
Total	237

Current levels of water use per activity

Findings from the ZINWA raw water database on current levels of use per activity give different volumes used on an annual basis for each category. Local Authorities use on average up to 42.4% of the total volume of water used annually. An interview with the ZINWA River Inspector indicated that the volumes used by Local Authorities is high due to a large consumer base. The other factor is that there are some industrial activities present in the Local Authorities consumer base which use treated water. As such, these industries cause higher water demand for local authorities. Some of the industries that rely on treated water include Delta Beverages, Dendairy and ZIMASCO.

Agriculture combined (A1, A2 and Agriculture Communal) as one activity has an estimated consumption rate of 39% of the total volume used in the 2018-2019 water year. Water use in agriculture was mainly for irrigation purposes which extend throughout the year. Findings from key interviews alluded to the fact that more water in agriculture is used during the winter season especially by farmers engaged in wheat production. An estimated 6,5ML/ha is used during the winter season, whilst in early summer it is 3ML/ha and an estimated 2,5ML/ha during the summer supplementary. This is supported by FAO (2016) which states that during dry months, irrigation requires more water than other months of the year. According to the Ministry of Lands and Agriculture (2017), only 37% of the country receives rainfall considered adequate for agriculture. Irrigation is of vital significance due to the uneven distribution of rainfall and seasonality in the catchment (Buyukcangaz *et al.* 2017).

Mining had the lowest consumption rate in the catchment, namely 2.1% compared to other activities on an annual basis. This could have been caused by the fact that miners are charged more per Megalitres (\$50/ML) and the activity generally uses less water. Mining entities such as Prucible Mine engaged in water reuse since mineral processing is not dependent much on the quality of water. Findings from key informants revealed that miners are charged more due to the cost associated with controlling pollution.

The manufacturing industry as an activity has an average of 16% water use level for the water year 2018-2019. The water use in industry as a sector varies according to the scale of operations. For example, the volumes of water used at Delta beverages are relatively high compared to the use of water at ZIMASCO. The factor responsible for this is that there are more different activities which require water the Delta compared to those that use water at ZIMASCO.

Category (Activity)	Annual Water usage volumes(ML)	Percent in Use
Mining	4 090.56	2.1
Industry	32 859.00	16.9
Agriculture A1	1 412.05	0.7
Agriculture A2	72 188.84	37.1
Agriculture communal	1 534.25	0.8
Local Authority	82 500.00	42.4
TOTAL	194 584.70	100

Trend analysis of water supply levels per activity

Evidence gathered from ZINWA annual reports database shows that there are changes to supply levels of water for the past 3 years in the catchment. Volumes of raw water abstraction have been changing in all the sectors for a number of reasons. Researchers were able to get information for three consecutive years (2016-2019) in order to establish the trends in water supply levels per activity in the catchment area.

Category/ major users	Annual volumes (ML)			Percentage in use		
	2016-2017	2017-2018	2018-2019	2016-17	2017-18	2018-19
Mining	3 823.76	13 403.00	32,859.00	2.7	2.2	2.1
Industry	11 545	3 467	4 090.56	8.2	8.3	16.9
Local authorities	84 300	85 300.20	82,500.00	59.6	52.9	42.4
Agriculture A2	37 721.00	53 552.41	72,188.84	26.7	33.2	37.1
Agriculture A1	781.25	1 716.10	1,412.05	0.6	1.1	0.7
Agriculture C	3 229.80	3 507.50	1,534.25	2.3	2.2	0.8
Totals	141 386.81	161,225.13	194,584.70	100	100	100

Table 23.6 is an illustration of water supply levels per activity in the catchment area since the water year 2016-2017. For major water users such as Agriculture A2, Local Authority there is evidence of high demand as indicated by the rise in respective percentages. However, according

to a ZINWA Sanyati catchment engineer technician, the increase in levels of water by some sectors since the years mentioned could be attributed to the gap between supply and demand. Users made use of more water as it was available. However, the changes may also be attributed to inefficient water use, the expansion of activities and population growth (Madebwe and Madebwe, 2013).

Possible Inter-basin transfer routes in Sanyati Catchment

The possible Inter-basin transfer routes shown in Figure 23.5 were generated on the basis of slope, flow accumulation and flow direction. As such four classes of slope determined four basins with notable variations in elevation. More water accumulates and flows in basin 1 compared to other basins. Justification of the uneven distribution comes after calculating the basin area. However, from visual analysis one can conclude that basin 1 is bigger and hence water that accumulates here especially in the Sanyati River is more than that accumulating in other basins. Again this fact can be attributed to the natural region in which basin 1 lies in respect of levels of rainfall received. To the users of water in the Sanyati catchment it means that the distribution of water is uneven, hence some of the strategies to curb this problem have been countered with the construction of dams. These dams serve as key water resources to the various users, with the major uses being agriculture, mining and industry.

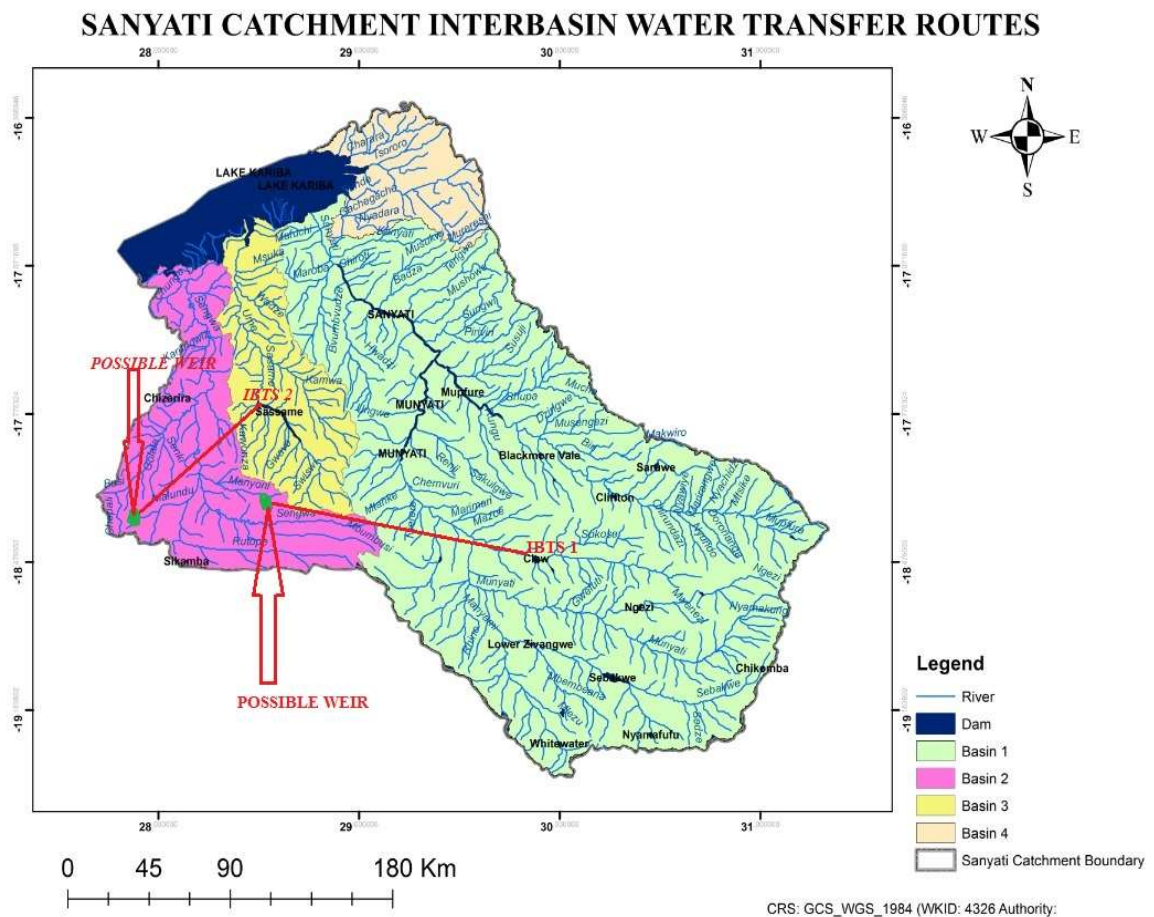


Figure 23.2: Possible IBTS routes

The availability and distribution of the rainfall in the Sanyati catchment can prejudice water users in drier localities. The average amount of precipitation need not necessarily be a constraint to successfully carrying out an agricultural or water resources operation (Mazvimavi *et al.* 2005). Therefore, IBTS serve as very important projects that address the issues of water shortages in the catchment.

In Figure 23.2 the map shows that more precipitation is received on the upper reaches of the catchment, with figures ranging from 750mm and above. The rainfall totals gradually decrease as one moves towards the western side of the catchment. These areas on an annual basis receive rainfall totals ranging from 500mm and below. The difference in the amount of rainfall received in the catchment has a bearing on water availability. It means that areas in the Sanyati catchment do not receive equal volumes of water since rainfall is unevenly distributed. This distribution in rainfall further explains the different climatic conditions which affect the catchment, which are varied when one moves from the upper reaches of the catchment to the low-lying areas.

Future water requirements simulation

A look into the future water requirements for the Sanyati catchment was done using the Water Evaluation and Planning (WEAP) using Muzvezve sub-catchment as a reference case. The flow data for Muzvezve river was run in the model using the current data available of 2015/2016 from ZINWA especially C87 gauge station. In terms of water abstraction, the city of Kadoma draws its water from this dam and hence Kadoma city is a major demand site. Agriculture in Muzvezve is a major water user and draws significant amounts of water annually from the dam, hence a demand site in the WEAP model. The two demand sites were of concern to the researcher since these are the major water users as far as abstraction of raw water is concerned in the catchment as a whole. Simulation was done under two scenarios of population increase and irrigation expansion (future A and B). Projections indicated a steady increase in water demand levels in the next 10 years for both scenarios.

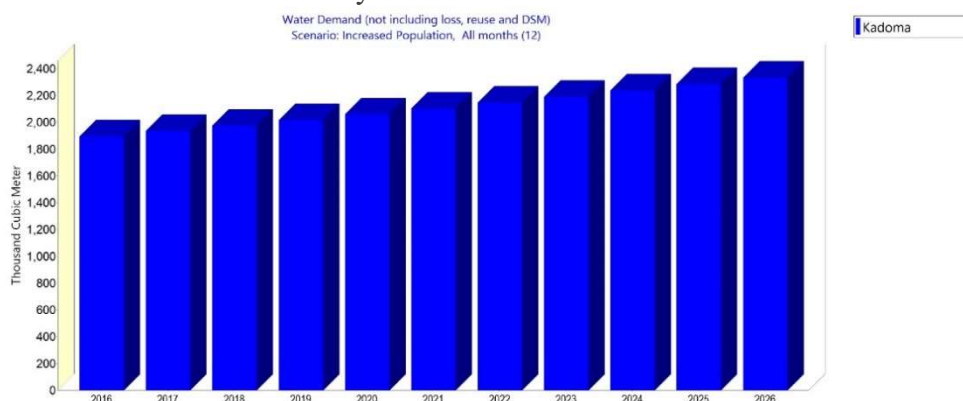


Figure 23. 3: Spatial distribution of rainfall in the Sanyati catchment

The annual activity for the urban area Kadoma is based on population totals acquired from the country’s 2012 census, which indicated the city having an estimated population of 61 397 people. The estimated population growth rate was calculated at 2.05% per year and hence formed the basis for future water requirements. For Agriculture the future water demand was projected assuming that irrigation will increase by 2% annually, against the background of increase in clients over the past years. Figure 23.4 shows the first projection in relation to Kadoma city as a demand site and how an increase in population also means an increase in the

demand for water in the projected years. The findings show a link between the number of people and future demands. However, this could be overcome through water conservation.

Figure 23.4: Increased population scenario effect on water demand

Figure 23.4 clearly shows a steady rise in the water demand levels in the next 10 years with current accounts of 2016 for Kadoma city. It means that when populations increase the *per capita* demand also increases and hence water demand levels rise due to the effect of population. If population continues to grow at this rate over the next 10 years, it means that Kadoma city will require more water from the source in time. Figure 23.4 shows the level of increase or change in water demand levels for Kadoma City in the next 10 years. It depicts a sharp rise which will occur when population is on the rise until the year 2026

The same trend was exhibited when the model was run on the basis of increase in hectares under irrigation in the catchment. Therefore, it goes to show that water demand is increasing despite unreliable precipitation, which is a major input to surface water used in the catchment.

According to FAO (2016) the future demand of water is set to increase due to the increase in competition amongst major users around the world. As urban areas expand and populations increase over time, it means there is a significant amount on the available water resources. This statement has been supported by the scenario population increase in the WEAP model for Kadoma city. There is evidence of cubic meters of water used annually as population increase at an estimated growth rate of 2.1% until the year 2026. In the case of Muzvezve sub-catchment, against the successful running of the model, it means that if the current trends on head flow continue until 2026, there will be increased pressure on the source of the precious liquid, which might affect other activities such as agriculture, mining and industry in the study area as a whole.

Conclusion and recommendations

The study revealed pertinent issues that exist in the study area concerning water demand levels and future water requirements. The catchment transverses different ecological regions making the catchment an area of possible IBTS provided a proper operational criterion is established. The catchment also needs close monitoring of water developments such as dam construction because some farmers were given permission to build dams and réservoirs on their property. Demand for water is on the rise for both agriculture and local authorities. Therefore, it is of paramount importance that the raw water available in the catchment area is managed in an efficient way in order to satisfy the growing needs of water users. The rate of increase in the demand of water is closely related to the growing number of users in the past years.

Agriculture and urban withdrawals have the highest percentage in the consumption of water compared to mining and industry as other users. Urban withdrawals are slightly above agriculture and that has been attributed to the wide base of urban users.

The different natural regions in the catchment area have an impact on available water resources in the catchment when considering the effect of rainfall totals annually. It means that some rivers as major sources of water to users are not perennial. The different climatic regions within the catchment heavily influence the dominating type of socio-economic activities existing in a particular sub-catchment or area within the study area.

The future water requirements in the catchment modelled using the WEAP model in Muzvezve sub-catchment points to an increase in water demand levels. The scenario of population increase modelled in the model projected a significant increase in water demand for

Kadoma city considering a 2.01% growth rate. It means therefore that with the expected increase in population numbers in the city, levels of water demand from the Claw dam will increase significantly as well. The increase in the number of users is the main reason for the rise of water requirements in the near future as clearly modelled.

Recommendations

Taking into consideration the findings obtained from this research, the following suggestions were given:

- Sanyati Catchment Council needs to invest in serious water conservation strategies and education in order to achieve efficient water use and avoid an obvious demand pattern that rises simultaneously with population increase.
- ZINWA and Sanyati Catchment Council should consider using the powerful WEAP model in managing its water resources as far as changing water demand is concerned by simulating storage and supply capacities of major sources of water in the study area.
- Sub-catchments need to improve data collection within the catchment boundaries such as stream flows, evaporation rates, monthly variations in water usage timeously to enable the use of current data in water demand analysis.
- Water harvesting is also a possible management approach particularly for the western drier part of the catchment.

References

- Armstrong, J.W. and Graham, M.C. 1972 *Comparative Study of Methods for Long-Range Market Forecasting: Management Sci.*, v. 19, no. 2, p. 211-221
- Attanasi, E.D. Close E. R. and Lopez, M.A. 1975. *Techniques for Water Demand Analysis and Forecasting: A Case Study of Puerto Rico*
- Banerjee, A., Chaudhury, S., Singh, D.K., Banerjee, I., Mahato, A.K. and Halder, S. 2007. *Statistics Without Tears. Inputs for Sample Size Calculations.*
- Carson, E. and Cobelli, E. 2001. *Modelling Methodology for Physiology and Medicine*, Academic Press, San Diego, CA
- Chikozho, C. 2005. *Policy and institutional dimensions of integrated river basin management: Broadening stakeholder participatory processes in the Inkomati River Basin of South Africa and the Pangani River Basin of Tanzania*. Commons Southern Africa Occasional Paper Series No. 12. Pretoria: Centre for Applied Social Sciences/ Programme for Land and Agrarian Studies/ International Water Management Institute.
- De Fraiture, C., and Wichelns, D. 2010. *Satisfying Future Water Demands for Agriculture*. *Agricultural Water Management*, 97(4), 502-511.
- Finn, J., and Jacobson, M. 2008. *Just Practice: A Social Justice Approach to Social Work*. Peosta, IL: Eddie bowers publishing
- Global Water Partnership (GWP) 2000. *'Integrated Water Resources Management'*, Technical Advisory Committee, Background Paper, no. 4, Stockholm.
- Groves, R. M., and Heeringa, S. 2006. *Responsive Design for Household Surveys: Tools for actively controlling survey errors and costs*. *Journal of Royal Statistics Society*, p. 439-57.
- Hancock, B. 1998. *Trent Focus for Research and Development in Primary Health Care: An Introduction to Qualitative Research*. Trent Focus.
- Henry J.G and Heinke G.W. 1989. *Water Use in North American Cities: Environmental Science and Engineering*, Prentice-Hall.

- Howard K.W.F. 1997. *Impacts of urban development on ground water*. In Eyles (eds) Environmental Geology of urban areas. Geological Association of Canada, Newfoundland pp.93– 103.
- Hunt, N. and Tyrrell, S. 2001. *Stratified Sampling*. Webpage at Coventry University
- Kjeldsen, T.R., Lundorf, A. and Rosbjerg, D. 1999. *Barriers to sustainable water resources management: A Zimbabwean case study*. Special Issue: Barriers to Sustainable Management of Water Quantity and Quality. *Hydrological Sciences Journal*.
- Moriarty, P., Butterworth, J. and Batchelor, C. 2004. *Integrated water resources management and the domestic water and sanitation sub-sector*, Delft: IRC International Water and Sanitation Centre.
- Mulder, M.W. 2005. *A political policy analysis of the integrated water resources management approach in South Africa's water policy (1998 - 2001)*. Masters dissertation. University of Pretoria.
- Musingafi, M. and Chando, C. 2013. *The Legal Framework in the Governance of Potable Water Supply in Zimbabwe: A Global, Regional And National Overview of The IWRM Paradigm* Journal of Law, Policy and Globalization
- Ogula, P.A. 2005. *Research Methods*. Nairobi: CUEA Publications
- Schulze, R.E. 2007. *Coefficient of Variation of Annual Precipitation: South African Atlas of Climatology and Agro hydrology*. Water Research Commission, Pretoria, RSA, WRC Report 1489/1/06, Section 6.3.
- Shiklomanov, I.A. 2000. *Appraisal and Assessment of World Water Resources*. Water International, 25(1) 11-32.
- Tevera, D. and Crush, J. 2003. *The new brain drain from Zimbabwe*. Southern African Migration Project (SAMP).
- United Nations Development Programme 2002. *Zimbabwe Land Reform and Resettlement Assessment and Suggested Framework for the Future*, Interim Mission Report, January, Harare.
- FAO 2013. *World Food and Agriculture*. Food and Agriculture Organization Statistical Yearbook
- Van Der Zaag, P. 1999. 'Water allocation Principles in Catchment Areas', in Manzungu, E. Senzanje, A. van der Zaag P. (eds.), *Water for Agriculture in Zimbabwe: Policy and Management Options for the Smallholder Sector*, University of Zimbabwe: Harare.
- Windham, C. 2008. Description of Target and Sample Populations for Research Methods. Sanyati River System Outline Plan (RSOP) 2009.