The Hydrochemical Characterization of the Mgobezeleni Catchment in Sodwana Bay

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PREFACE

The hydrochemical characterization of the Mgobezeleni catchment study forms part of the "Linkages between the hydrodynamics and biological drivers of the Mgobezeleni catchment project" which is a Water Research Commission Project (**WRC K5/2259**). The link between the terrestrial and hydrological systems is highly complex and was not initially well understood. The Project was established to investigate the linkage between hydrological and ecological drivers in the Mgobezeleni catchment. The relationship between these systems was achieved through hydrological, social, pedological, and wetland assessment of the Mgobezeleni catchment. The Mgobezeleni catchment was selected in this project as it represents a microcosm of the Maputaland region.

In order to achieve some of the project objectives, the hydrochemical characterization of the Mgobezeleni catchment study was established to quantitatively assess the hydrochemical composition of the Mgobezeleni catchment. The characterization was achieved through understanding the catchment social demographics, surface and groundwater chemistry and peat chemistry assessments.

DECLARATION

I declare that the work in this thesis was performed in the Department of Hydrology at the University of Zululand, KwaDlangezwa in KwaZulu-Natal Province. The original work was performed by the author and has never been published by anyone else in any form such as diploma or degree at this University or any other institution.

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PUBLICATIONS AND CONFERENCES

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ABSTRACT

The Maputaland region comprises one of the world's most remarkable areas of biodiversity and aquatic systems. It also has the largest primary aquifers in South Africa, constituting 25% of all coastal plain aquifers found in the country.

The increasing number of rural households' development along the Maputaland coastal plain pose significant eutrophication risks on the hydrological system, owing to the use of informal sewage management facilities. To understand the anthropogenic impacts on the hydrological system the Mgobezeleni catchment was selected in this study as it represents a microcosm of the Maputaland region. The Mgobezeleni Estuary is connected to the two lakes (Lake Mgobezeleni and Lake Shazibe), and large swamp forest, and mouth is affected by tidal influence.

The hydrological system in the catchment is directly controlled by the groundwater system. The overlying paleo-dune sands are permeable permitting high percolation of the annual rainfall. The catchment is dominated by three aquifers namely, the uppermost KwaMbonambi Formation, Kosi Bay Formation and Uloa Formation. The water table is dynamic, affecting the dimension of the unsaturated zones, the hydraulic gradient and the groundwater flow in the aquifers. The groundwater recharge only becomes visible as base flow in surface water resources after several years. Contaminants that have accumulated over decades are therefore still present in the aquifers, being restricted mainly in the upper KwaMbonambi Formation. Therefore, leaching of nutrients from the informal sanitation systems pose adverse impacts on the groundwater chemistry, which in turn can result in eutrophication of surface water resources.

The growth in population in the Mgobezeleni catchment has therefore increased the nutrient load in the groundwater system due to the presence of confining layer that restricts nutrients to the shallow aquifer. Nutrients are relatively elevated in groundwater close to highly populated areas such as Mbazwana. Moreover, the discharge of groundwater as a base flow component in surface water resources (lakes, estuary and wetland) causes the eutrophication (growth of dense macrophytes and microalgae, including toxic cyanobacteria species) due to high nutrient composition. The dense macrophytes species together with the cultivated peat, are decomposing to produce high levels of dissolved OM with humic substances (humic acid and fulvic acid) causing the *blackwater* in the surface water resources and also increasing the population of microalgal species.

The water in the catchment is generally characterized by a sodium-chloride ions signature with relatively low Ca, Mg, K, and SO_4 concentrations. It is generally high in Al, Fe and Mn concentrations.

The high levels of nutrients and planktonic algae in hydrological system threaten the ecological system in the Mgobezeleni catchment. The presence of the bacteria *Microcystic aeruginosa* can affect the domestic and wildlife including the water supply to Ezemvelo KZN Wildlife’s residential areas. In addition, the cultivation of peat in the Mgobezeleni catchment causes the peat to decompose, thus also increases the N and P concentrations and OM content in the wetlands which are also influencing the water quality in the lakes and estuary.

It is recommended that in future, nitrogen (N) and phosphorus (P) concentrations be used to indicate the levels of anthropogenic impact on the water resources. The current study can act as a baseline for such future studies.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Amsl	above mean sea level
CHN	Carbon, hydrogen and nitrogen
CV	Calorific Value
DEM	Digital elevation model
DGPS	Differential GPS
DO	Dissolved oxygen
DWA	Department of Water Affairs
DWAF	Department of Water Affairs
DWS	Department of Water and Sanitation
EC	Electrical conductivity
FA	Fulvic acid
HA	Humic acid
IR	Infrared Spectroscopy
KZN	KwaZulu-Natal
LDs	Long drops
N and P	Nitrogen and phosphorus
NH_4-N	Ammonium ions analysed in the form of nitrogen
NO_2-N	Nitrite ions analysed in the form of nitrogen
NO_3-N	Nitrate ions analysed in the form of nitrogen
OC	Oxidizable carbon
OM	Organic matter
PO_4-P	Orthophosphate ions analysed in the form of phosphorus
TDS	Total dissolved solids
RDP	Reconstruction and Development Programme
RSA	Republic of South Africa
SANAS	South African National Accreditation System
SANS	South African National Standard
TIN	Triangular irregular network
TN	Total nitrogen concentration (as inorganic nitrogen, sum of NH_4-N, NO_2-N and NO_3-N concentrations)
TWQG	Target Water Quality Guideline
UNESCO	United Nations Educational, Scientific and Cultural Organization
UV-Vis	Ultraviolet- visible region

VIPs	Ventilated improved pit latrines
WMA:	Water management areas
WMA	Water Management Authority
WTW	Water treatment works

CHAPTER 1

INTRODUCTION

1.1 Background

The Maputaland region comprises one of the world's most remarkable areas of biodiversity with unusual concentrations of rare fauna and flora species focused in a small area. The vegetation in the region has been classified into 15 major types, ranging from coastal grassland and dune forests to various types of bushveld, sand forest and swamps to the forest on the Lebombo Mountain Range (Moll, 1980). Most of the coastal environment in this region is critically important for biodiversity conservation due to the large number of endemic species found in this area (EKZNW, 2011). However, only 14% of the ecological region (coastal forest mosaic) in the Maputaland region falls within protected areas (EKZNW, 2011).

The Maputaland region has the largest primary aquifers in South Africa, constituting 25% of all coastal plain aquifers found in the country (Campbell *et al*., 1992). These primary aquifers are predominantly shallow water systems which strongly control the surface water resources. The shallow groundwater results in the formation of many permanent interdunal swamps and marshes, with perched aquifers found within the dunes draining to the interdunal valley floor (Hattingh, 1998, Grundling *et al*., 1998).

The area has highly permeable soil dominated by shallow water table (Kelbe *et al*., 2016), which allows for high rainfall recharge into the groundwater systems. The rainfall infiltration generally follows a preferential subterranean pathway through the groundwater system into the surface water resources (Beven, 2001).

Maputaland region experiences a rapid growth in rural settlement development along the coastal plain. (UMkhanyakude Integrated Development Plan, 2014/15). The establishment of these households is generally unstructured in terms of adequate town planning because these areas are not urban. The growth in population has triggered an increase in the establishment of sewage systems such as long drops (LDs), ventilated improved pit latrines (VIPs) and septic tanks, as opposed to flushing sanitation systems (UMkhanyakude Integrated Development Plan, (2014/15). The use of these types of sanitation systems in areas with shallow primary aquifers and high rainfall causes the groundwater to be vulnerable to pollution from nitrogen (N) and phosphorus (P) leachates. Contamination of the groundwater is likely to pollute the coastal lakes and the estuaries in future. Contamination of the coastal lakes and the estuaries with nutrients can render hydrological systems in the catchment eutrophic, which can have detrimental impacts on the important ecology of the catchment.

Therefore, there was a need to understand the impact of population growth with an influx of tourists during the holiday periods, on the hydrological systems along the Maputaland coastal plain. In order to understand this impact in the Maputaland region, the Mgobezeleni catchment was selected in this study for hydrochemical characterization, as it represents a microcosm of the Maputaland region.

1.2 Maputaland regional resources

The Maputaland region stretches from Maputo Bay (Mozambique) southward to Richards Bay. It is bordered in the north by the Inkomati and Limpopo Rivers in southern Mozambique, in the south by the Mlalazi Estuary in northern KwaZulu-Natal, and in the west by the Lebombo Mountain Range (Van Wyk, 1996; Moll, 1997).

The coastal environment from Mfolozi Estuary to the Mozambique border is almost entirely proclaimed as a nature reserve, the iSimangaliso Wetland Park, owing to its national and international importance. The entire coastal plain, including the estuaries, falls within the iSimangaliso Wetland Park: UNESCO World Heritage Site, which was proclaimed in 1999 under the National World Heritage Convention Act (Act No 49 of 1999, Porter and Clark, 1998). A small portion of the estuarine functional zones falls within the buffer area of the iSimangaliso Wetland Park (**Figure 1**). The coastal and estuarine environments are governed by international agreements such as the Convention Concerning the Protection of World Cultural and Natural Heritage, 1992.

The Maputaland region has many valuable wetlands that are rich in peat deposits. Wetlands are the most threatened ecosystem in South Africa (Moll, 1980; Wessel, 1997), while swamp forests are the rarest forest type and only occur in isolated patches. Most of the swamp forests in the country occur in this region (Grundling *et al.*, 1998, Grundling and Grobler, 2005).

The region has natural forests and heritage sites (such as iSimangaliso Wetland Park, World Heritage Site), as well as the Jesser Point, an international diving site located within the Mgobezeleni catchment in Sodwana Bay Beach. The diving site is protected and consists of coral reefs of national and international importance, which are a hotspot for tourist divers. Tourists also visit Sodwana Bay Beach for its fishing wealth. The recreational activities taking place in this have affected the mouth and the ecological functions of the Mgobezeleni Estuary (Bate *et al*., 2016).

The region has four estuaries, namely, St Lucia, Kosi Bay, Mfolozi and Mgobezeleni estuaries. The estuaries range from the very large St Lucia Estuary to the smallest Mgobezeleni Estuary system. The estuaries in this region are hot-spots for marine ecology (Van Niekerk and Turpie, 2012) and form a link between the ocean and the land (such as rivers, lakes, wetlands and groundwater), which makes their physical, chemical and biological properties (ability to sustain life) vulnerable to natural and anthropogenic impacts.

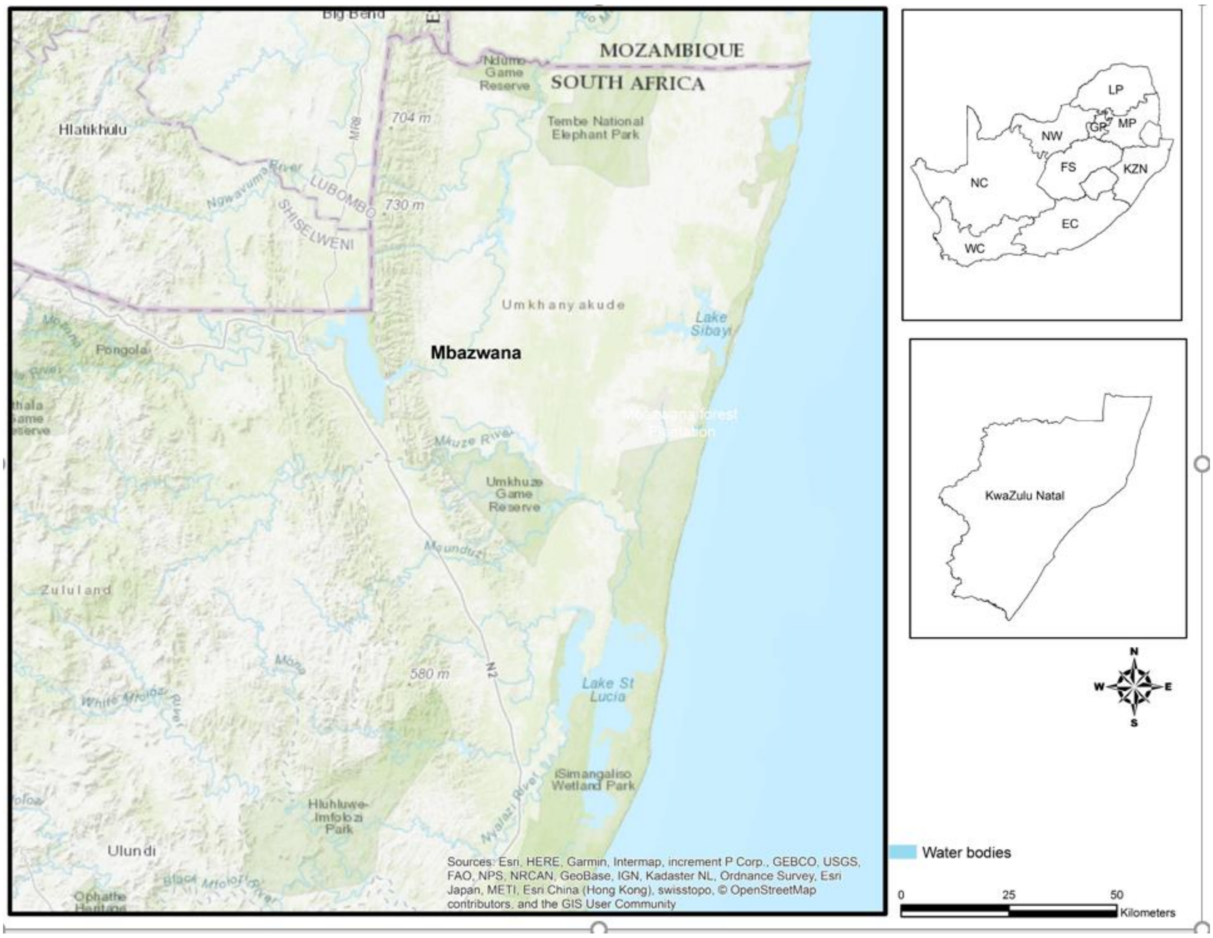

Figure 1: iSimangaliso Wetland Park in relation to the estuarine and coastal environments along the Maputaland coastal plain

The main anthropogenic impacts affecting estuaries in the Maputaland region are rural settlements, which cause eutrophication of the system resulting from primitive sanitation facilities. Fishing results in over-harvesting of most species and greatly reduces estuary nursery functions (DWAF, 2004; James *et al.*, 2008).

Because of these influences, these estuaries are likely to become a sink rather than a source of fish production (Kyle, 2012). The terrestrial environment associated with or located within the estuarine environment has been classified by the South African National Biodiversity Institute (SANBI) as being endangered or vulnerable (Mucina and Rutherford, 2006).

Van Niekerk and Turpie (2012) also reported that estuaries around Sodwana Bay and St Lucia are affected by sediment erosion which has reduced fishing and the nursery functions. The freshwater inflow that is important for the maintenance of salinity profiles, sediment scouring and nutrient supply in the estuaries is often polluted. This has resulted in the degradation of the ecological functions of the estuaries resulting in the loss of endemic species (Whitfield, 1998; Love, 2000; Wooldridge, 1999). The future ecological integrity of the regional estuaries depends on direct management of the quantity and quality of the freshwater inflow.

The recharge and discharge of groundwater in estuaries is controlled by periodic tidal and evapotranspiration fluctuations, irregular rainfall and regional groundwater flow. Flushing of animals and crab burrows situated in the beds and banks of these estuaries can provide mechanisms that enhance water exchange and the transportation of material such as salt, nutrients, oxygen and pollutants into the coastal environment (Riedel *et al*., 1997).

1.3 Mgobezeleni catchment

The Mgobezeleni catchment is the smallest catchment in the Maputaland region, constituting a total extent of approximately 6 926 ha. It is located close to Mbazwana area (including Sodwana Bay) and falls within the uMhlabuyalingana Local Municipality in the UMkhanyakude District Municipality. It has important natural resources which were used to represent the microcosm of the Maputaland region in this study. It is in close proximity to areas of the growing population. The growing population is likely to have an adverse impact on these natural resources because of the use of primitive sanitation facilities and the dependence of the ecological system on groundwater recharge. The area has high rainfall infiltration because of unconsolidated sediments.

The Mgobezeleni catchment has permeable soil that limits surface runoff and promotes rapid rainfall infiltration (about 50%). The infiltration recharges the groundwater aquifer to the extent of about 7000 Mm^3 above the Cretaceous sediments (Bate *et al.*, 2016). The infiltrate is later discharged as base flow to the streams, lakes and estuary to balance the net recharge and changes in the groundwater storage. The average annual groundwater recharge in the catchment is estimated at 31 Mm^3 with an average annual evapotranspiration loss of 80 Mm^3 (Bate *et al.,* 2016). The annual loss to the aquifer as baseflow is estimated at 49 Mm^3. The monthly groundwater abstraction for domestic use is estimated 330 Ml (Bate *et al.,* 2016).

The main water features within the catchment are Lake Mgobezeleni and Shazibe; shallow aquifers and wetlands (rich in peat) recharging the Mgobezeleni Estuary. The water found in Lake Shazibe, Lake Mgobezeleni, the Mgobezeleni Estuary and the wetlands is dystrophic (black in colour). The

Mgobezeleni Estuary covers a total extent of approximately one hectare and has been classified as being Critically Endangered in terms of the Whitfield (1992) ecosystem classification system (Turpie and Chesterman, 2011). The Mgobezeleni Estuary is connected to the two lakes (Lake Mgobezeleni and Lake Shazibe) by a large swamp forest dominated by common reed (*Phragmite Australis*) and its mouth is generally affected by tidal influence.

The estuary is an important nursery ground for fish, 28 species of which are saltwater species (Begg, 1978). Seven of these species were found to be rare with limited distribution in South Africa. There are also 98 bird species, 32 of which are estuary associated. The movement of crab and fish species in the estuaries is restricted by the construction of the bridge (Rajkaran and Adams, 2011), which is reported to have led to the loss of several species of fish, crab and mudskippers (Bruton & Appleton, 1975).

1.5 Environmental impacts

Residential housing in Mbazwana town (including Sodwana Bay) is expanding rapidly. Since, these areas are rural settlements not urban areas, there is also an increase in the establishment of non-flushing sewage systems. Mbazwana (Sodwana Bay) is a hotspot for tourists for diving, hiking, camping and fishing purposes. Tourists visit this area annually (usually on quarterly basis) during holiday periods (Kelbe *et al.*, 2016) which also increasing the load on the sanitation systems. The groundwater quality is also prone to contamination by the sewage effluent discharged from the septic tanks at the accommodation facilities (outside the Sodwana Bay residential areas, which have its own water treatment plant catering for the tourists that visit the area annually during holiday periods). Ecotourism therefore disturbs the Mgobezeleni Estuary habitat (Van Niekerk & Turpie, 2012).

Shipping also poses a major threat to the coastal environment because of the use of large vessels in the offshore area (Porter and Clark, 2012). Flushing of their bilge tanks, oil leakages and engine failures results in ships oil washing ashore which has major adverse environmental effects.

Mbazwana has large-scale commercial forests which are used for black empowerment and also as income for a number of people in the area. However, this activity is causing fluctuations in the water table thus reducing freshwater inflow to the surface water systems (Rawlins and Kelbe, 1998). Fluctuations in the water table results in peat decomposition in the wetlands.

Eutrophication of the surface water resources affects the estuary and the in-shore marine environment of the catchment, especially the coral and the rocky reef habitats. Currently, the laws protecting these environments are not sufficiently strictly enforced for socio-political and socio-economic reasons. The local government generally prioritises short-term developments to the detriment of long-term and more sustainable developments. This in turn has resulted in less protection for sensitive environments (Porter and Clark, 2012). The relationship between the local resident communities and the conservation agencies is inadequate to encourage the protection of the region's highly sensitive environment by local communities.

Since the demands for eco-tourism are growing in the catchment, there is a need to implement the SDF for the Mbazwana area and to install flush sewer systems to reduce the impact on the groundwater systems. The current sewage systems in-use are posing environmental threats to the vulnerable shallow primary aquifers.

1.6 Statement of the problem

The Maputaland region comprises one of the world's most remarkable areas of biodiversity. Most of the coastal environment in this region is critically important for biodiversity conservation due to the large number of endemic species found in this area. It has the largest primary aquifers in South Africa, constituting 25% of all coastal plain aquifers found in the country.

The increasing number of rural housing development along the Maputaland coastal plain pose a significant eutrophication risks on the hydrological system of this region, through use of long drops and pit latrines as sanitation facilities. In order to understand the impact on these systems in the Maputaland coastal plain, the Mgobezeleni catchment was selected in this study as it represents a microcosm of the Maputaland region.

The Mgobezeleni catchment is located within Mbazwana town and contains remarkable areas of biodiversity that have been proclaimed as of national and international importance. These areas include iSimangaliso Wetland Park, declared a UNESCO World Heritage Site in 1999; Lake Sibaya, the biggest freshwater lake in South Africa, also recognised under the Ramsar Convention as a wetland of international importance; Mgobezeleni Estuary, a breeding ground for marine ecology; and Jesser Point, an international diving site with coral reefs. The Mgobezeleni Estuary is connected to the two lakes (Lake Mgobezeleni and Lake Shazibe) by a large swamp forest dominated by common reed (*Phragmite Australis*) and its mouth is generally affected by tidal influence.

The catchment has valuable, intrinsically linked aquatic systems which support the biodiversity and are also heavily controlled by the groundwater system. The overlying paleo-dune sands are permeable permitting high percolation of the annual rainfall. The catchment is dominated by three aquifers namely, the uppermost KwaMbonambi Formation, Kosi Bay Formation and Uloa Formation. The water table is dynamic, affecting the dimension of the unsaturated zones, the hydraulic gradient and the groundwater flow in the aquifers. Bate *et al*., (2016), indicated that the water table head in the upper layer of the Kosi Bay Formation differs significantly from the head in the Uloa Formation due to the confining intermediate layer of the Kosi Bay Formation. The groundwater recharge only becomes visible as base flow in surface water resources after several years. Contaminants that have accumulated over decades are therefore still present in the aquifers, being restricted in the upper KwaMbonambi Formation.

The groundwater in the Mgobezeleni catchment is threatened by the growing population and other forms of anthropogenic pressures. The use of long drops (LDs), ventilated improved pit latrines (VIPs) and septic tanks as sanitation facilities is increasing N and P concentrations in the groundwater thus causing a eutrophication problem in the lakes and estuary. Eutrophication of the hydrological system pose detrimental impacts on the ecology of the catchment. Still and Nash (2002) also indicated that there is elevated nutrient composition in groundwater in high density residential areas.

The aim of study was to assess the impact population growth has had on the quality of water resources in order to determine the extent of anthropogenic pollution in the catchment. It was to assess the Mgobezeleni catchment population, characterize the water quality (surface and groundwater) and peat chemistry, as well as to ascertain the impact of the population growth on the catchment water quality in order to determine the threshold levels of anthropogenic pollution in the catchment. The study involved assessment of the population growth and sanitation facilities in catchment residential areas and sampling and analyses of the tap water supply (sourced from Lake Sibaya), private water boreholes, surface water resources (Lake Mgobezeleni, Lake Shazibe, Mgobezeleni Estuary, and wetlands) and sampling of the peat soils in the catchment wetlands.

1.7 Intended contribution to the body of knowledge

The study forms part of a Water Research Commission (WRC) Project titled "Linkages between the hydrodynamics and biological drivers of Mgobezeleni catchment project" (K5/2259/1/1). The study contributes by

a) Providing Mgobezeleni catchment social demographics
b) Ascertaining the groundwater quality of the Mgobezeleni catchment to determine the effect of population growth on sewage effluent disposal into the groundwater
c) Assessing the surface water (lakes and estuary) quality of the Mgobezeleni catchment and determining the cause of the *blackwater*
d) Assessing the wetland water (*blackwater*) chemistry of the Mgobezeleni catchment and determining the cause of the blackwater
e) Assessing the Mgobezeleni catchment peat chemistry.

1.8 Aim of the study

The aim of the study was to assess the impact of population growth in the Mgobezeleni catchment, through the characterization of the hydrochemical composition of the Mgobezeleni catchment water resources (groundwater, lake, estuary and wetlands) and to assess the peat chemistry. This characterization contributed toward the determination of the extent of anthropogenic pollution in the catchment.

1.9 Objectives of the study

1.9.1 Assessment of the Mgobezeleni catchment social demographics:

a) Assessment of the Mgobezeleni catchment population and households
b) Determination of available municipal basic services (water supply, waste disposal practices, sanitation facilities) in selected residential areas
c) Establishment of the current rate of household increase
d) Estimation of the amount of nitrogen (N) and phosphorus (P) generated by the total population, which is anticipated to eventually percolate to the groundwater storage

1.9.2 Assessment of the groundwater quality of the Mgobezeleni catchment to determine the effect of population growth, specifically sewage effluent disposal, on the groundwater quality:

a) Conducting of a hydro census of the private boreholes, tap water sources (including the raw water) and collect rainwater samples (from rainwater harvesters) in selected residential areas
b) Assessment of the groundwater, tap water and rainwater quality for N and P, physical and chemical composition
c) Comparison of the groundwater, tap water and rainwater quality against the Ecological Guideline (TWQG) and Drinking Water Standards (SANS 241:2011) limits; and using graphical correlations.
d) Evaluation of the groundwater quality against the population with regard to nutrient composition

1.9.3 Assessment of the surface water (lakes and estuary) quality in the Mgobezeleni catchment:

a) Collection of water samples from Lake Mgobezeleni, Lake Shazibe and Mgobezeleni Estuary from the upper and bottom layers

b) Collection of sludge samples as a by-product of the Ezemvelo KZN Wildlife water treatment works (WTW) clarifiers to determine the water quality at the bottom of Lake Mgobezeleni
c) Comparison of the lake water quality with the groundwater quality of the boreholes located near the lakes to determine quality of the groundwater that recharges the lakes
d) Analysis of lakes and estuary water samples for N and P, physical and chemical composition and organic substances (organic carbon, organic matter, humic acid and fulvic acid components)
e) Characterization of humic substances using infrared (IR) and UV-Vis spectrophotometers
f) Comparison of N and P composition with the TWQG limits
g) Comparison of the organic substances with the values suggested by Volk (2001
h) Determination of the humic substance components using UV-Vis and E4/E6 ratios

1.9.4 Assessment of the wetland water (*blackwater*) chemistry of the Mgobezeleni catchment to determine the cause of the *blackwater:*

a) Collection of wetland water samples from all wetlands identified to be recharging the lakes
b) Analysis of wetland water samples for N and P, physical and chemical compositions, and organic substances (organic carbon, organic matter, humic acid and fulvic acid components)
c) Characterization of humic substances using infrared (IR) and UV-Vis spectrophotometers
d) Checking of N and P composition against the TWQG limits
e) Checking of the organic substances against values suggested by Volk (2001)
f) Determination the humic substance components using UV-Vis E4/E6 ratios

1.9.5 Characterization of the Mgobezeleni catchment peat chemistry:

a) Collection of the core peat samples from all peatlands selected
b) Analysis of physical composition of peat in the field
c) Analysis of peat total N and P, organic matter, humic acid, proximate analysis, CHNS, cations and trace elements
d) Establishment of the degree of peat humification

1.10 Hypothesis

a) The groundwater quality in the Mgobezeleni catchment is affected by the growing population which is increasing the nutrient composition in the primary aquifer due to sewage effluent disposal

b) The groundwater base flow recharge to the surface water resources increases the nutrient composition thus contributing to eutrophication which has resulted in the growth of macrophytes and microalgal species in the surface water resources
c) Cultivation of peatlands and decomposing vegetation increases the organic substances in the wetlands, lakes and estuary contributing to *blackwater*

CHAPTER 2

LITERATURE REVIEW

2.1 Background history of the Maputaland region

Maputaland has been occupied by humans since the early Stone Age. Three occupational sites of the Acheulean Period dating between 1 00 000 to 50 000 years BP were identified in St Lucia Wetland Park. People of the Middle and Late Stone Age cultures inhabited the Maputaland area following the last Interglacial Period (Beaumont *et al*., 1978 in Bruton *et al*., 1980). It was later inhabited by pre-colonial agriculturists in the early and late Iron Age. They occupied sites along the coastline as early as 1600 years ago, where they harvested their fields while living in the coastal forests (Bruton *et al*., 1980). Subsequently, in the early nineteenth century, the area was occupied by Nguni tribes (Zulu speaking) in the south and the Tembe-Thonga people in the north (Ross, 1999 in WWF, 2001). The prevalence of malaria and the cattle disease (*Trypanosomiasis*) caused by the tsetse fly (*Glossina)*, resulted in extensive areas of Maputaland becoming uninhabited (Bruton *et al*., 1980).

During the colonial period the area was visited by hunters and traders, and later by missionaries (Beaumont *et al*., 1978 in Bruton *et al*., 1980). In recent years many refugees from the Mozambican conflict crossed the international border and settled in the area (Kloppers, 2003). The hunters' and traders' sites are now protected by the National Heritage Resource Act (Act N0 25 of 1999).

The present African inhabitants of the Maputaland area are Tembe-Thonga people. Their oral history and culture are very rich, dating back many centuries. The Tembe-Thonga people are believed to have migrated from Karanga in Zimbabwe in the middle of the seventeenth century (Junod, 1962). Their cultural heritage includes the relationship of the local community with their physical environment; traditional fishing practices (such as isifonyo basket fishing), the indawo spirit cult and the use of wild fruit. The significance of the mother and brother in their social organisation, settlement rules and history are very important. They are characterized by their language, cross-border identities, trade across the border and the history of various traditional authorities in the area.

Currently, the Maputaland area is underdeveloped and rated as an RDP priority in terms of developmental resources. It is limited in industrial development options owing to a lack of mineral wealth (Watkeys *et al*., 1993). The area has popular nature reserves, such as St. Lucia, within a World Heritage Site and the Mkuze Game Reserve. Other reserves include Tembe Elephant Park and Kosi Bay Coastal Forest Reserve. The rich biodiversity and the reserves support a comprehensive ecotourism potential. Reserves and developmental improvement of the region's agricultural output provide muchneeded employment opportunities for a rapidly growing and already impoverished rural community (Watkeys *et al.*, 1993).

2.2 Sources of water quality degradation in South Africa

The growing human population and expanding agricultural and industrial activities are exerting great pressure on freshwater resources worldwide. The growing population and their socio-economic needs are the main cause of freshwater quality degradation (Schindler, 2006; Millennium Ecosystem Assessment, 2005; Smol, 2008). The main anthropogenic factors affecting the freshwater systems are sewage effluent, excessive nutrient loads in return flows from agriculture, modification of the rivers load regime, and changing land use or land cover patterns (Oberholster *et al.,* 2009a, b).

Consequently, some of the freshwater systems have elevated levels of dissolved nutrients causing algal blooms, loss of macrophytes, increased turbidity and death of fish (due to depleted dissolved oxygen levels and toxic cyanobacteria [blue-green algae]). Intercellular toxins produced by some of the cyanobacteria species are fatal for humans and animals if ingested in large quantities. Cyanobacteria flourish in eutrophic shallow water resources and pose water treatment problems due to dense cell accumulations (biofilm). The biofilm controls the functional diversity of the plankton community resulting in health threats for recreational and water use (Oberholster *et al*., 2009a, b; Chorus *et al*., 2000).

2.3 South Africa's water challenges

South Africa has a large number of valuable aquatic ecosystems providing various services to the population (CSIR, 2010). However, the systems are under great pressure due to increasing demands from the growing population (Boccaletti *et al*., 2010). Many of the country's dams are also eutrophic.

The country is ranked the 30th driest country in the world with an average annual rainfall of 450 mm which is below the global average annual rainfall of 860 mm (CSIR, 2010). Some parts of the country receive higher annual rainfall than others (minimum annual rainfall of 100 mm in the west and maximum annual rainfall of 1500 mm in the east). The study area falls into the higher rainfall region of the country.

The high evaporation rates, growing population and expanding economy are resulting in freshwater shortages in South Africa (DWAF 2006a; Davies *et al*., 1993). As the country is still redressing the past political history and inequitable use of natural resources, the environmental changes are driven mainly by social, political and economic needs. This has resulted in water resources being compromised for urbanisation, afforestation, agricultural, mining and industrial needs (Ashton *et al.,* 2008; Davies *et al*., 1993). This compromise has caused severe degradation in water quality and impairment to the integrity of aquatic life.

The country is facing looming water quantity challenges (Boccaletti *et al*., 2010; Thelwell, 2014; DWS 2015). Demand for water is increasing and is anticipated to exceed the water supply. The country is already using 98% of its available water and future water demand in South Africa is estimated to be 17.3 billion m^3 in 2030 (Boccaletti *et al*., 2010; DWS, 2015). The current water supply is estimated at 15 to 16 billion m^3 per annum and is restricted by low rainfall and insufficient regional aquifers.

Approximately 40% of the country's water treatment plants are in a critical state with approximately 37% of tap water being lost through leakages (Thelwell, 2014). The country's water supply depends on Transfer Schemes between basins and from neighbouring catchments and countries. One of the basin Transfer Schemes is the Tugela Vaal Water Transfer Scheme, through which water is obtained from KwaZulu-Natal and transferred to the Vaal Dam Catchment. About 25% of the total water supply is sourced from Phase 1 of the Lesotho Highlands Scheme, which was established to supply water to the Gauteng Vaal Water Management Authority (WMA) through water transfer from the Katse and Mohale Dams in Lesotho (DWA, 2013). There are currently 29 inter-basins and inter-river system transfer schemes comprising a total capacity exceeding 7 billion m^3 per annum. Phase 2 of the Lesotho Highlands Scheme has been approved to supply water to South Africa (DWS, 2015).

Climate change is expected to exacerbate the water quantity problem in South Africa as it is predicted that the annual rainfall will decrease (Boccaletti *et al*., 2010). This, it is estimated, will increase the water supply shortage by approximately 3.8 billion m^3 (Boccaletti *et al*., 2010). The available water per capita is estimated at 1000 m^3 per annum, which is lower than that of neighbouring countries which have a higher rainfall and lower population density (DWAF, 2008).

The country relies predominantly on surface (68%) and groundwater (13%) resources and return flows (13%) for water supply and water use (DWS, 2015). The sectors that are the main water users in South Africa are agriculture (62%), municipalities (27%), mining (3%), industry (3%) and energy (3%) (DWS, 2015). The total ecology of the country requires approximately 9.5 billion m^3 of water per annum to satisfy its needs (Backeberg, 1997; DWAF, 2004; DWS, 2015; Water wise, 2016).

Industrial and municipal sewage effluent spillages often occur because of dilapidated and inadequate maintenance of waste water treatment plants (WWTP) and untrained operators (Snyman *et al*., 2006; Rietveld *et al*., 2009). Informal settlements, inadequate sanitation, sewage spillages, waste removal and agricultural (through fertiliser and pesticides) practices are causing major freshwater and groundwater quality deterioration in South Africa (Walmsley, 2000).

Natural freshwater lake systems in South Africa together with rivers are rich in nutrients and have been classified as being moderately to highly eutrophic (CSIR, 2010). They are affected by drought, floods, low water flow and high nutrient influx from point sources. Moreover, the rivers are mostly turbid due to erosion from unstable riverbeds, causing the loss of fauna species that live on planktonic algae, which in turn results in the generation of cyanobacteria such as *Microcystic aeruginosa* (Hart, 2006).

A river receiving water from eutrophic lakes is likely to be recharged with cyanobacteria due to the high concentration of cyanobacteria in the lake outflows (CSIR, 2010). Moreover, cyanobacteria grow significantly in slow moving water with long retention times. In turbulent water, they are easily removed from the water downstream, resulting in lower population growth.

Some of the lakes are rich in dissolved organic carbon. In most lakes this is attributed to humic substances of terrestrial origin (from surrounding vegetation), which cause the blackwater in dystrophic (contain waters acidified by humic acid) lakes (Kortelainnen, 1999). Humic substances affect light absorption and temperature stratification in the water column of the lakes (Keskitalo and Eloranta, 1999); they buffer against the harmful effects of low pH and free aluminium and bind inorganic and organic nutrients into non-bioavailable forms (Munster, 1999). Lakes that are enriched with humic substances have a distinct food web of prominent heterotrophic microbes and phytoplankton (Järnefelt, 1952, 1956; Arvola *et al*., 1999; Kerskitalo and Eloranto, 1999). Rivers, lakes, wetlands and estuaries are some of the key ecosystems that need to be protected.

The degradation of freshwater quality in South Africa by domestic effluents, agricultural and industrial activities has resulted in shortages of water of a suitable quality (Oberholster *et al*. 2009a, b), as the available water requires treatment prior to domestic supply. The degradation of water quality has also resulted in irreversible impairment to aquatic life, as water quality degradation limits water utility value, places an economic burden on society for treatment costs and therefore has an impact on the economy.

Groundwater enriched with high levels of nitrates poses significant health risks such as methemoglobinemia (blue baby syndrome) in infants. Several outbreaks in the country have been reported to have been caused by contamination of the groundwater with viruses and bacteria (Griesel *et al*., 2006).

In South Africa, the National Water Act (Act No. 36 of 1998) is the overarching framework for water resources and water use regulation. It governs the management, protection and distribution of water under the jurisdiction of the Department of Water and Sanitation (DWS). Law enforcement for water protection in both the private and the public sectors has not been stringent owing to social, political; economic needs and an inadequate number of environmental inspectors. Nevertheless, various norms and standards have been promulgated under the Act for water resource quantity and quality management. Water quality is classified in terms of biological, chemical, microbiological and physical composition limits.

2.4 Eutrophication problems in South Africa

Human-induced eutrophication of aquatic ecosystems is a global threat (Schindler, 2006). Primary producers such as phytoplankton and benthic diatoms are good indicators of eutrophication in these systems owing to their reliance for growth on inorganic nutrients such as nitrogen (N) and phosphorus (P) (Stevenson *et al*., 2004; Hering *et al*., 2006; Johnson *et al*., 2006a, b). They are also considered to be efficient indicator organisms in lakes because of their greater reliance on inorganic nutrients in the water column than macrophytes, which can use nutrients in the sediments once the water column nutrients are depleted (Best and Mantai 1978; Barko and Smart 1981; Rattray *et al*., 1991). The response of phytoplankton assemblages to water column nutrient enrichment is assumed to be faster due to their higher affinity with inorganic nutrients than that of phytobenthos (Cattaneo, 1987; Vadeboncoeur and Steinman, 2002).

Although eutrophication occurs naturally, it is generally exacerbated by point and non-point pollution sources (Harper, 1992; Hall and Smol, 1999). Sewage effluent from point sources increases nitrogen and phosphorus (N and P) concentrations. The high levels of N and P in lakes promote the growth of phytoplankton, thereby changing the trophic state (Wetzel, 1983; Harper, 1992). Diatoms leave their remains well preserved in most aquatic sediments. They are the most abundant group of microscopic algae in almost all aquatic habitats and constitute approximately 25% of the earth's primary autotrophic production in lake systems (Werner, 1977). They are also a good indicator group for determining the ecological condition of lakes (Hall and Smol, 1999) as diatom assemblages provide sufficient ecological information (Dixit *et al.*, 1992). An increase in diatom growth rates is often brought about by a change in environmental conditions (Hall and Smol, 1999). Diatoms also respond to salinity (Round *et al*., 1990; Gell, 1997; Potter *et al*., 2006).

South Africa's freshwater resources have been identified as vulnerable to eutrophication (Van Ginkel, 2011). Approximately 15% of the country's dams and 72% of the river catchments are affected by eutrophication (DWAF, 2003; De Villiers and Thiart, 2007). The main dams are enriched with cyanobacteria including *Microcystic* and *Anabaena* species (Scott, 1991; Van Ginkel, 2004). Toxins generated by these cyanobacteria species affect domestic and wild animals around the country and threaten the domestic water supply available for the South African population (Van Ginkel, 2004; Oberholser *et al.*, 2009a, b). Domestic effluent spillages into catchment areas promote eutrophication in aquatic systems due to water enrichment with nutrients such as nitrogen (NO_2^-, NO_3^- and NH_4^+) and phosphate ions (PO_4^{-3}). This eventually has an impact on the natural aquatic biota composition and functions (Oberholster *et al*., 2009a, b).

Bate *et al.* (2013) identified 333 epipelic diatoms in 19 south estuaries in cool to subtropical temperature conditions. These species were present in intertidal and sub-tidal areas thus indicating salinity tolerance. However, the diatoms found in these estuaries had little relation to the diatoms found in the tributaries of those estuaries.

2.5 Maputaland wetlands

The Maputaland region is host to extensive wetlands with the best developed peat deposits in both KwaZulu-Natal and South Africa as a whole (Grundling *et al*., 1998). Wetlands vary in size from a few hectares to thousands of hectares. Approximately 1600 to 20 000 km^2 of peat areas have been identified in South Africa, varying in size from small seep lines and valley bottom fens in the Highveld and the escarpment region to enormous fens in the 880 ha Mkuze Delta (Grundling *et al*., 1998). Approximately 266 peatlands are found in the Maputaland region within the coastal plain. Approximately 60% of South Africa's peat is in the Maputaland region (Smuts, 1992; Grundling *et al*., 1998). The Kosi Bay system has freshwater swamp forests and mangrove swamp forests which differ geographically. There are about 10 342 ha of coastal environment and 79 210 ha of estuarine functional zones. Approximately 61% of South Africa's most significant estuarine functional zones fall within the boundaries of this region.

Wetland ecosystems in Maputaland are found adjacent to the coastline, distinct from mangroves affected by tidal interactions (Sliva *et al.*, 2004). They serve as buffers between marine and freshwater systems, preventing saline intrusion into the coastal plain and underlying groundwater resources (UNDP, 2006). The groundwater fluxes control the wetland productivity. They also control the accumulation and removal of nutrients, toxins, chloride ions, hyper saturation, sediments, pH and soil moisture in the wetlands (Hughes *et al.*, 1998). Fluctuations in the water table influence the distribution of the peat swamp forests (Colvin *et al.*, 2007). The effects include degradation of the landscape, shrinkage and damage to the remaining wetland ecosystems. They also result in water scarcity and a decline in the natural biodiversity of the affected wetlands (Grobler *et al.,* 2004; Sliva *et al.,* 2004; Grundling, 2011).

2.6 Maputaland peatlands

Peat is mainly formed from reeds/sedge vegetation and, in this region, is of a poor quality compared to the *Sphagnum* peat moss found in the northern hemisphere (Taylor, 1991). Peatlands are generally located at topographic levels of less than 50 metres above mean sea level (amsl) due to high rainfall (> 800 mm/pa). The high rainfall causes a perennial water supply and the accumulation of biomass.

Maputaland peat thickness varies from 0.5 to 10 metres (Sliva *et al.*, 2004). The Mkuze swamp forest has the largest wetlands containing peat with a maximum thickness of 6 metres. While the Mfabeni peatland has a peat thickness profile of 10 metres (Sliva *et al.*, 2004). The largest pristine peat swamp forests in South Africa are found adjacent to the Syhadla River.

The heavily disturbed peat swamp forests are characterized by the absence of fully developed trees. They have hydrological modifications such as drains or ditches and are predominantly disturbed by the cultivation of bananas (*Musa xparadisiaca*) and amadumbes (*Colocasia esculenta*). Bananas require drier wetland conditions, and this is created by cutting drainage ditches (at 90° to the valley's length) into the peat. The ditches cause intensified peat decomposition by exposing it to aerobic conditions (Sliva *et al*., 2004). Peat decomposition is also caused by groundwater abstraction and evapotranspiration, causing fluctuations in the water table (Rawlins and Kelbe, 1998).

A large portion of the peat swamp forests in the region was previously affected by vegetation clearance for sugarcane farming, forestry, slash and burn, agriculture and eradication of tsetse fly and mosquito habitats (Sliva *et al*., 2004). The impact is currently mitigated by legislative measures and insect control practices. Although wetlands are now regulated by international and national legislation, the effects of the existing farming and forestry activities are still significant on the groundwater levels (Sliva *et al.*, 2004). The sugarcane and forestry plantations, although distant from the peat swamp forest habitats, are still responsible for lowering the water table and large amounts of water are removed from the catchment through evapotranspiration and (excavation of drains) drainage.

2.6.1 Maputaland peat chemistry

The peat in Maputaland is classified according to the different plant communities growing on the wetlands (Smuts, 1997; Mazus and Grundling, 1998). The plant communities include reeds (*Phragmites Australis*), sedge with papyrus (*Cyperus papyrus*), bulrush (*Typha capensis*) and ferns; while the swamp forests contain species such as waterberry (*Zyzigium cordatum*) and Ficus and mangroves species. The current plant communities do not necessarily reflect the vegetation that formed the peat in the past. In order to understand the past peat-forming vegetation, micro-fossils within it such as pollen grains and spores are examined to reveal the vegetation types and environmental conditions during peat accumulation. Grundling and Mazus (1995) classified Maputaland peat composition by proximate analysis as indicated in **Table 1**.

Table 1: Maputaland peat classification by proximate analysis (Grundling and Mazus, 1995)

Classification	Ash (%)	Moisture (%)	CV (MJ/kg)	Volatile (%)	H20 (%)	Fixed Carbon (%)
Low Ash	< 15	> 78	> 18	> 48	> 14	> 29
Medium Ash	16–29	75–63	16–13	47–35	11–9	23–17
High Ash	30–50	64–50	12–7	34–23	8–6	16–12
Inorganic Ash	> 51	< 51	< 6	< 22	< 5	< 11

The peat in the Mgobezeleni catchment varies from surface to bottom (Grundling, 2001). The top layers of the peat profile are generally reddish brown, followed by dark brown peat, then the dark peat with reddish nodules and a lower layer being the dark peat. The fibre content decreases from the surface downwards but increases again near the bottom. The upper part of the peat is high in fibre which corresponds to its reddish colour. The ash content varies from 4 to 45% which increases towards the bottom. A study by Smuts (1992; 1997) indicated that the ash content of Lake Mgobezeleni's peat is unevenly distributed.

Smuts (1992; 1997) states that the rate of peat accumulation in modern reed-sedge is 100 mm/year in Southern Africa. Smuts and Kirstein (1995) state that the rate of accumulation is also supported by ^{14}C and various decompaction factors from Maputaland. According to Grundling (2004), the current accumulation rate of peat in this region is lower than suggested by Smuts (1992; 1997) and Smuts and Kirstein (1995). Grundling (2004) also states that the pollen supports the accumulation rates estimated by Mazus and Grundling (1995) and Thamm *et al.* (1996) and that compaction factors play a minor role in the peat accumulation rate and peat determination.

The peat north of the Mkuze River inflow into Lake St Lucia and south of Kosi Bay has been classified as being Holocene age deposits, with an average accumulation rate of 1.06 mm/year (Grundling, 2004). The youngest peat deposits are found in the Mgobezeleni peatlands south of Lake Mgobezeleni. These have been dated at 1100 ± 40 years BP. The oldest peatland is Nhlangu peatlands dated 7000 ± 80 years BP with a depth of 8.43 m (Grundling, 2004). Mfabeni peatland is classified as being of the Late Pleistocene age and is likely to be the world's oldest known peatland. The Mfabeni peatland is 43 100 (+ 3900, -2600) years BP at a depth of 9.93 m (Grundling, 2004).

The peat in Maputaland and Mfabeni was not compacted during the period of accumulation. This may suggest that the peat accumulation dominated compaction. Moreover, the compaction was only observed at 0.5 m below the surface. The compaction at this depth was caused by the cell walls of the plant material, which are slowly destroyed by saturated conditions (Maltby and Proctor, 1996).

2.7 Maputaland coastal lakes

Natural freshwater lakes and water bodies with relatively deep open water are limited in South Africa, occurring mostly along the coastal plain. Their ecological structure and functions are influenced by the interaction of both marine and groundwater components. Although coastal lakes have no consistent pattern of water stratification, their thermal and salinity strata have been established. The water temperature ranges from 24 to 27 °C in summer and 19 to 24 °C in winter. The lakes are further classified as being subtropical, warm temperate or Mediterranean, depending on their geographical location in South Africa.

The salinity levels vary widely depending on their location and the frequency of marine inflow. For instance, the northern Zululand lakes (Sibaya, Mgobezeleni, Shazibe and Kosi Bay) are classified as being subtropical, isolated from the sea and warm with temperatures ranging from 19 °C in winter to 30 °C in summer. Although the freshwater lakes such as Sibaya, Mgobezeleni, Mzingazi, Nsezi, and Cubhu are located within the high rainfall region, they are brackish due to a high chloride concentration. This high chloride concentration is attributed to recent cyclic salt input from the sea or from fossil sources in the Tertiary sand of the underlying basin and from over pumping (Allanson and Van Wyk, 1969). Salinity in Lake Sibaya is approximately 0.6% with a chloride concentration of 135 mg/l due to the high evaporation rate and a lack of outlet structures (Allanson and Van Wyk 1969).

The dissolved oxygen (DO) levels of the coastal lakes are relatively close to saturation even in deep water. However, sharp localised oxygen depletion has been measured in the deep-sediment water interface during the night in the northern section of Lake Sibaya. This is assumed to be caused by biological metabolic activities in the warm temperature (Bolt, 1969). The deep layers of the lake have a strong vertical density gradient. The progressive stagnation of water leads to oxygen depletion and eventually oxygen exhaustion. The turbid water of Lake Bhangazi during the day at or near the deep-sediment water interface has been recorded to cause a major reduction in dissolved oxygen (DO). The transparency of the water ranges widely between coastal lakes and also varies seasonally. The northern, southern and southwestern regional lakes are dystrophic (contain peat-stained waters, acidified by humic acid). The pH values of the water of these lakes are relatively neutral or alkaline, even in the humic acid stained black or yellow waters. Changes in water clarity are associated with the input of peat following the flooding events of a tropical cyclone (Begg, 1980).

The coastal sands of the northern lakes are generally oligotrophic except for Lake Nsezi and Lake Nhlabane, in which the catchments are agriculturally developed with extensive sugarcane. Phosphorus levels are consistently quite low with a total phosphorus concentration below 30 μgl^{-1}. Nutrient levels are higher in the smaller and shallower lakes than in the large deeper lakes, and higher in isolated water bodies than in interconnected systems.

The salinity of the estuaries ranges from close to that of seawater in the tidal basin (Kosi mouth) to freshwater. The water levels in all the lakes are relatively stable, ranging from 1.0 to 1.7 m, with any rise in water level occurring after high rainfall (Lubbe, 1997).

The presence primary producers (autotrophs) organisms are an indication of the accumulation of nutrient enrichment, which is a major global threat to aquatic ecosystems. Macrophytes are effective nutrient filters that are capable of absorbing increased phosphorus loading in the system (Howard-Williams, 1978). Anthropogenic activities promote major macrophyte encroachment into lakes, but under the influence of reduced hydraulic flushing and nutrient enrichment from agricultural activities and other sources in the catchment, macrophytes act as nutrient filters.

Sedimentation, segmentation and swamp encroachment are estimated to have reduced the total surface area of lagoons in Zululand by 60%. Lake Mgobezeleni has been reduced approximately 22 times from its previous size (Orme, 1973). The surface areas of the lakes change significantly both seasonally and inter-annually.

2.7.1 Lake Sibaya

Lake Sibaya is a freshwater lake situated on the seaward margin of this region. It has a total area of 60 to 70 km^2 (averaging approximately 64 km^2) and has a perimeter of approximately 86 km and an average depth of 13 m (Miller, 1998). The water storage capacity of the lake is estimated at 832 x 10^3 Ml. It is situated in the uMkhanyakude District close to the rural towns of Mbazwana and Mseleni (**Figure 2**). It is separated from the sea by high forested sand dunes.

Lake Sibaya is an important source of freshwater for the ecology especially for birds and mammals during drought periods (Weitz and Demlie, 2013). It is an integral part of the iSimangaliso Wetland Park World Heritage Site and has also been classified as one of the RAMSAR Convention wetlands of international importance (Allanson, 1979, Meyer *et al*., 2001).

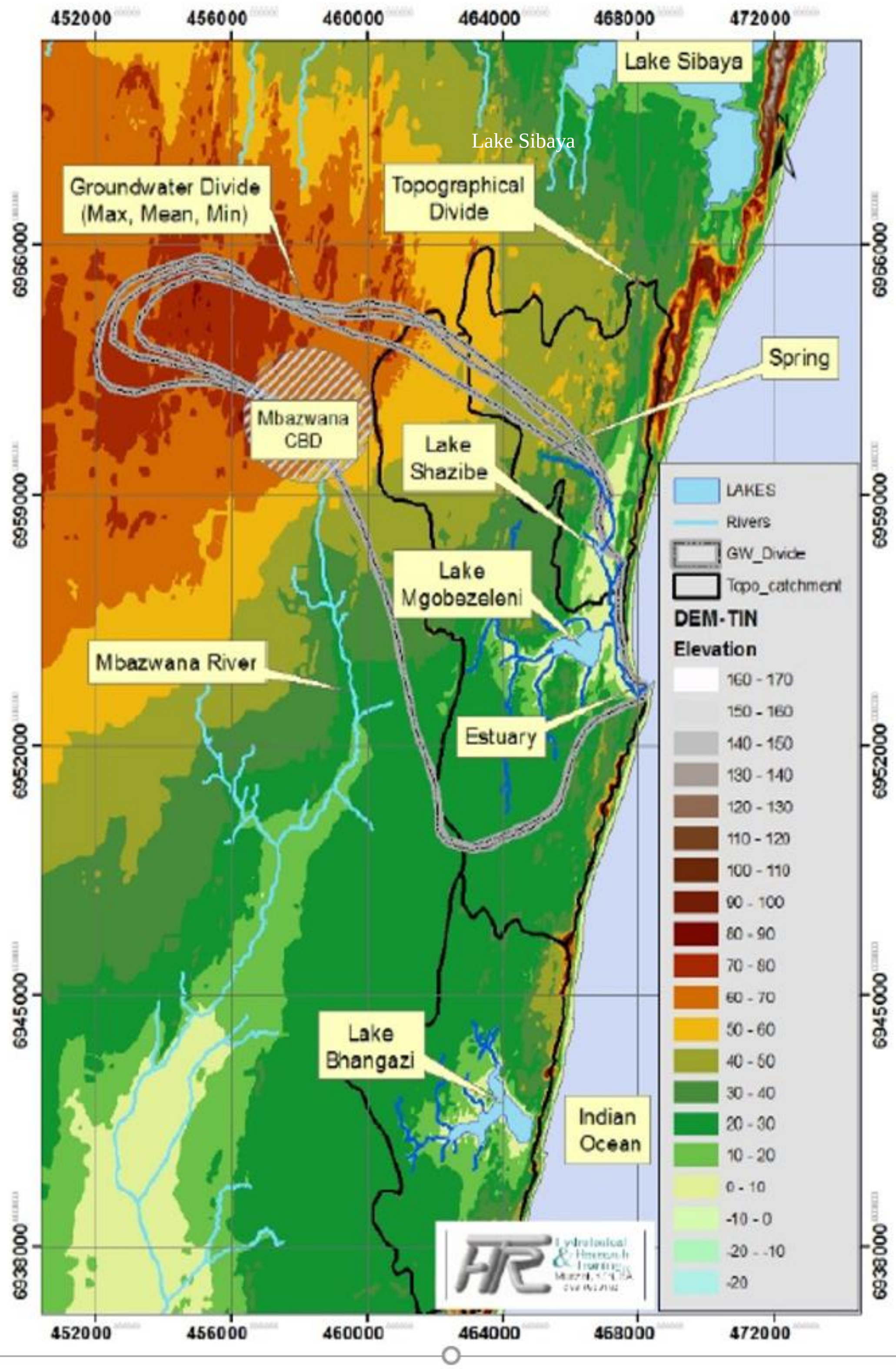

Figure 2: Location of the coastal lakes along the Mgobezeleni catchment (Bate *et al*., 2016)

It is also used for urban and rural domestic water supply for the local communities (Allanson, 1979; Meyer *et al.*, 2001). Mbazwana Water Supply Scheme abstracts its water for Lake Sibaya. Water abstraction from the lake and the surrounding aquifers together with drought has reduced Lake water levels by about 2 m. A further reduction in the water level to a depth of 7 m below groundwater level will reverse the hydraulic gradient of the groundwater resulting in sea intrusion into the Lake (DWS, 2015). The study by Weitz and Demlie (2013) indicates that water from the Lake seeps through the dune cordon into the Indian Ocean.

The surrounding developed areas around the Lake have expanded in recent years (Bruton *et al.*, 1980; Combrink *et al.*, 2001). These developments are making the conservation and management of the Lake difficult because any increase in water abstraction could, as previously mentioned, reverse the hydraulic gradient in the future. It is therefore very important that any further development in the area should take cognisance of the water balance of the Lake (Weitz and Demlie, 2013).

The shallow aquifers of the Lake are less saline than the deeper aquifers (Weitz and Demlie, 2013) and the water in the Lake is more saline (average 650 µS/cm) than the groundwater. The groundwater quality near the dune cordon has the same salinity levels as the Lake, indicating water seepage from the Lake through the dune cordons to the sea. The Lake is dominated by K^+, Na^+, Cl^- and HCO_3^- ions which contribute to its salinity levels (Weitz and Demlie, 2013). The shallow aquifers are dominated by K^+, Na^+, Cl^- ions while the deeper aquifers are dominated by Ca^{2+} and HCO_3^- ions. The hydrochemistry of the Lake and its surrounding aquifers (near the dune cordon) is high in Fe^{2+} ions concentration.

2.8 *Blackwater* in natural water resources

The term *blackwater* refers to the yellowish or brownish water colour found in surface water resources such as lakes, estuaries and wetlands. In wetlands, the *blackwater* can be caused by peat decomposition resulting from fluctuating water tables and draining of the peat soils for cultivation purposes. High summer ambient temperatures can accelerate microbial decomposition in the peat to produce the *blackwater* (Johnson, 2004). This results in high dissolved organic matter (DOM) and low dissolved oxygen (DO) levels in the wetlands (Sammut *et al.*, 1996; Roach, 1997).

The *blackwater i*n natural waters can also be caused by summer floods and domestic effluent discharges (Eyre and Kerr, 2006). Sewage effluent, traces of pesticides, fertilisers and synthetic chemicals can result in a high nutrient influx in water resources causing the *blackwate*r or turbid water with dense phytoplankton concentrations (Lapointe *et al*., 2004).

Drainage of peat swamp forests produces aerobic conditions that result in peat carbon oxidation (decomposition of organic matter in the peat). This alters the chemistry of the peat swamp through the release of humic and fulvic acids thus forming the *blackwater* colour (Sliva *et al*., 2004). Humic and fulvic acids are toxic organic substances which result in the depletion of DO in the water. Low levels of DO can cause the death of vulnerable aquatic species (NSW Government, 2012). The *blackwater* generated by peat decomposition is affected by the chemical composition and molecular structure, soil moisture content and organic matter content of the peat (Lishtvan *et al*., 1989; Szajdak, 2002). Therefore, the amount of water retained in the peat before release is an important factor in the water quality composition of the swamp forests. FAO (1988) reported on a study conducted in Brazil which found that their *blackwater* contains organic substances with antibiotics for water sterilisation. The *blackwater* in Brazil the rivers have been reported to have less microbiological activity and no algae or fish.

The aquatic systems containing *blackwater* are usually low in nutrients (oligotrophic) and DO, but high in acidity (UNDP, 2006; Rahim *et al*., 2009). The hydrochemical composition of these systems is generally high in levels of natural organic leachates, such as humus, humic acid and tannins produced from the decomposition of organic material which generates the dark-brown to black coloured water (Gerhke *et al*., 1993). The stained water produced by the organic leachates is a natural wetland process of unknown deoxygenating action that may lead to fish and crustacean mortality (NSW Agriculture and Fisheries, 1989). The stained water also leads to unique biodiversity in these systems with the occurrence of uncommon species fish (Ng *et al.*, 1994; Beamish *et al.*, 2003). The *blackwater* from oligotrophic peats is very low in nutrients and biological activity. The cation concentration is < 5 ppm and is low in drinking water potential and deficient in most trace elements (FAO, 1988). Eutrophic peat water has 50 ppm or more of major cations such as Ca^{2+}, Mg^{2+}, K^+ and Na^+, with an electrical conductivity (EC) greater than 1000 µS cm^{-1} or 640 ppm total dissolved salts (TDS) (FAO, 1988). Acidic *blackwater* may contain a high concentration of iron (III).

2.9 Nutrient composition

Water resources are vulnerable to pollution by the N and P composition received from the groundwater as a baseflow recharge. Other sources of pollution include direct precipitation, stormwater runoff, decomposing peat, underlying surface water basins and stream water recharge. However, there are various biological mechanisms that play a role in nutrient reduction in these systems, such as nutrient assimilation by plants and algae and denitrification processes (Stevenson *et al*., 2004; Herring *et al*., 2006; Johnson *et al*., 2006a, b). High levels of nutrient composition in the water column lead to eutrophication, which in turn causes a reduction in DO levels, which is lethal to oxygen-dependent aquatic organisms such as fish. It also causes the growth of microalgal species.

Nitrogen in aquatic systems occurs as nitrates (NO_3^-), nitrite (NO_2^-) and unionised ammonia forms (NH_3 aqueous) or ionised forms (NH_4^+). Ammonium ions are non-toxic in aquatic systems, but they are assimilated by aquatic plants. However, at pH > 8 these ions are converted to toxic aqueous NH_3 which builds up in the blood and internal tissues of aquatic organisms potentially causing death (DWAF, 1996). The proportion and toxicity of $NH_{3(aq)}$ is affected by the temperature, DO, CO_2, TDS and the presence of trace metals. Ammonium ions are one of the common pollutants contributing to eutrophication in aquatic systems. In this study the total inorganic nitrogen (TN) concentration was used to estimate the trophic state of the water resources using the TWQG limit.

Phosphorus in most natural water occurs as orthophosphate (PO_4^{3-}). The soluble inorganic species of phosphorus such as $H_2PO_4^-$ and HPO_4^{2-} are directly utilised by aquatic biota (DWAF, 1996). However, they are easily converted into insoluble form (unavailable form) by natural processes. Phosphorus concentration is unstable in natural waters due to decomposition and the synthesis of organically bound phosphorus and the oxidation of inorganic phosphorus. The common phosphorus concentration in South Africa's surface water resources ranges from 0.01 mg/l to 0.05 mg/l (DWAF, 1996). An increase in phosphorus concentration in surface water resources indicates potential contamination. The main point sources of phosphorus are discharge of sewage and industrial effluents, while non-point sources include the atmosphere and runoffs from drainage areas. Phosphate ions are removed from the water column through particulate settlement and by the uptake of biota, and they accumulate in the sediments at the base of lakes or estuaries. During high rainfall or floods the phosphorus concentration becomes elevated due to wave agitation of the particulate matter deposited in the sediments. Inorganic phosphorus (PO_4-P) is one of the main nutrients limiting biological productivity in natural water resources and was therefore selected for this study.

Organic carbon (OC) and organic matter (OM) relate to dissolved organic substances in the water column. Sources of these components are decomposing plant material and peat underlying the basins. The basins are also recharged by streams rich in peat deposits and groundwater rich in nutrient composition. This results in an increase in dissolved organic substances in these systems leading to high levels of microalgal and macrophytes species. The major organic constituents of natural waters are humic substances. These substances are characterised by a yellow to black colour with high molecular weight compounds with various water solubilities (Stevenson, 1994). Humic acids are insoluble in acidic water (pH 2), but soluble in alkaline water. Fulvic acids, on the other hand, are soluble in water at all pH values (Stevenson, 1994). Humic acid is a brown-black, polymeric, alkali soluble acid found in surface water, soils, plants and marine waters.

Organic substances are found in surface water as a result of its interaction with the surrounding biogeochemical environment, resulting in water having various organic matter contents. The dissolved natural organic matter content in surface water ranges from 0.10 to 20 mg/l (Volk, 2001). It is composed mainly of humic substances varying according to water type, depending on the microbiological activities, and the chemical and photochemical transformation of plant and animal residue (Rose and Waite, 2003). The major constituents of the dissolved organic matter in water are humic acid, hydrophilic acid, proteins, lipids and hydrocarbons. The organic components of the water resources in this study were determined using OC, OM, fulvic acid (FA) and humic acid (HA) components.

The main aim of this study was to determine the quality of the surface water resources and to establish the cause of the blackwater colour in these systems. Humic substances such as humic acid (HA) and fulvic acid FA) are produced from the decomposing plant material in the water resources. In this study, the crude extract of the HA and FA was used to determine the cause of the blackwater in the surface water resources.

CHAPTER 3

THE STUDY AREA

3.1 Location of the study area

The Mgobezeleni catchment is located within Maputaland region and is situated close to Mbazwana. Mbazwana is situated within UMhlabuyalingana Local Municipality in the uMkhanyakude District Municipality. UMhlabuyalingana Local Municipality forms part of the Ingonyama Trust land and is classified as being 99% rural. Its population is spread among 17 municipal wards and four traditional councils, including Mashabane, Tembe, Zikhali and Mabaso. Approximately 60% of the municipal land falls under the ownership of traditional councils, with the remaining 40% constituting commercial farms and conservation areas. The main towns are Manguzi, Mboza, Mseleni, Mbazwana (partially within the catchment) and Sikhemelele (uMhlabuyalingana IDP, 2014/15).

According to SAS (2011), the Local Municipality covers an area of 3 613 km^2 and, in 2011, the population was estimated at 156 735 people. This number represented approximately 25% of the district population at the time and was the third largest population in the district. The Local Municipality is reported to have experienced phenomenal population growth over the years. The average population growth was estimated at 3% from 1996 (uMhlabuyalingana IDP, 2014/15).

About 50% of the dwellings in the UMhlabuyalingana Local Municipality are built from traditional material. In addition, the modern structures in the area are often erected without any approval of building plans by the Local Municipality in terms of the National Building Regulation and Building Standard Act (Act N0. 103 of 1977). On average, the Local Municipality comprises very low intensity and sparsely populated rural settlements. However, Manguzi, Mbazwana, Mseleni and Skhemelele are fast emerging as urban centres with various levels of concentration.

Over the years there has been an increase in the household density in some of the areas along the main road, with the expansion of commercial activities at strategic points, causing an increase in developmental nodes. According to the Local Municipality, development in the area was discouraged by the previous government to control the movement of the freedom fighters between South Africa and Mozambique (uMhlabuyalingana IDP, 2014/15). The lack of development in the area was also caused by the prevalence of malaria.

The UMkhanyakude Local Municipality was formed following the unplanned establishment of small rural towns and villages. Therefore, the culture of identifying suitable land for housing purposes was not implemented or practised (uMhlabuyalingana IDP, 2014/15). However, the Municipality is currently developing a Spatial Developmental Framework (SDF) and Schemes for Manguzi and Mbazwana towns respectively. The SDF identifies and designates land for future housing development. A study by the Municipality conducted in 2014/15 indicated that there was a housing backlog of approximately 8806 housing units.

Self-employment has been estimated at 1% of the population. Public spending is the main source of income for the municipality although this has been declining in recent years (uMhlabuyalingana IDP, 2014/15). Tourism is increasingly making a greater contribution to the local economy and has been growing over the years. For this reason, an increase in agricultural activities would impact on the tourism potential of the area.

The area has been identified as having a high eco-tourism potential due to the presence of World Heritage Sites such as iSimangaliso Wetland Park and game reserves such as the Tembe Elephant Park and Ndumo. These areas form part of the proposed Trans-Frontier Conservation Initiative involving South Africa, Mozambique and Swaziland (uMhlabuyalingana IDP, 2014/15). Accordingly, a Tourism Development Plan has been developed and approved for the municipality, which identifies tourism attractions within the area ranked by the population comparison with the northern KwaZulu-Natal (KZN) population attraction. Subsequently, Hluhluwe-Umfolozi was identified as a leading population attraction in northern KZN.

Approximately 10% of the households have access to piped water into the dwellings. The water supply to households has increased from previous years; however, most of the households still depend on streams for water (uMhlabuyalingana IDP, 2014/15). There are limited numbers of households with flush toilet sewer access (including septic tanks) except for Ezemvelo KZN Wildlife residential area, which has its own wastewater treatment plant. Between 2001 and 2007 an increase in the number of households with sanitation facilities was noted.

3.2 Mbazwana population demographics

The Mbazwana area consists of the Mbazwana, Thungwini (including Shazibe), Qondwane, Hagaza, Olakeni, Esiphahleni and Sodwana Bay residential areas **(Figure 3**). It falls within the Mkuze River catchment area forming part of the uSutu to Mhlathuze Water Management Area (WMA, uMhlabuyalingana IDP, 2014/15). Since Mgobezeleni catchment falls within Mbazwana, it has also experienced expanded development and an increased population. In 2011, the population was estimated at 8281 people, representing approximately 19% of the local municipal population. It was mostly dominated by black African (91.2%) and a small white population of 8.35% (SSA, 2011). In 2011, the number of dwellings was estimated at 1954, with a population density estimated at two persons per hectare. At that time, Mbazwana was the most populated residential area in the catchment consisting of one dwelling per hectare. The less populated residential areas were Thungwini, Esiphahleni and Sodwana Bay.

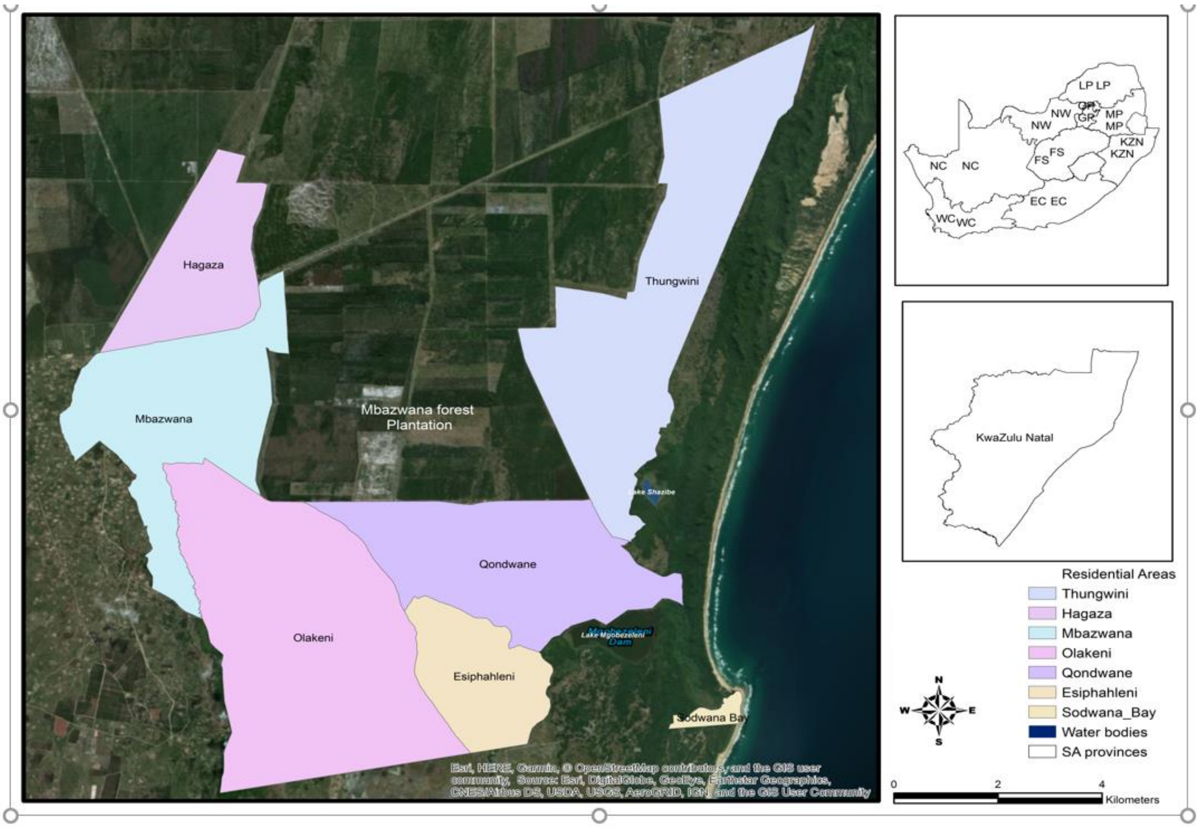

Figure 3: Mgobezeleni catchment residential areas (SSA, 2011)

3.2.1 Land use

The area is developing from a rural to a peri-urban settlement (**Figure 4 and 5**) and comprises commercial forestry, peri-urban centres, residential areas and ecotourism facilities. Several residential areas (greater than 1123 households) are serviced by the local municipality with metered water connections (DWAF, 2011), while some of households sourcing their own domestic water from private boreholes. The needs for domestic water supplies vary considerably for the different communities. Most of the water is utilised by the ecotourism facilities for the approximately 450 000 tourists who visit the area annually (Bate *et al*., 2016). These facilities generally source most of their water from private boreholes, although some supplement the water with harvested rainfall from roofs. Most of the residential areas, however, depend heavily on the local municipal water supply provided through a reticulated system.

The land use has a direct impact on the rainfall harvested through water interception, leading to an annual rainfall groundwater infiltration reduction. The harvested rainfall is, however, returned to the environment as wastewater. This wastewater eventually finds its way to the groundwater through wastewater disposal on land (after cleaning) and as domestic wastewater (from sanitation systems).

Figure 4: Rural settlement type of infrastructure (Kelbe *et al*., 2016)

The commercial forests are responsible for stream flow reduction activities (SFRA) which are having a significant impact on the groundwater quantity (groundwater level), causing fluctuations in the groundwater table (Bate *et al*., 2016). The common plantations responsible for SFRA are eucalyptus and *genus* Pinus trees.

The anthropogenic impacts of the Mgobezeleni catchment population growth and infrastructural development, if not properly managed, may eventually have adverse effects on the ecological functions and chemical composition of the aquatic systems. It will have marked negative impacts on the recreational activities, ecotourism, and important biodiversity.

3.2.2 Mbazwana Water Supply Scheme

The Mbazwana Water Supply Scheme supplies domestic water to Mbazwana town and its surrounding rural communities. It is the main source of reticulated domestic water in the area; however, frequent water cuts occur because of leakages and illegal connections. It comprises a water treatment works (WTW), which receives its water from the Lake Sibiya pump station. The pump station is located approximately 12.5 km from Mbazwana town. The average WTW output is estimated at 1.53 Ml/day (560 Ml/a, DWAF, 2011). Raw water abstraction, including groundwater use for the scheme, has been estimated at 1.74 Ml/day (630 Ml/a) based on the average per capita consumption and estimated water losses.

Figure 5: The peri-urban settlement type of infrastructure (Kelbe *et al*., 2016)

The scheme is permitted to abstract 183 Ml/a of raw water from Lake Sibaya. It is equipped with water screens, a raw water pump station (with a capacity of 33.5 l/s or 2.65 Ml/day based on 22 hours of pumping) and the WTW. The WTW consist of three pressure filters (rated at 40 kl/hr each) and chlorination facilities (**Figure 6**). The peak hydraulic design is 120 kl/hr (2.64 Ml/day) with an average annual flow rate estimated at 2.0 Ml/day.

Figure 6: Mbazwana Water Treatment Works (Bate *et al.*, 2016)

The raw water is pumped from the pump station to the WTW through a 12.5 km long, 150 mm and 250 mm diameter pipeline. On arrival at the WTW, it is passed through a set of filter media, similar in bed construction to open rapid gravity filters, which are contained in a steel pressure vessel (**Figure 7**). The filtered water is then chlorinated, before being pumped into two elevated reservoirs for distribution to the town and rural areas.

The total reservoir storage capacity of the scheme is 2.4 Ml. The capacities of reservoirs range from 0.2 Ml tanks to 1.0 Ml reinforced concrete (RC) service reservoirs. The capacities of the elevated pressure steel tanks are each 0.2 Ml. The service storage capacity provides for one to six days or 38-hours storage based on the 2011 gross average annual daily demand. In the summer months, the capacity is reduced to about 25-hours storage or 1-day storage based on the 2011 water requirement (DWAF, 2011). The water supply was considered to be a less than acceptable standard for a 48-hour summer peak requirement for an urban area (DWAF, 2011). The pump stations pump water from the main service reservoir to the villages of Manzimbomvu and Mbumbeni. All pump stations are equipped with standby capacity.

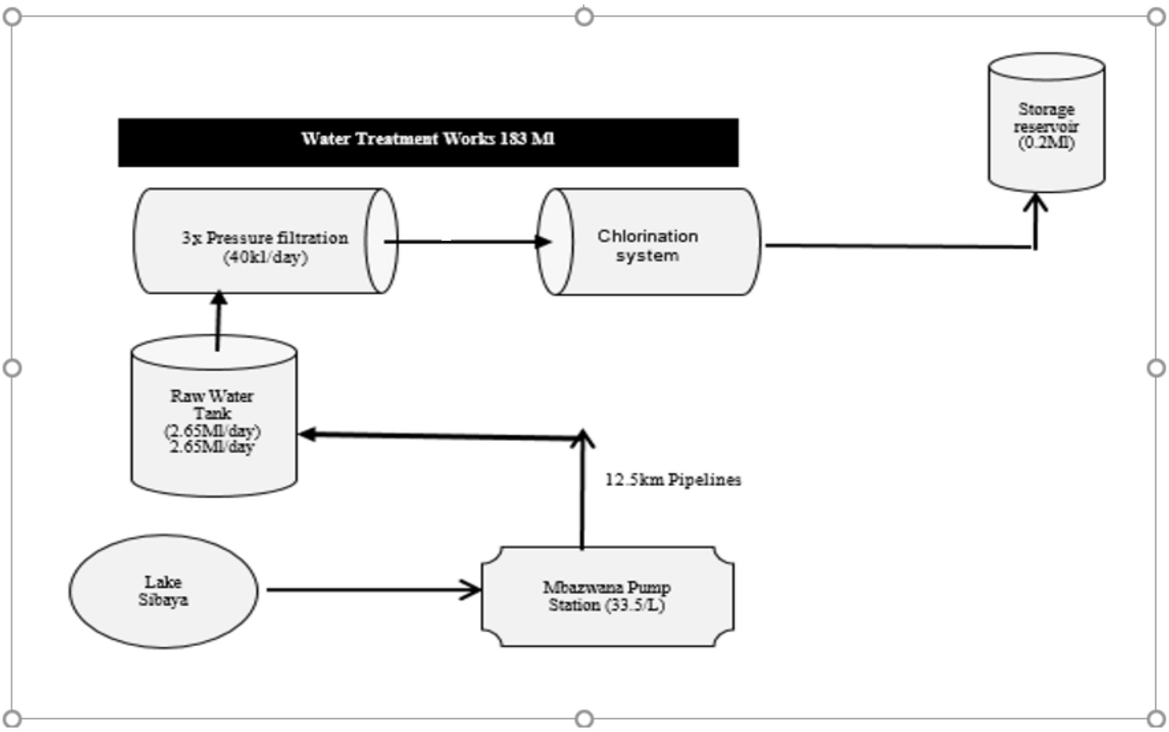

Figure 7: Mbazwana WTW flow diagram

A 2011 study by the Department of Water Affairs and Forestry (DWAF 2011) indicated that the water supply output of the Mbazwana WTW was sufficient to meet the water requirements of the Mbazwana population but that the plant output was insufficient to meet future needs. The reasons given included the growing population and the high percentage of water loss in the distribution networks. This water loss results from wastage, leakages from the distribution network and illegal water use/connections. The water losses were estimated at 30% of annual raw water abstraction of the 2008 consumption (DWAF, 2011). The percentage loss was anticipated to increase by 32% annually up to 2030. The 2011 water loss was estimated at 0.5 Ml/day (200 Ml/a) based on water use and operational practices.

Because of the breakdown of the water supply, some of the rural villagers, especially small businesses, are pumping water from their private boreholes. The private borehole drilling network has increased in the area, reducing the stress on the water scheme and providing jobs for local inhabitants.

3.2.3 Ezemvelo KZN Wildlife Water Supply Scheme

The tap water for the iSimangaliso Wetland Park is supplied by Ezemvelo KZN Wildlife Water Supply Scheme. The raw water is sourced from Lake Mgobezeleni located approximately 4 km from the Ezemvelo KZN Wildlife Water Supply Scheme WTW. Approximately 378 m^3 of raw water is pumped daily from the lake to a reinforced concrete (RC) raw water storage dam of 139 m^3 capacity. The water is passed through clarifiers equipped with a SUDFLOC chemical treatment facility (12.5 l/d) for water flocculation over a 12-hour working period (**Figure 8**). De-sludging of the raw water is done daily. Water from the clarifier is passed through sand filters, after which it passes through a chlorination process. The treated water is stored in an elevated steel reservoir tank of 0.2 Ml capacity before it is gravitated through pipelines to the residential areas, office complex and businesses.

Figure 8: Clarifiers at the Ezemvelo KZN Wildlife Water Treatment Work

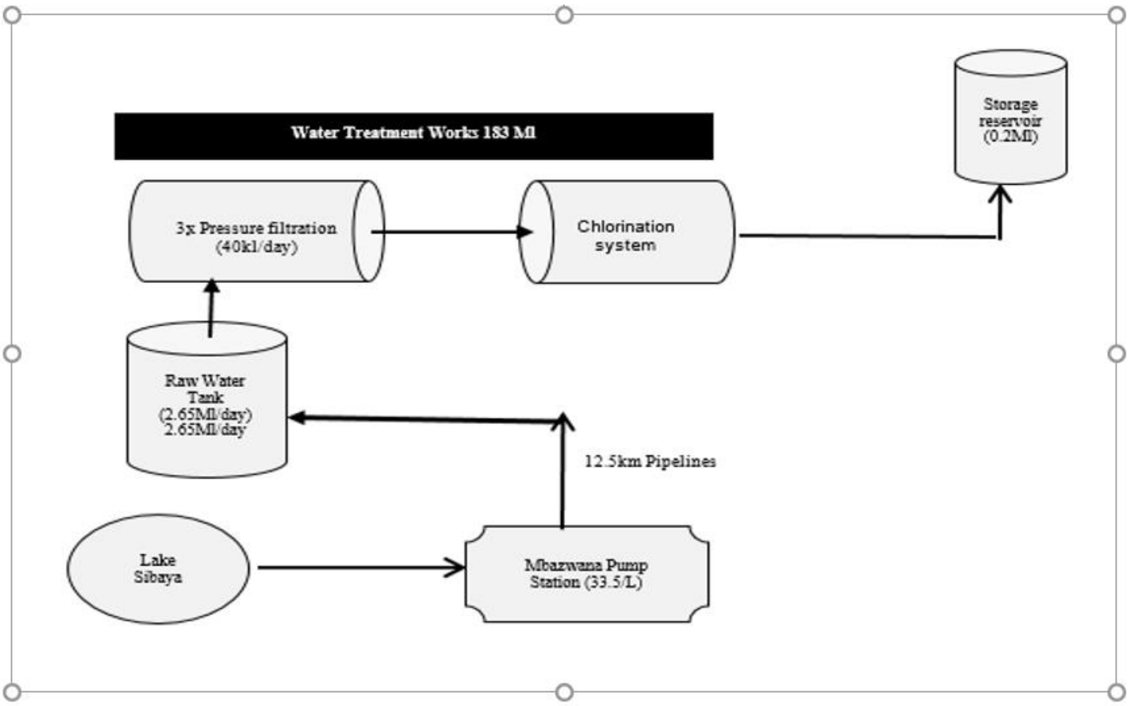

Figure 9: Water flow from Lake Mgobezeleni and Lake Shazibe (Kelbe, 2014)

3.3 Mgobezeleni groundwater

The Maputaland coastal plain has high yielding aquifers due to unconsolidated and unconfined alluvial, estuarine, aeolian sands and clay material (Worthington, 1978). The groundwater movement and the water table directly influence the vegetation patterns in the region. The region consists of shallow and deep aquifers of the KwaMbonambi Formation and the Uloa Formation respectively. The water table of the shallow aquifer depends on the landform and the annual rainfall (Sliva *et al.,* 2004).

The primary aquifers consist of unconsolidated sediments of the post Cretaceous period which are affected by regressive the sea-level cycles. This has resulted in paleochannels aligned with major drainage channels (Bate *et al*., 2016). Groundwater seepages elevate the water in the valleys forming permanently wet-conditions which promote peat accumulation (Grobler *et al.,* 2004). The vertical seepage rate of the soil is estimated at 0.1 m/day. Therefore, significant amounts of rainfall infiltrate and percolate into the groundwater. The groundwater in the Mgobezeleni catchment is eventually released into the drainage channel at a slow rate, thus forming continuous baseflow to the wetlands, streams and lakes (**Figure 10**). Therefore, any anthropogenic pollution in the study area has a high potential of reaching the groundwater storage and being discharged into the surface water resource as baseflow.

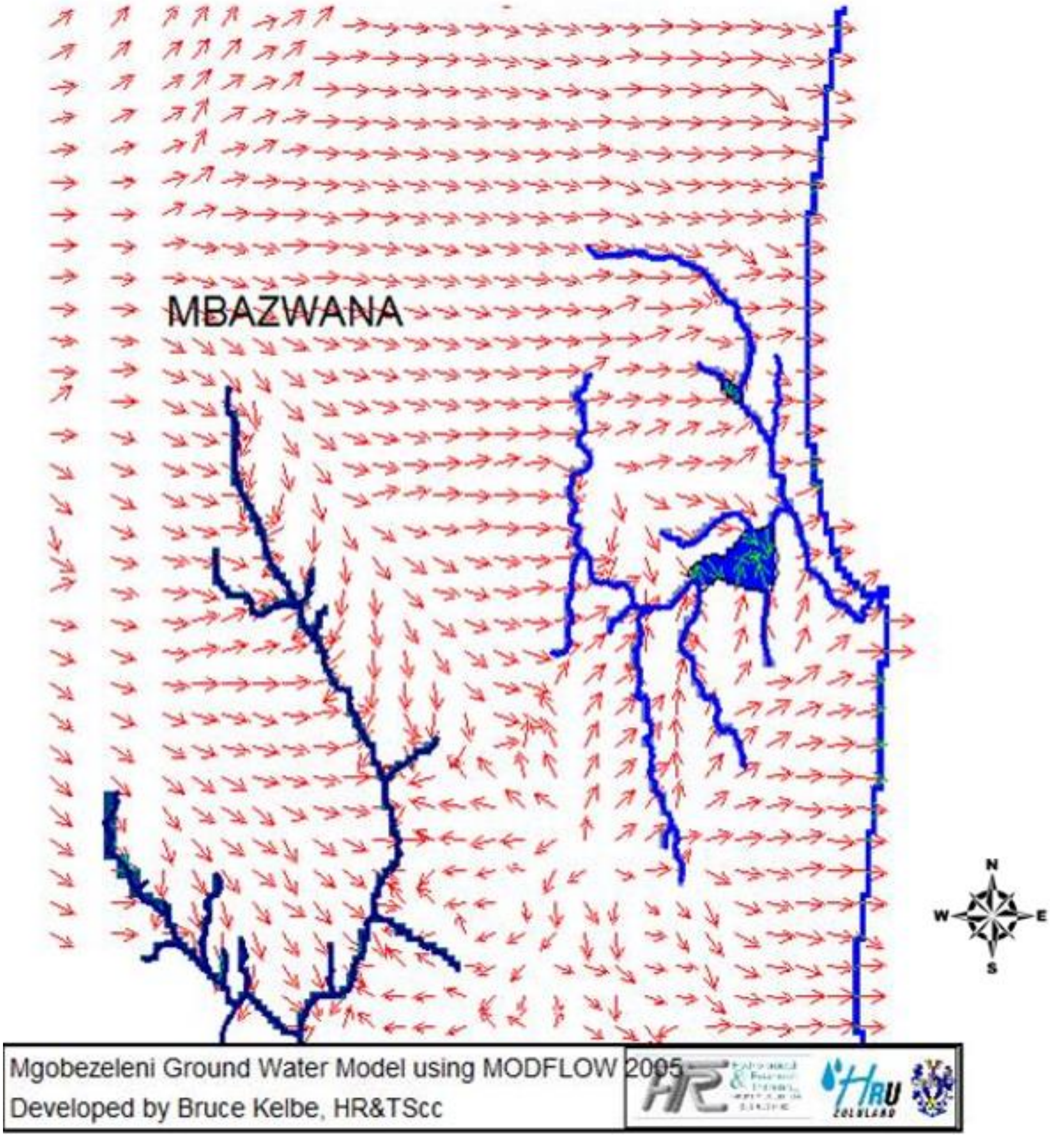

Figure 10: Mgobezeleni catchment groundwater flow directions (Kelbe, 2014)

The shallow aquifer of the KwaMbonambi Formation is used for the domestic water supply to the local communities. The shallow and deep aquifers water yield rates are given in **Table 2**. The primary aquifers are, however, being over-exploited by various developments (including human settlements) taking place along the coastal plain (Campbell *et al.,* 1992). This has resulted in deterioration in the water quality of the primary aquifers. The region has various groundwater-fed water supply schemes of small to medium scale from Sodwana Bay to Kosi Bay. They include small agricultural water supply initiatives and a school water supply of approximately 5 m^3/day (DWAF, 2012).

The high groundwater supply schemes include Coastal Cashews Farm and the major groundwater fed or augmented Water Supply Scheme of KwaNgwanase. These schemes have a domestic water consumption of up to 1000 m^3/day. The groundwater levels and discharge in the entire region has not been properly monitored (DWAF, 2012).

The primary aquifers receive approximately 50% of the annual rainfall from direct recharge. The storage capacity of the primary aquifers above the Cretaceous unit in the Mgobezeleni catchment was estimated at 70 000 Mm^3 (Bate *et al.,* 2016). The hydraulic gradient in the area influences the transport of solutes into the groundwater, while the groundwater discharge fluctuates with the water table. The groundwater flow in the eastern is towards the Indian Ocean and the western trend is towards the Mbazwana River, which flows towards St Lucia (Kelbe, 2014) (**Figure 10**). This creates a groundwater divide in the study area. In addition, there are localised internal and external boundaries in terms of the groundwater flow direction (**Figure 10**). The internal boundary forms the boundary of the study area.

Table 2: Borehole yields (DWAF, 2012)

Aquifer	**Stratigraphic Formation**	**Pump rate** (l/s)	**Pump Cycle** (hr/day)	**Daily Delivery**	**Early Transmissivity (T) FC** (m^2/day)	**Late Transmissivity (T) FC** (m^2/day)	**Late Transmissivity (T) FC** (Cooper Jacobs)
Shallow	KwaMbonambi	2.2–20	24	190–1728	3–5281	5.3–29.7	10 –5544
Deep	UMkwelane/Uloa	0.45–17.5	10–24	38.9–670	7.0–5249	5.2–560	5.1–547

The water table in the Mgobezeleni catchment is very dynamic; it affects the dimensions of the unsaturated zone and hydraulic gradient which in turn influence the groundwater flow rate in the aquifers. Based on the conceptual model of Kelbe (Bate *et al*., 2016), the water table head in the upper layers of the Kosi Bay Formation differs significantly from the head in the Uloa Formation due to the confining intermediate layer of the Kosi Formation. The groundwater recharge rate is very slow especially in the Mbazwana area; the recharge is only visible as baseflow in the streams and lakes after several decades (Bate *et al*., 2016). Therefore, contaminants from anthropogenic activities of the past 10 to 20 years are still present in the aquifer. The pathways of the surface contaminants are restricted or slowed down by the upper KwaMbonambi Formation. These pathways are localised in the KwaMbonambi Formation (shallow aquifer. The recharge from the surface layers into deeper aquifers is estimated at less than 20%. Both private boreholes and streams are anticipated to suffer a significant drawdown as a result of the forested plantations. The total drawdown was estimated at 30 Mm^3 per annum in 2015 (Bate *et al*., 2016).

The groundwater in Mgobezeleni catchment is vulnerable to N and P pollution from natural and anthropogenic sources. Nitrogen is assumed to be well preserved by mature natural forests. However, it can contaminate the groundwater when the natural forests are disturbed by man. The groundwater contamination caused by natural forest disturbance is relatively insignificant in relation to the impact caused by sanitation systems and other agriculture activities (Hallberg and Keeney, 1993).

Domestic waste is one of the anthropogenic sources of nitrogen contaminating the groundwater, while human, animal and industrial waste are major sources of nitrogen and phosphorus contaminating the groundwater. The main sources of nitrogen and phosphorus around the world are pit latrines and septic tanks and groundwater contamination generally relates to the concentration of sanitation systems (Hallberg and Keeney, 1993). Therefore, anthropogenic sources are the major cause of elevated nutrient levels in the groundwater.

3.4 Surface water resources

The Mgobezeleni catchment consists of a river, small perennial streams, coastal lakes (Lake Mgobezeleni and Lake Shazibe), a small estuary (Mgobezeleni Estuary), wetlands and pans. Because of the existing groundwater divide in the catchment area, this study focuses on the Mgobezeleni catchment which drains towards Lake Mgobezeleni, Lake Shazibe and the Mgobezeleni Estuary. Hence, the Mbazwana River does not form part of the study area because it drains towards St Lucia (**Figure 11**).

3.4.1 Small perennial streams

Streams are situated in the northern, southern and western parts of the catchment, approximately parallel to the interdunal depressions (**Figure 11)**. They all drain towards the lakes and the estuary through very low gradient swamp forests (Kelbe *et al*., 2016). The upper parts of the streams are generally semi-perennial while the lower parts are perennial. They are all directly fed by the groundwater and are underlain by peat deposits under dense vegetation. The vegetation near streams ranges from herbaceous to woody.

3.4.2 Lake Mgobezeleni

Lake Mgobezeleni is situated on the southern side of the catchment and upstream from the Mgobezeleni Estuary (see **Figure 11)**. A portion of the Lake is protected under the iSimangaliso Wetland Park World Heritage Site. It also located downstream from the Qondwane residential area. It is subtropical, and a topographically open system isolated from the sea. Kelbe (2014) indicates that there is a paleo-drainage channel from the Lake into the sea. The Lake has a total surface area of approximately 93 ha (0.93 km^2), a perimeter of 4.6 km, and a length of 3.3 km (from inlet to outlet). The water level in the Lake generally fluctuates, ranging from 3.16 to 3.69 mRL (metres above a relative level) with an average water level of 3.36 mRL (Bate *et al*., 2016). It has an average depth of 4.6 m.

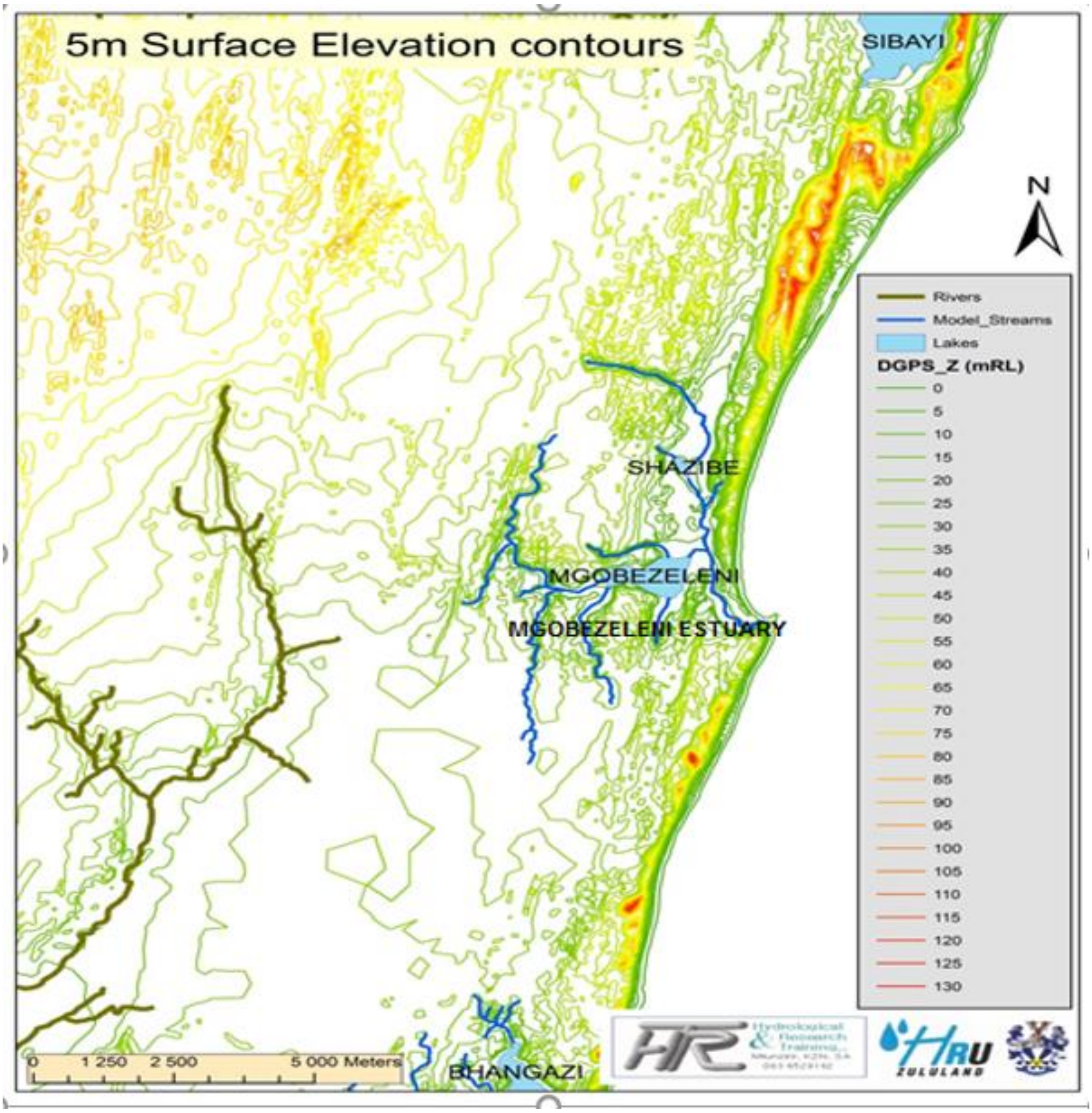

Figure 11: Location of the coastal lakes in Mgobezeleni catchment (Bate *et al*., 2016)

The Lake is warm in temperature ranging from 19 °C in winter to 30 °C in summer. The strong summer and winters winds make the Lake relatively turbulent. It has been classified as being brackish due to chloride concentration. The high chloride concentration is associated with recent cyclic salt input from the sea or from fossilised material in Tertiary sediments of the underlying basin (Allanson and Van Wyk, 1969). The dissolved oxygen (DO) concentration is generally close to saturation even in the deep layers of the Lake (Bolt, 1969).

The Lake is directly supplied by four groundwater-fed perennial streams (**Figure 11**), as well as groundwater base flow. The Lake outflow after joining with Lake Shazibe water outflow drains into the

Mgobezeleni Estuary through a very low gradient stream which has been converted into a channel (Bate *et al*., 2016). It is surrounded by dense sedge and woody swamp forest with large peat deposits. Falling leaves from the woody vegetation surrounding the Lake are deposited inside the lake. No submerged macrophytes were observed inside the Lake except for those located near the outlet.

The Lake is also surrounded by wetlands such as Sangweni Pan on the southern side, Bhekaphandle Wetland on the western side and Qondwane on the north-eastern side. Wetlands are rich in peat deposits causing the Lake to be dystrophic (contains *blackwater*). The Lake is assumed to be oligotrophic (low in nutrients) owing to the lack of vegetation growth in it. The water from the Lake is abstracted to supply raw water to the Ezemvelo KZN Wildlife WTW. The treatment plant provides potable tap water to Ezemvelo KZN Wildlife residential area.

3.4.3 Lake Shazibe

Lake Shazibe is situated on the north-eastern side of the catchment, upstream from the Mgobezeleni Estuary, approximately 5 km south of Lake Sibaya and 8 km east of Lake Mgobezeleni. It was formed in an interdunal depression (**Figure 11**) and is also located downstream of the Sodwana Bay Lodge ($\leq$500 m).

Lake Shazibe is the smallest lake in the catchment and is sometimes referred to as a pan. It is subtropical and is a topographically open system isolated from the sea. Kelbe (2014) indicated the presence of a paleo-drainage channel from the Lake into the sea. It has a total extent of approximately 8 ha (0.8 km^2), a perimeter of 1.3 km and a length of 1.2 km (from inlet to outlet). The water level in the Lake is estimated at 3.86 mRL (Bate *et al*., 2016). It has an average depth of approximately 3 m.

The Lake is directly recharged by two groundwater-fed streams, as well as the groundwater baseflow. The main tributary of Lake Shazibe is a perennial spring stream, flowing past Tolla se Gat (Tolla se Gat road crossing), known as the Thungwini stream. The stream passes through a dense swamp forest prior to draining into the Lake. The swamp forest between the upstream spring and Tolla se Gat road crossing is called the Thungwini swamp.

The Lake Shazibe outflow passes through a quite dense woody swamp forest before reaching the Sodwana road crossing. The water tends to dam up at the culverts owing to the restricted outflow under the culverts at the main road to Sodwana. The damming of the water has resulted in an extensive swamp forest underlain by thick peat deposits (Bate *et al*., 2016). The peat swamp is called the Culvert swamp. After the culvert crossing, the Lake outflow joins up with the Lake Mgobezeleni outflow and passes through a dense low gradient channel to the Estuary. The wetlands are rich in peat deposits causing the lakes to be dystrophic. Further, the Lake Shazibe is assumed to be eutrophic (high in nutrients) owing to the presence of the submerged and fringing macrophytes.

3.4.4 Mgobezeleni Estuary

The Mgobezeleni Estuary is situated on the eastern side of the catchment, downstream from the two lakes (**Figure 12**). It is located north of the St Lucia Estuary and south of the Kosi Bay Estuary. The Mgobezeleni Estuary has a maximum width of 5 m and average depth of 0.31 m. It is connected to the lakes by a dense sedge and woody swamp forest. The mouth of the Estuary is influenced by tides, usually by high tide overwash. There is normally a small shallow outflow channel which opens and closes regularly. The estuarine mouth is located approximately 3.5 km downstream from the confluence of the two lakes (Bate *et al*., 2016). The Estuary is classified as a temporary open/closed estuary for some purposes but owing to the whole area being below the 5 mamsl mark it can also be considered an estuarine lake system according to the National Water Act (Act No. 36 of 1998).

The Estuary receives water mainly from a stream that passes through a dense swamp forest from the two upper lakes. The swamp forest is hydraulically connected to the regional water level (Bate *et al*., 2016). The stream inflow controls the salinity in the estuary and the sediment dynamics of the estuary mouth.

The water level at the bridge when the mouth is closed reaches a maximum height of 3.27 mRL (Bate *et al*., 2016). A large amount of water is released during mouth breaching events which results in a significant drop in the water level at the bridge. The floodplain of the Estuary contains deep decaying layers of vegetation with high hydraulic conductivity (Bate *et al*., 2016). The prevailing high water table and the woody vegetation surrounding the estuary are the cause of the development of the peat swamp forests.

3.4.5 Wetlands

The study area consists of lacustrine, palustrine stream and estuarine wetlands directly controlled by the groundwater (**Figure 12**). These are located on the northern side of iSimangaliso Wetland Park and on the eastern side of the catchment. Wetlands in the area are associated with the shallow water tables of the interdunal depressions (Bate *et al*., 2016). All these wetlands are rich in peat deposits of various depths.

Palustrine wetlands occur in the interdunal depressions. A number of pans have been observed on the eastern side of Lake Shazibe stream draining towards the south away from the Lake (Bate *et al*., 2016).

Sangweni Pan is located on the southern side upstream from Lake Mgobezeleni (**Figure 12**). Sangweni Pan is frequently grazed by cattle, which increase the nutrient composition through animal droppings. Water in Sangweni Pan is dystrophic. KwaZikhali Pan is located south of Sangweni Pan and is also frequency grazed by livestock. It was dry during the study period and is affected by wildfires.

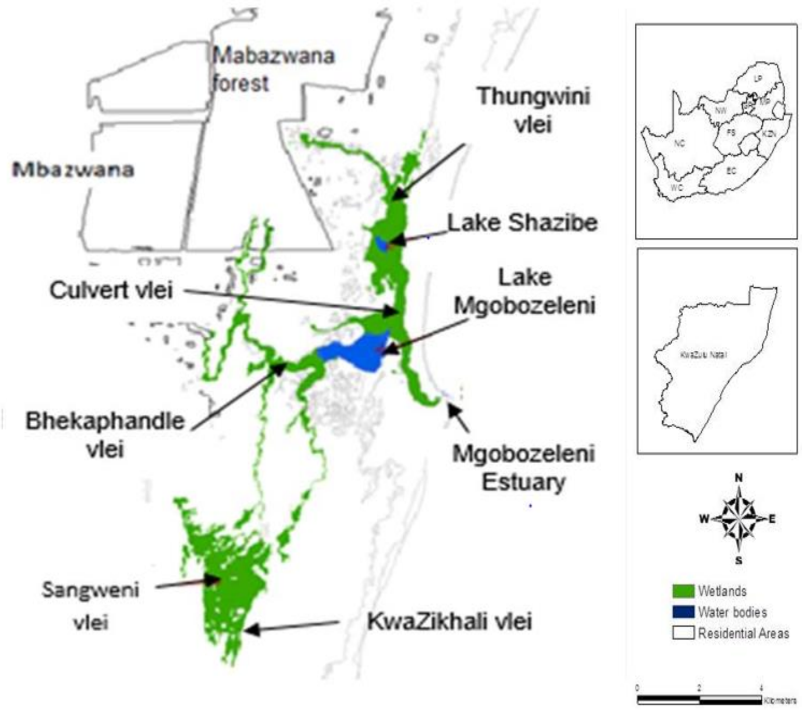

Figure 12: Location of the wetlands in the catchment (Kelbe *et al*., 2016)

Lacustrine wetlands are associated with Lake Shazibe and Lake Mgobezeleni and estuarine wetlands are associated with the Mgobezeleni Estuary. The intervalley wetlands are associated with Lake Shazibe (Thungwini swamp), Lake Mgobezeleni (Bhekaphandle and Qondwane swamps) and the downstream Lake Shazibe outflow stream (Culvert Swamp). These wetlands, together with Sangweni Pan and KwaZikhali Pan, were assessed for peat chemical composition and water quality during the study.

3.5 Biodiversity

The study area falls under the Maputaland biodiversity region. The Maputaland region is situated within the coastal Bushveld/Grassland Biome of Southern Africa (Low and Rebelo, 1996). It is rich in flora and faunal species (Moll, 1980; Harrison *et al*., 1997; Stattersfield *et al*., 1998; WWF, 2001).

Floristically, the area forms part of the Tongaland–Pondoland Region Mosaic (Meadow, 1985). It is an internationally renowned area for its biodiversity. The biodiversity in the region extends from the Coastal Forest Mosaic to Mozambique in the north (WWF, 2001). It consists of approximately 2500 plant species/interspecific taxa (with a minimum of 225 species or infraspecific taxa being endemic or near-endemic to the centre). There are more than 472 species of birds in the region, approximately 60% of which are South African, while four species and approximately 43 subspecies are endemic or near endemic. There is a high proportion of endemic plants of which 9.2% are vascular plant species (Moll, 1980; Van Wyk, 1994; Harrison *et al*., 1997; Statterfield *et al*., 1998; WWF, 2001, Van Wyk *et al*., 2001). Endemic or near-endemic species and infraspecific taxa also include 14 species of mammals, mainly of sub-specific rank, 23 species of reptiles, three species of frogs and eight of 67 species of freshwater fish (Van Wyk, 1996).

The diverse mosaic consists of forests, woodlands, grasslands, swamps and coastal habitats. The vegetation in this region has been classified into 15 major types, ranging from the coast with grasslands and dune forest through various types of bushveld, sand forest and swamps to forest on the Lebombo Mountain Range (Moll, 1980). The study area also includes commercial forests of timber. The forests are mainly responsible for stream flow reduction in the area, thereby removing nutrients in the groundwater storage and channels. Eutrophication of the hydrological system will have an adverse impact on this ecology.

3.6 Climate

The Mgobezeleni catchment is located in sub-tropical coastal conditions (Matthews, 2001). The area is controlled by migrating low current and anticyclone circulation from the Indian Ocean (Garstang *et al*., 1987). The climate is moist subtropical along the coast and dry subtropical a short distance inland.

The summer rainfall is influenced by subtropical anticyclones while the winter rainfall occurs as a result of the cold fronts that migrate from the south up the east coast, influenced by mid-Atlantic cyclones (Kelbe, 1988). Bate *et al*. (2016) identified the mean annual rainfall between 2000 and 2015 for Sodwana and Mbazwana to be 1066 mm and 811 mm respectively. The precipitation is seasonal and generally increases eastward towards the coast. Most of the rain falls during the summer, although summer droughts frequently occur. The average winter rainfall is approximately 25 to 30% of the average summer rainfall (Kelbe *et al*., 2001). The area receives rain almost all year round (Meadows, 1985).

It is hot and humid (< 75% between November and February) in summer, cool (22 °C), drier and frostless in the winter (Meadows, 1985; Kellerman, 2004). The daily temperature varies between 5 ˚C to 36 ˚C with an average mean daily temperature of 21 °C (Bate *et al.,* 2016).

Heavy dew and dense mist occur during the winter; the dense valley mists generally occur during the morning resulting in heavy dew with occasional light showers (Gaugris *et al*., 2004; Matthews *et al.,* 2001). The prevailing wind direction is NNE to E and SW to W with the mean monthly wind velocity varying between 0.6 m/s to 2 m/s (Bate *et al.*, 2016).

3.7 Geology

The study area falls within the Maputaland Coastal Plain Formation. The area comprises of soils of the Mesozoic and Cenozoic ages that continue to the north and south along the Mozambican Coastal Plain. The geology of the area consists of Quaternary and Tertiary sediments of the Maputaland Group which overlay flat to undulating Cretaceous sandstones. The Cretaceous sandstones are predominantly underlain by marine siltstones as base material forming part of the St Lucia Formation.

A decline in sea levels resulted in the marine strata being elevated above mean sea level (Botha, 1997). The strata are now eroded and exposed along the banks of the main river valleys in Zululand (uMfolozi, uMzinene and Mkuze) and around sections of the coastal lakes. The continental shelf of siltstones and mudstone marine strata has low hydraulic conductivity and storativity. The Cretaceous unit acts as an aquiclude and contains salty water and forms the base of the Mgobezeleni catchment aquifers (Bate *et al*., 2016). The siltstone material is overlain by calcrete deposits of Uloa and UMkwelane Formation of the Maputaland Group (see **Figure 13)**. These in turn are overlain by dune sands of the Maputaland Group of early Pleistocene (fossilised as old dune sediments) and late Pleistocene.

3.7.1 Cretaceous Period

The late Cretaceous Period is underlain by Jurassic basalt and rhyolite rocks and overlain by a sequence of sediments generally sloping eastwards at an angle of 3º (Botha *et al*., 2013; Botha, 2015). During the late Cretaceous Period, Jurassic basalt and rhyolitic rocks were submerged below sea level (Worthington, 1978). Sediments were deposited along the continental shelf to form marine siltstones and mudstone.

3.7.2 Miocene-Pliocene

The Cretaceous and Paleocene siltstones are overlain erratically by relatively thin Miocene sediments. The Miocene unit in Umfolozi has been termed the "Uloa Formation" in recent geological classifications (**Figure 13**) Maud and Orr (1975). The Uloa Formation generally consists of fine grain sediments with low permeability, thus creating leaky aquifers (Bate *et al*., 2016). Maud and Orr (1975) describe the Miocene strata as comprising a lower coquina (Uloa Formation) and an upper calcarenite (UMkwelane Formation) which constitute the main aquifers in the study area. The coquina rests uncomformably on the marine siltstones. It is hard and gravel with abundant mollusc fossils. The top of the Cretaceous layer frequently contains pebble-rich glauconite derived from the underlying siltstones. The Uloa Formation generally consists of fine grain sediments with low permeability, thus creating leaky aquifers (Bate *et al*., 2016). The UMkwelane Formation consists of coarse light-greenish grey sand interlayered at the base by calcareous sandstone/calcarenite with shell fragments. The Uloa Formation contains calcrete with numerous shell fragments (DWAF, 2012). Other areas contain peat material interlayered with sand and clay material.

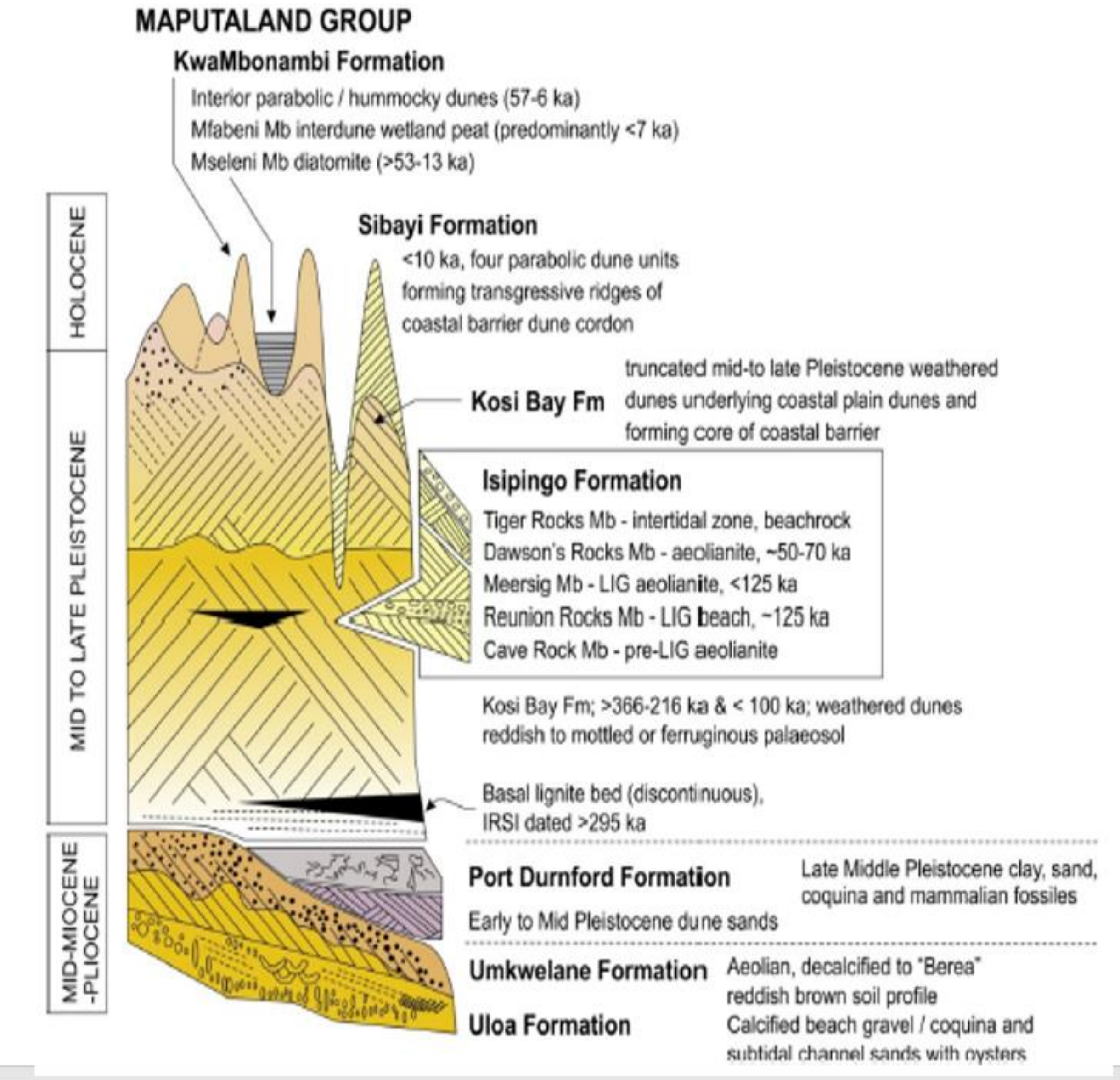

Figure 13: Vertical schematic diagram of the Maputaland Group lithostratigraphic units (Botha, 2008)

The upper surface of the coquina was subjected to karst solution weathering during the deposition of the overlying calcarenite. The coquina is generally yellowish-brown in colour and is frequently leached.

The calcarenite is a hard light-grey sandy. Its lowermost section is coarse and well-bedded. The upper part is typical aeolian sand with steep cross-bedding karst solution. The weathered upper surface of the calcarenite was observed in the Mhlathuze flood plain (Worthington, 1978). The dunes sands are the youngest marine formation in Southern Africa. The coastal plain is characterized by an undulating dune landscape on the low-lying coastal plain, with sand covers forming north–south orientated parabolic dunes on the coastal plain.

3.7.3 Pleistocene deposits

A prominent lignite bed of about 1.3 m thickness can be traced northwards from the south of the Port Durnford lighthouse to north of Mbonambi Beach (**Figure 13**). In other places, its composition is in the form of carbonaceous sand and it is occasionally split into several thinner beds by clean quartz sand of up to a metre in thickness (Worthington, 1978). The elevation of the lignite band varies from about 2 to 4 mamsl. The uppermost arenaceous member (Kosi) is comprised predominantly of aeolian facies with large-scale cross-bedding. It is generally white, yellow or yellowish-orange in colour and is predominantly fine grained. Discontinuous thin beds of carbonaceous sand and lignite occur at various levels (Worthington, 1978). The thickness of the uppermost arenaceous member at the coast is about 15 m with a surface elevation of up to 20 mamsl.

The total thickness of the Port Durnford and the Kosi Bay Formation is believed to reach 25 to 30 m at the coast (Worthington, 1978). However, as the unit grades westwards into a variable succession of sands, clays and silts, it becomes extremely difficult, if not impossible, to distinguish between the uppermost part of the Port Durnford Formation and the underlying Holocene sands. For this reason, the western limit of the formation could not properly be defined although it is almost certain that the inland areas are essentially the result of the Port Durnford deposition (Worthington, 1978) (**Figure 13**). However, the most extensive development almost certainly occurs offshore, as fragments of this material are frequently washed up onto the beaches (Worthington, 1978). This has been grouped with other aeolian sands under the name "KwaMbonambi Formation" in recent geological plans (**Figure 13**).

The Port Durnford Formation consists of marine clay, silt and sand deposits with lower hydraulic conductivity and storativity than the Uloa Formation. It comprises partially of confined leaky aquifers connected hydraulically to the Indian Ocean (Kelbe and Germishuyse, 2010). Kelbe (2014) indicates that there is an absence of the Port Durnford Formation in the study area.

3.8 Maputaland soils

Soils overlaying the entire Maputaland coastal plain are formed from aeolian and alluvial deposits of the Tertiary and Quaternary period. Soils together with the climatic conditions in the region influence the vegetation patterns. The physical and chemical properties of the soils are infertile responsible for the low agricultural potential (Maud, 1980) and soils are generally leached by the regional high annual rainfall (Von Harmse in Werger, 1978; Watkeys *et al*., 1993). Bate *et al*. (2016) indicated that the inland palaeodune sands have low surface runoff due to high permeable soils. Young soils have limited vertical mixing (Kelbe and Germishuyse, 2010).

Soils in the Maputaland region are highly permeable thus limiting surface runoff processes and inducing rapid water infiltration to the shallow aquifers (Bate *et al*., 2016). The permeability of the soils promotes rapid infiltration of pollutants into the groundwater. Hence, the rainfall percolates through the sediments and collects in the interdunal valleys. The interdune valleys have a high-water table, causing the soil to be waterlogged. This has resulted in the formation of peat swamp forests which have resulted from the interaction between vegetation and hydrology. The high-water table of the interdunal depressions is due to the impermeable Pleistocene age of the Port Durnford Formation (Maud, 1980). The interdune depressions have well-drained, yellow Clovelly or grey Fernwood soils (Matthews *et al.*, 2001; Gauring et al., 2004).

The soils of the shallow and deep aquifers consist mainly of fine to coarse grained sand with other areas comprising silt and clay material. In other areas they are coarse with gravel of limited extent in the KwaMbonambi and Kosi Formations. The dominant soils in the region are well drained with a high base status and are classified as being Hutton or Clovelly. Young soils are whitish while older sands are reddish to brownish with higher clay content. Older dune sands are dominated by woody vegetation where soils are dark greyish-brown with relatively high humus content (Weisser and Cooper, 1993). Dune sands consist of pure quartz with a high concentration of heavy minerals such as ilmenite, rutile, zircon and magnetite (Hobday and Orme, 1979).

The Mgobezeleni catchment consists of aeolian and fluvial sand deposits. Soils are well drained forming a large sand aquifer (**Figure 14**). This catchment area consists of 64% deep sandy and dystrophic soils of grey or yellow Fernwood Soil Form (Bate *et al*., 2016), (**Figure 14**). Wetland soils cover 12% of the area, comprising Champagne, Katspruit, Kroonstad and Longlands Soil Forms (**Figure 14)**. Soils are acidic with pH values ranging from 3.18 to 6.55 with a mean of 4.50. The inland has older sands. The young sands are sandy with no rocks and are well leached with little clay content. They are low in nutrient status and are generally acidic.

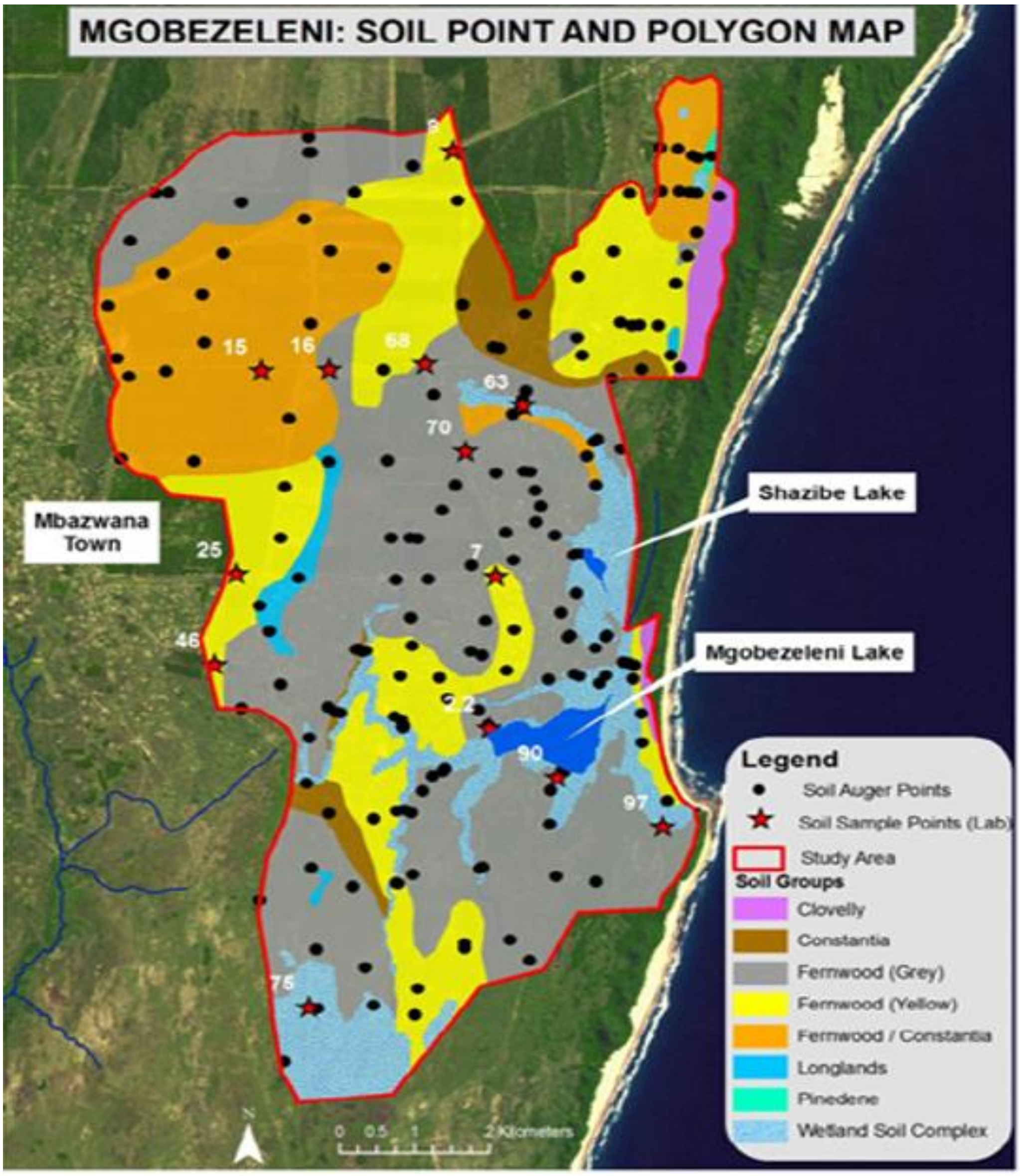

Figure 14: Soil classification of the Mgobezeleni catchment (Atkinson & Barichievy, 2015)

CHAPTER 4

EXPERIMENTAL PROCEDURE

4.1 Mgobezeleni catchment socio-economic survey

A decision was taken by the **WRC K5/2259** Project Team to investigate the socio-economic component using BSc. Hydrology postgraduate students from the University of Zululand. The Mgobezeleni population survey provides insight into the Mgobezeleni catchment demographics in terms of population growth, available municipal basic services (water supply, solid waste disposal and sanitation facilities) and the rate of new household establishment in selected residential areas. The selected residential areas for survey falling within the Mgobezeleni catchment were Mbazwana, Hagaza, Thungwini, Qondwane, Sodwana, Esiphahleni and Olakeni (**Figure 3**). The survey was conducted over a period of a year and involved two site visits.

The main objective of the survey was to determine the impact of population growth and the sanitation systems on the groundwater quality of the catchment through N and P composition. The following two methods were used for the Mgobezeleni catchment population demographic survey:

a) Establishment of the current total population and number of households in the catchment
b) Physical survey involving interviews with household residents for information collection. The information was used to establish the available social services and the rate of new household establishment.

4.1.1 Catchment population

The population size and number of households within the catchment area were obtained through a literature survey. The information was derived from the 2011 South African Population Statistics for all residential areas falling within the Mgobezeleni catchment (SSA, 2011). The population and household totals obtained from the 2011 Population Statistics for each residential area were then multiplied by 3.4% annually from 2012 to 2015 to obtain the latest population and household figures for each area (**Figure 15**). The current total population figures for all residential areas were added together to provide a total Mgobezeleni catchment population. This total excludes the tourists that visit the area, as only permanent residents of the areas were considered.

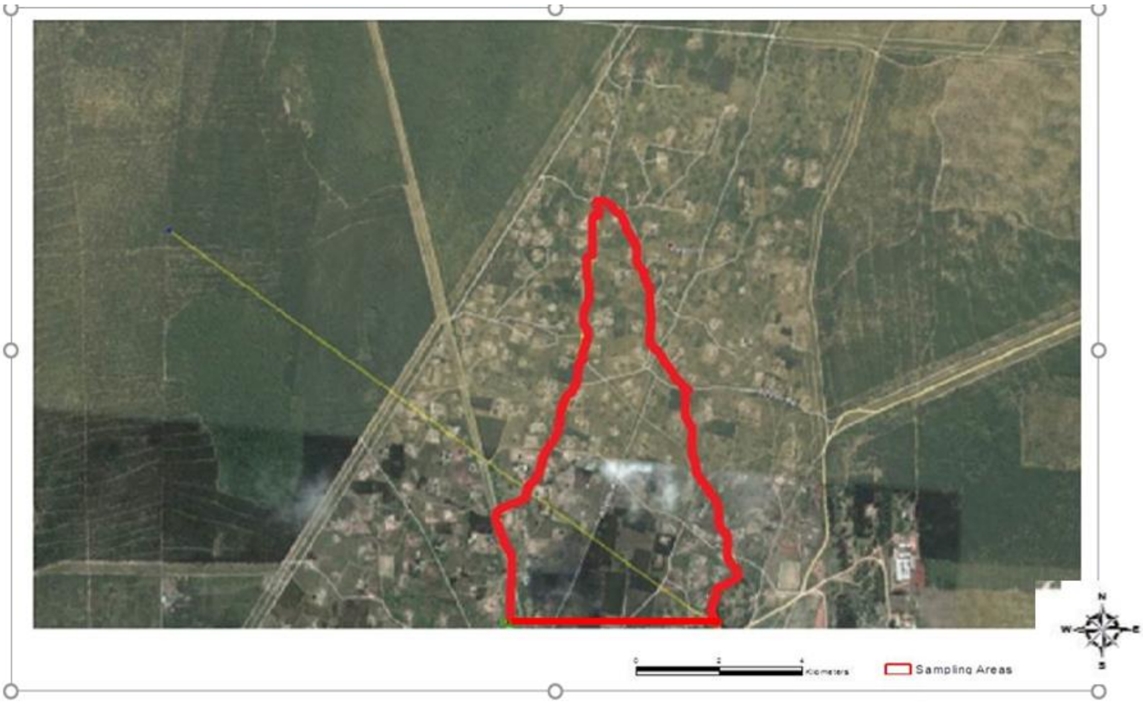

Figure 15: Sampled area surveyed for the available municipal services

4.1.2 Residential areas survey

The University of Zululand requested approval for undertaking the project from the local *izindunas* (local chiefs). The local authority also gave permission for the project to be undertaken in the catchment.

A questionnaire was developed to collect information from the residents of the residential areas. Households were selected based on their accessibility and the physical presence of people at the time of the survey. The following features formed part of the questionnaire:

a) Number of persons per household (adults)
b) Number of children per household (5 years and younger)
c) Sources for water use (taps, boreholes)
d) Solid waste management practices (municipal or individual disposal)
e) Sanitation facilities (septic tanks, VIP, pit latrine, bush)
f) Domestic animals (cattle, dogs, goats and chickens)
g) Gardening and use of fertiliser
h) New household establishment

The study commenced by giving the students thorough training in administering the questionnaires. Surveys were conducted during May 2014 and June 2015. The completed questionnaires were checked and all problems identified were discussed with the students daily during the survey. All the information collectors were fluent in IsiZulu which ensured better information collection and, in general, everyone interviewed cooperated with the survey. The information collected was subsequently converted into a useable format for the assessment.

A total of 119 households were visited in residential areas (**Figure 15**). Social services were found to include domestic water supply, waste removal practices and sanitation facilities. New household establishment status was based on the number of new households that were under construction during the time of the survey.

4.2 Groundwater, tap water and rainwater quality assessment

The main aim of the assessment was to evaluate the levels of anthropogenic pollution in the groundwater arising from the use of sewage disposal facilities in the catchment. The impact of the sewage effluent disposal on the groundwater (increased nutrient loading through percolation) was anticipated to be higher in the densely populated areas such as Mbazwana, Thungwini and Qondwane. Nitrogen (N) and phosphorus (P) concentrations were used as indicators of anthropogenic effects in the groundwater.

In addition, the following were evaluated:

a) Tap water leakages impacts into the groundwater. This was assessed by comparing the tap water quality with the groundwater quality.
b) The impact of atmospheric pollution on the groundwater was assessed on the basis of the rainwater quality.

4.2.1 Sampling method and Field measurements

Samples were collected using Quality Domestic Water Supplies-Volume 2: Sampling Guide (DWAF, 2000). Samples were collected by a team of postgraduate students from the Hydrology Department of the University of Zululand, using plastic water sampling bottles (500 ml) which were rinsed three times with the sample prior to sealing the sample with a cap to eliminate potential contaminants. No sample preservatives were used. After collection, samples were stored in a cooler box before being sent to the accredited laboratory for analysis.

a) Groundwater sampling

Samples were collected from private boreholes in Mbazwana, Qondwane, Thungwini, Mtanenkosi, Olakeni and Hagaza (**Figure 15**). Sodwana Bay and Esiphahleni were excluded because of low population densities. The DWS monitoring boreholes were also not accessible for sampling (locked) and thus sampling was limited to private boreholes (**Figure 16**). The water was collected directly from the pump or from the taps supplied by the pumps in the residential areas (**Figure 17**). Households with private boreholes at Mtanenkosi, Olakeni, Mbazwana and Hagaza were limited in numbers due to their reliance on the water supply from the Local Municipal. Therefore, boreholes sampled in these residential areas were classified as Mbazwana boreholes in this study.

A total of 72 samples were collected in the catchment from the Qondwane (37), Mbazwana (16) and Thungwini (19) residential areas. Only some of the boreholes were analysed in the field for physical parameters (pH, temperature, salinity, turbidity, DO, EC and TDS) using the Aquaread AP 7000 multimeter probe.

Figure 16: Groundwater water sample collected from private boreholes (Bate *et al*., 2016)

b) Tap water sampling

The tap water was collected during the study from Lake Sibaya pump station and at the Mbazwana WTW before it was processed (as raw water). In addition, collection from households' taps and pipelines was classified as processed water.

c) Rainwater sampling

The initial plan was to install rainwater collection systems in the residential areas and to appoint community members to collect rainwater on rainy days. However, owing to a lack of rain over the sampling period, we resorted to collecting water from rainwater harvesting in the area (**Figure 18**). At the time of the survey only one sample was collected during a rain event.

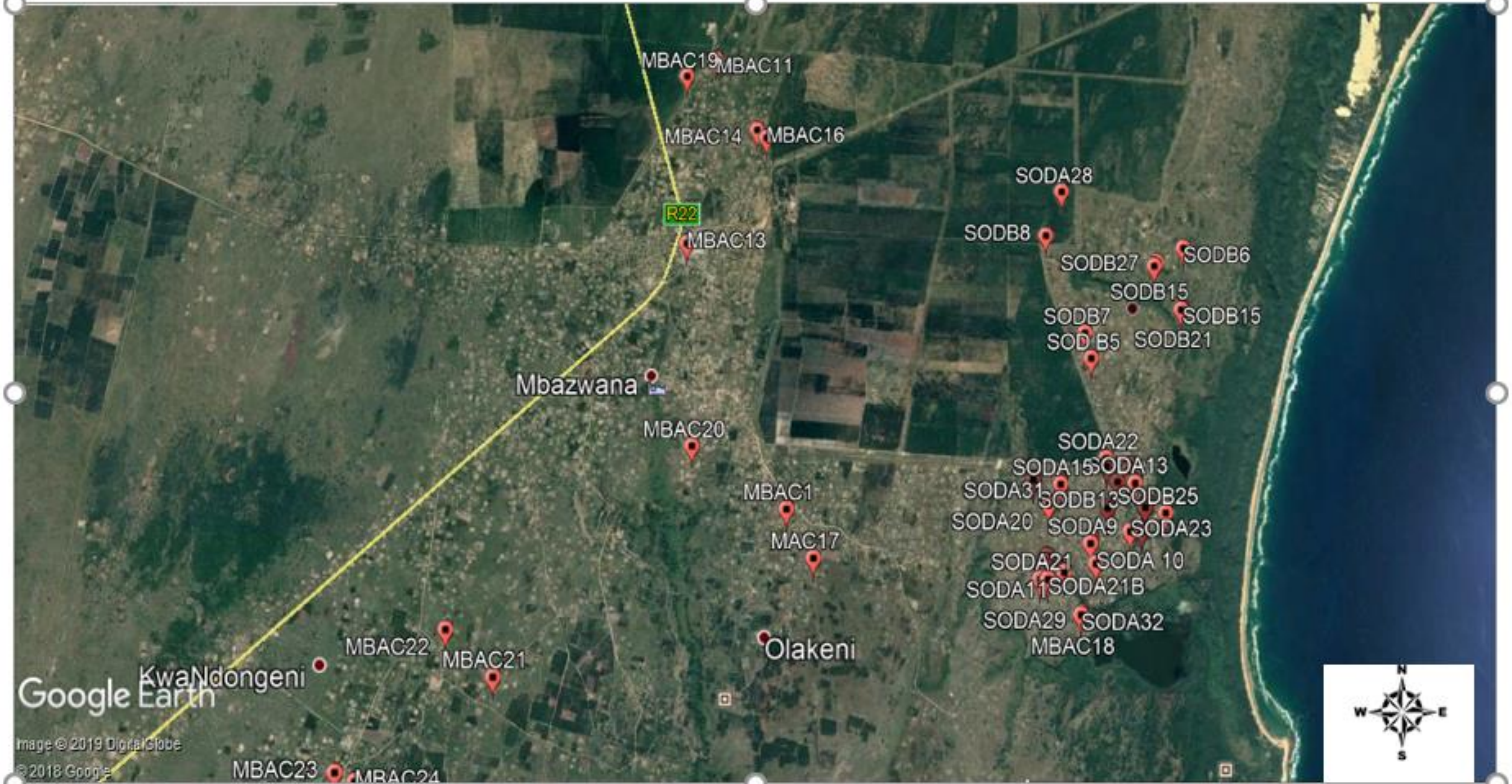

Figure 17: Groundwater sample collection points from private boreholes

Figure 18: Rainwater collection point in Mgobezeleni catchment (Bate *et al*., 2016)

4.3 Lakes and Estuary water sampling

This section discusses the water sampling method used for Lake Mgobezeleni, Lake Shazibe and the Mgobezeleni Estuary. The two lakes and the estuary were included in this survey to trace the pollution plume in the surface water resources of the catchment using N and P concentrations. A sampling protocol was accordingly developed for collecting water samples in the lakes and the estuary (**Figure 19**). The main aim of sampling was to establish the hydrochemistry of the systems and to determine the level of eutrophication.

4.3.1 Sampling method

These systems were sampled at different depths of the water column to determine the water quality at the various layers. They were sampled from surface level (about 15 cm depth) to bottom levels (about 0.5 m to 3 m depths using a pop bottle). Samples were collected in September 2013, June 2014, and June and July 2015 during a major drought in the area. They were sent to Yanka Laboratories (SANAS accredited laboratory) for nutrients, physical and chemical (including organic) analyses. The results were subsequently applied to check the pollution levels in the resources against the aquatic ecosystem quality requirements using the South African Target Water Quality Guideline (TWQG) Limits (DWAF, 1996).

a) Lake Mgobezeleni

Water samples from Lake Mgobezeleni were collected at depths of 15 cm, 0.5 m and 3 m (**Table 3** and **Figure 20**). Subsurface level samples were collected by means of a 750-ml pop-bottle (a weighted cork stoppered sample collecting bottle with a depth measuring tape) and a canoe. The sampling procedure involved submerging a pop-bottle over the side of the canoe to a pre-determined depth, after which a sharp jerk on the rope was exerted to remove the cork to collect water.

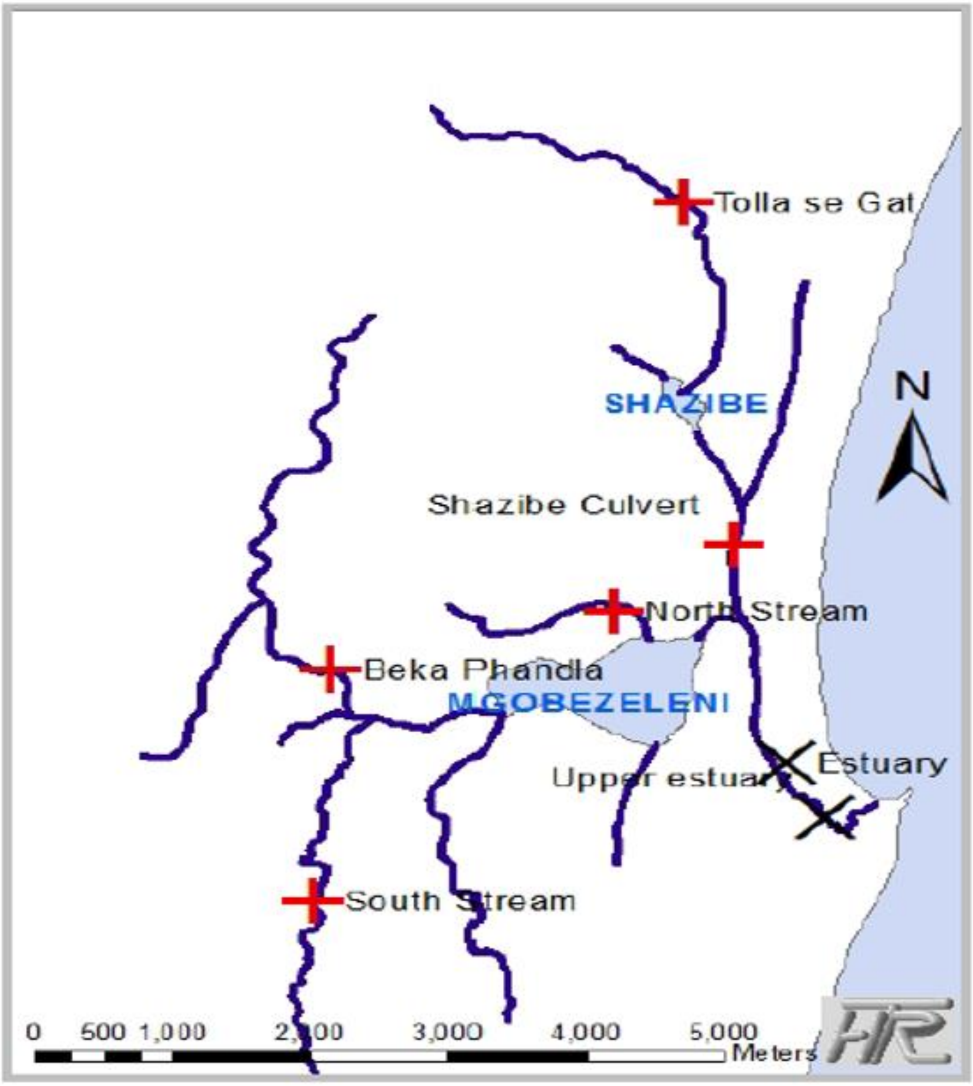

Figure 19: Mgobezeleni catchment surface water resources (Bate *et al*., 2016, crosses indicating sampled systems)

The bottle was then withdrawn from the depth and the sample bottle rinsed twice with the collected water to remove potential contaminants. The pop-bottle was then returned to the same depth for sample collection. The sample was decanted into a 500-ml plastic water sample bottle.

The water quality in Lake Mgobezeleni was also compared to the water quality of the two boreholes located near the Lake (less than 500 m from the inlet), SODA 29 and SODA 32 (**Table 3** and **Table 17**.

The water quality of the Lake was also compared to the Ezemvelo KZN Wildlife WTW clarifier sludge, which was collected and analysed to provide an indication of the water quality near the base of the Lake. The pipeline which source water from the Lake to the Ezemvelo WTW, is located near the base of the Lake.

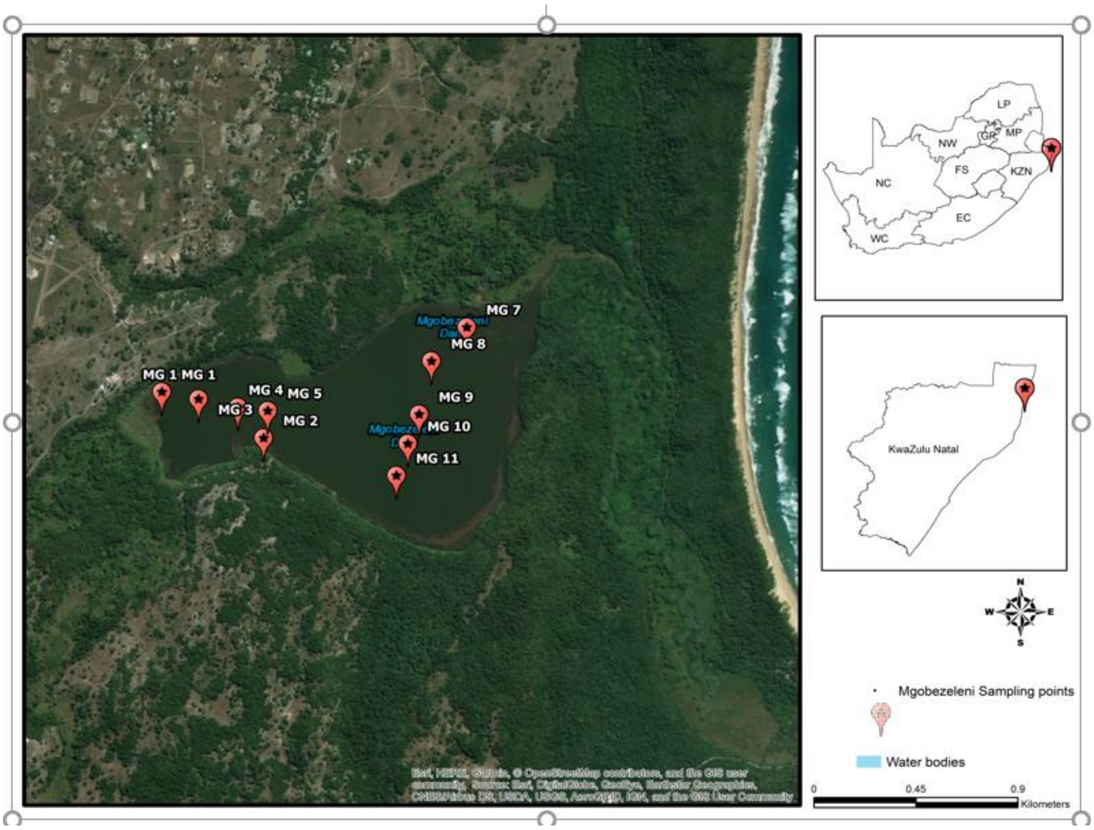

Figure 20: Lake Mgobezeleni water sampling points

Table 3: Lakes and estuarine water samples

Samples collected	Lake Mgobezeleni	Lake Shazibe	Mgobezeleni Estuary
Field analyses			
a) Surface at 15 cm depth	6	5	6
b) Subsurface at 0.5m to 3 m depths	4	4	4
Laboratory analysed			
a) Surface at 15 cm depth	8	12	8
Subsurface at 0.5 to 3 m depths			
b) Sludge sample	3	2	9
c) Groundwater sample	2	1	

b) Lake Shazibe

Water samples from Lake Shazibe were collected at the surface at about 15 cm and the sub-surface between 0.5 m and 2 m depths (**Table 3** and **Figure 21**). Samples were collected at pre-determined depths by means of a pop-bottle from a canoe.

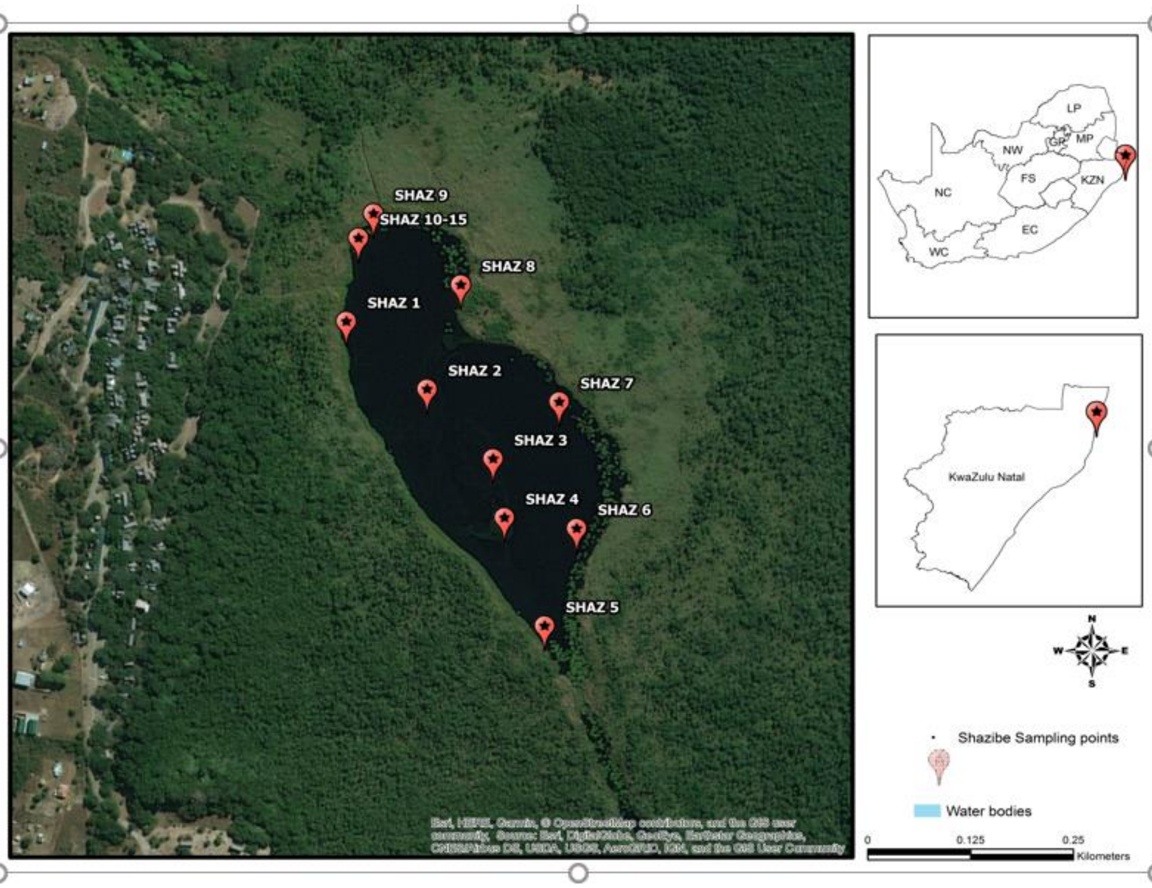

Figure 21: Lake Shazibe water sampling points

c) Mgobezeleni Estuary

Water samples from the Mgobezeleni Estuary were collected from the surface at about 15 cm and sub-surface at about 0.5 m to 1 m depths (**Table 3 and Figure 22)**. Samples upstream from the bridge were collected by means of a pop-bottle at predetermined depths.

4.4 Wetlands assessment

This section discusses the sampling method used for the wetlands of the Mgobezeleni catchment. Wetlands were also included in this survey to trace the groundwater pollution plume in the surface of the catchment using N and P composition. The main objective of this assessment was to determine whether peat decomposition is increasing the organic components in the wetlands and, thus, producing blackwater. The assessment was also intended to establish whether the chemical composition of the wetlands has any direct effect on the quality of the surface water resources. Samples were collected from Bhekaphandle, Thungwini, Qondwane, Culvert wetlands and Sangweni Pan. These wetlands are all groundwater fed.

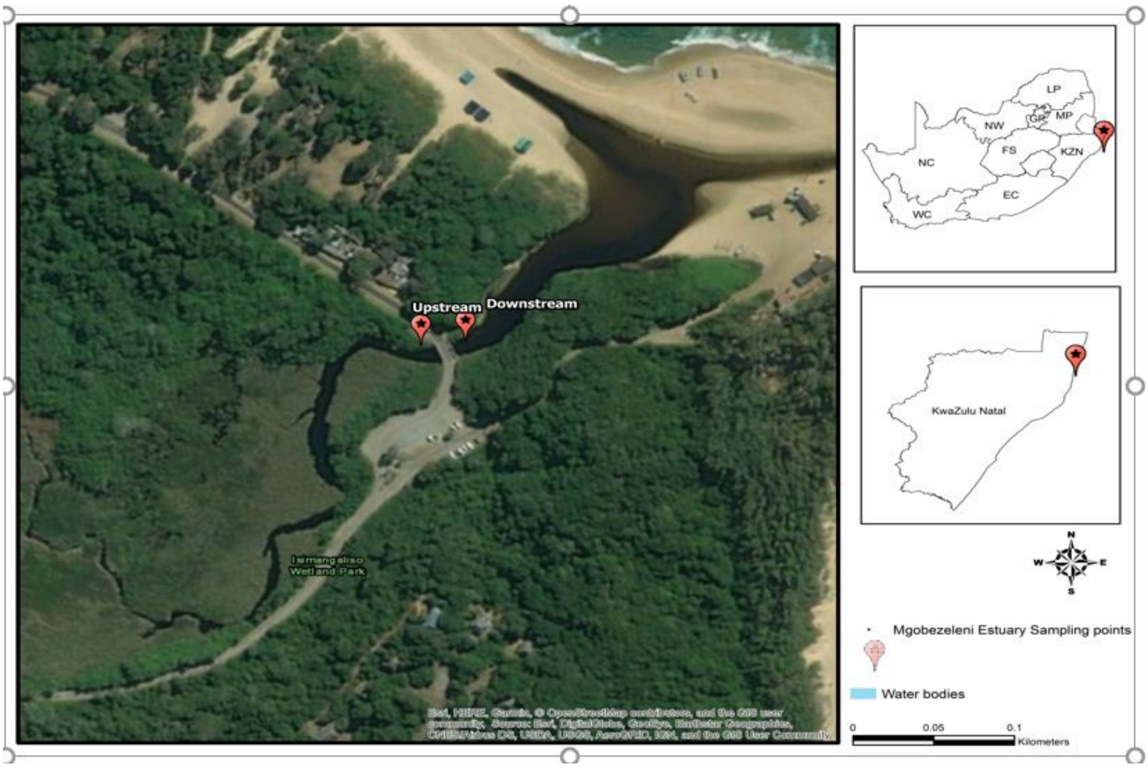

Figure 22: Mgobezeleni Estuary sampling sites

The water samples were collected during September 2013, June 2014, and June and July 2015 from the running stream water of the wetlands in the upper catchment and from pits dug for peat core collection. The samples were collected during a major drought period in the area. Samples were sent to Yanka Laboratories (a SANAS accredited laboratory) for nutrients, physical and chemical (including organic) analyses. The results were then used to check the pollution levels in the resources against the aquatic ecosystem quality requirements using the South African Target Water Quality Guideline (TWQG) Limits (DWAF, 1996).

4.4.1 Wetlands Sampling method

Samples were collected from peat-drilled holes for core peat sample collection and from the running stream in the wetland at Bhekaphandle and Thungwini wetlands, Culvert and Sangweni Pan as grab sampples.

4.5 Peat chemistry assessment

This section discusses an assessment of the chemical composition of the peat in the wetlands in Mgobezeleni catchment to understand the levels of peat decomposition/humification. The main objective of the section was to determine the extent to which the peat has decomposed and the potential of increasing the nutrients, inorganic components and trace elements in the water column of the wetlands. It was also intended to establish whether the chemical composition of the peat has any direct effects on the quality of the surface water resources. The peat is affected by the cultivation of peat soils and the draining of wetlands using furrows and drains (**Figure 23).** Drains expose the peat to atmospheric oxygen (reduces the water saturation in the wetlands).

Figure 23: Drain in the wetland (Bate et al., 2016)

4.5.1 Peat sampling method

Samples were collected during September 2013, June 2014 and June 2015 by means of a peat profile sampler (**Figure 24**). The peat profile sampler was used to establish the peat profile and to collect the peat from each of the selected sites. A measuring tape was used to measure the peat depth. Each site was assessed in the field for physical composition as well as peat depth. Peat samples were placed in plastic sample bags using a peat auger. The bags were then sealed to prevent peat decomposition by exposure to atmospheric oxygen.

Figure 24: Peat profile sampler

a) Bhekaphandle peatland

Six sites in Bhekaphandle peatland were assessed for peat composition (**Table 4** and **Figure 25**). The peat from these sites was collected during September 2013, June 2014 and June 2015 Samples were collected from the wetlands formed along the stream located on the western side of the Lake Mgobezeleni near the Qondwane residential area.

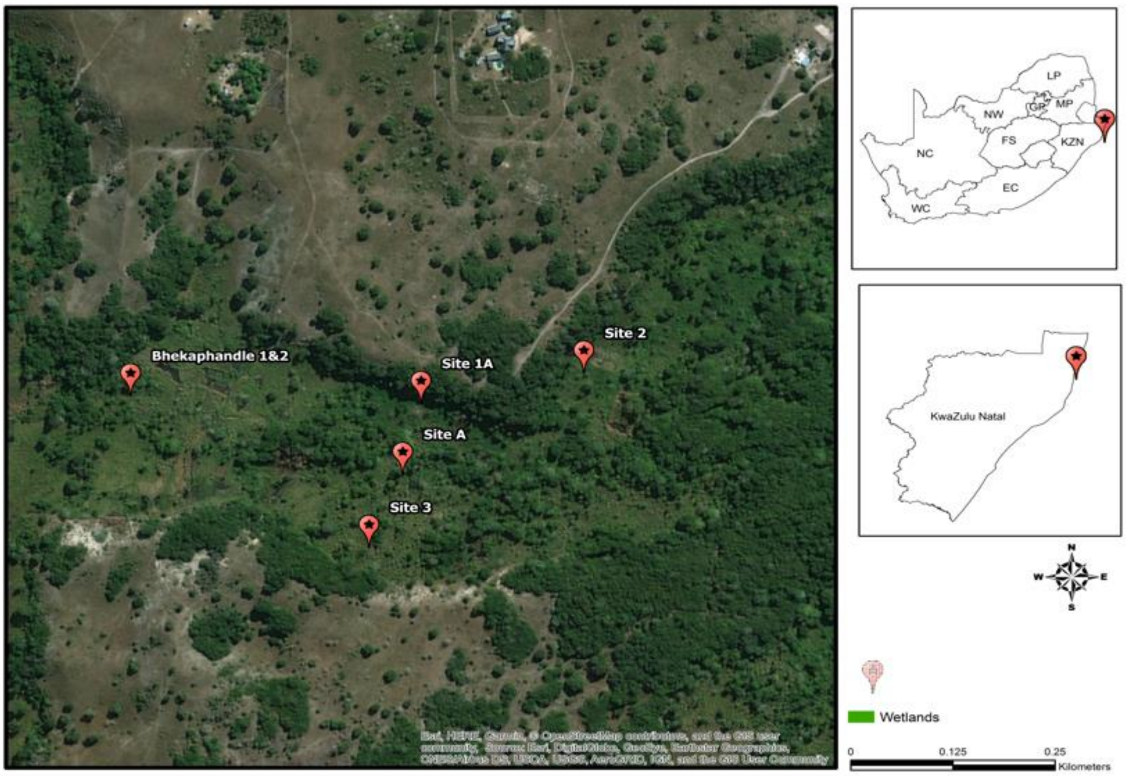

Figure 25: Location of sampling sites in the Bhekaphandle peatland

Table 4: Bhekaphandle peatland sampling sites

	Site 1AA	Site 1A	Site 2A	Site 1	Site 2	Site 3
Site peat profiling	No	Yes	Yes	No	No	No
Location	Riverine	Riverine	Riverine	Riverine	Riverine	Riverine
Human disturbance	Cultivated*	Uncultivated	Cultivated*	Uncultivated	Uncultivated	Cultivated*
Dominant vegetation	Grass/sedge	Grass/sedge	Grass/sedge**	Grass/sedge	Grass/sedge	Grass/sedge**
Equipped with ditches	Yes	Yes	Yes	Yes	NO	Yes
Laboratory analysis	Yes	Yes	Yes	Yes	Yes	Yes

*Cultivate and grazed

** Including banana trees

b) Thungwini peatland

Four sites in the Thungwini peatland were assessed for peat composition (**Table 5** and **Figure 26)**. The peat from these sites was collected during June 2014 and June 2015. Samples were collected from the wetlands formed along the stream located on the northern side of Lake Shazibe near the Thungwini residential area (**Figure 29**).

Figure 26: Sampling points in the Thungwini peatland

Table 5: Thungwini peatland sampling sites

	Site 1	Site 2	Site 4	Site 5
Depth (m)	2.60	2.75	1.0	1.0
Site peat profiling	Yes	Yes	No	No
Location	Riverine	Riverine	Riverine	Riverine
Human disturbance	Cultivated	Cultivated	Uncultivated	Uncultivated
Dominant vegetation	Reeds and sedge*	Reeds and sedge*	*Syzigium cordatum*, *Ficus* species, grass, reeds and sedge	*Syzigium cordatum*, *Ficus* species, grass, reeds and sedge
Ditches to drain peat	Yes	Yes	No	No
Laboratory analysis	Yes	Yes	Yes	Yes

* Including banana trees

c) Culvert peatland

Two sites in the culvert peatland were sampled for peat composition assessment (**Table 6** and **Figure 27**). Samples were collected from September 2013 to June 2015 in the in-stream peatland located downstream from Lake Shazibe outlet, at the Sodwana Bay road culvert crossing. The stream receives water from Lake Shazibe outlet.

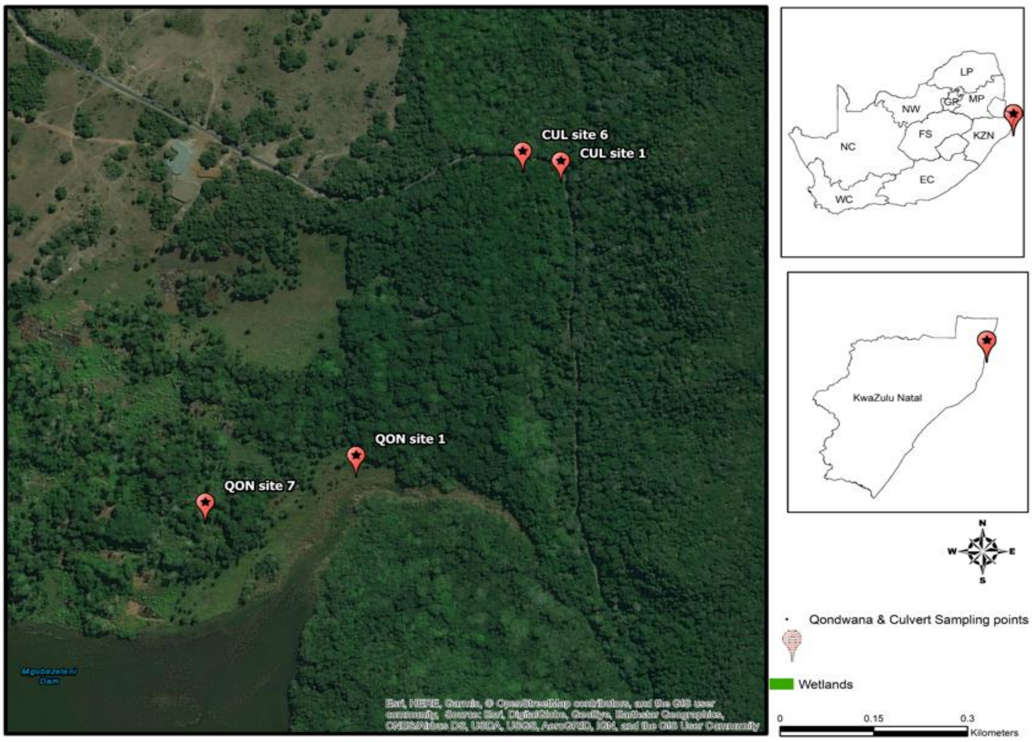

Figure 27: Sampling points in the Culvert and Qondwane peatlands

Table 6: Culvert peatland sampling sites

	Site 1	Site 6
Depth (m)	0.80	0.50
Site peat profiling	No	No
Location	Riverine	Riverine
Human disturbance	Uncultivated	Uncultivated
Dominant vegetation	swamp forest	swamp forest
Ditches to drain peat	No	No
Laboratory analysis	Yes	Yes

d) Qondwane peatland

Two sites in Qondwane were sampled for peat composition assessment (**Table 7** and **Figure 27**). Samples were collected from September 2013 to June 2015 from in-stream peatlands located on the western side of Lake Mgobezeleni (**Figure 30**), close to the lake outlet.

Table 7: Qondwane peatland sampling sites

	Site 1	Site 7
Depth (m)	0.80	1.0
Site peat profiling	No	No
Location	Riverine	Riverine
Human disturbance	Cultivated	uncultivated
Dominant vegetation	Madubes and banana trees	Swamp forest
Ditches to drain peat	Yes	No
Laboratory analysis	Yes	Yes

e) KwaZikhali peatland

Six sites in KwaZikhali peatland were assessed for peat composition (**Table 8**). Samples were collected in June 2014. KwaZikhali peatland is located on the southern side of Sangweni Pan. It receives water from groundwater and surface run-off recharge. It is used for cattle and game animals grazing. It is dominated by grass and sedge vegetation. It was dry at the surface during the time of sampling. The area has been previously affected by veld fires which has resulted destruction of the peat in other parts of the peatlands.

Table 8: KwaZikhali peatland sampling sites

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Depth (m)	41	40	39	32	32	30
Site peat profiling	Yes	Yes	Yes	Yes	Yes	Yes
Location	Palustrine	Palustrine	Palustrine	Palustrine	Palustrine	Palustrine
Human disturbance	Uncultivated*	Uncultivated*	Uncultivated *	Uncultivated *	Uncultivated *	Uncultivated *
Dominant vegetation	Grass/sedge	Grass/sedge	Grass/sedge	Grass/sedge	Grass/sedge	Grass/sedge
Laboratory analysis	Yes	Yes	Yes	Yes	Yes	Yes
Equipped with ditches	No	No	No	No	No	No

*Grazed

f) Sangweni Pan

Five sites at Sangweni Pan were assessed for peat composition (**Table 9**). Samples were collected in June 2014. Sample collection started from the Pan riparian zone on the western side and proceeded towards the inner part of the Pan on the eastern side. The Pan itself is located on the southern margin of Lake Mgobezeleni. It receives water from the groundwater and surface run-off recharge and is used as grazing for cattle and game. At the time of peat sampling it was semi-dry.

Table 9: Sangweni Pan peatland sampling sites

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Depth (m)	39	41	88	72	68	72
Site peat profiling	Yes	Yes	Yes	Yes	Yes	Yes
Location	Palustrine	Palustrine	Palustrine	Palustrine	Palustrine	Palustrine
Human disturbance	Uncultivated*	Uncultivated*	Uncultivated*	Uncultivated*	Uncultivated*	Uncultivated*
Dominant vegetation	Grass/sedge	Grass/sedge	Grass/sedge	Grass/sedge	Grass/sedge	Grass/sedge
Equipped with ditches	No	No	No	No	No	No
Laboratory analysis	Yes	Yes	Yes	Yes	Yes	Yes

*Grazed

4.6 Laboratory chemical and physical parameters

Laboratory analyses were conducted for groundwater, tap water, rainwater, lakes, estuary, wetlands and peat chemical assessment samples.

a) Groundwater, tap water and rainwater

The physical and chemical parameters are shown in **Table 10**. Samples were sent to SANAS accredited laboratories, namely, Mhlathuze Water Laboratory, Talbot and Talbot Laboratory and Yanka Laboratories for analysis. Results obtained was compared against South African National Standard for Drinking Water (SANS 241: 11) Class limit and South African Target Water Quality Guideline (TWQG) Limit Volume 7 for aquatic ecosystem

Table 10: Groundwater, tap water and rainwater physical and chemical parameters

Physical Parameters	Units	Chemical Parameters	Units
Temperature	^{O}C	**Nutrients:** NO_3-N; NO_2-N; NH_4-N; TN and PO_4-P	mg/l
Turbidity	NTU	**Cations and anions:** Ca^{2+}; Mg^{2+}; Na^+; K^+; Cl^- and SO_4^{2-}	mg/l
Salinity	ppt	**Trace elements:** Al^{3+}; Mn^{2+} and Fe^{2+}	mg/l
PH			
EC	mS/m		
TDS	mg/l		

b) Surface water and wetland water chemistry

The physical and chemical parameters for the lake, estuary and wetland assessments are also shown in **Table 11**. Samples were sent to Yanka Laboratories for analysis. Nutrients were selected to indicate eutrophication levels in the surface water systems. Organic substances and humic substances were selected to determine the cause of the *blackwater*. Other parameters were selected to obtain the chemical composition of the water in the systems.

Table 11: Surface water and wetland water quality

Physical Parameters	Units	Chemical Parameters	Units
Temperature	^{O}C	**Nutrients:** NO_3-N; NO_2-N; NH_4-N; TN and PO_4-P	mg/l
Turbidity	NTU	**Cations and anions:** Ca^{2+}; Mg^{2+}; Na^{+}; K^{+}; Cl^{-} and SO_4^{2-}	mg/l
Salinity	ppt	**Trace elements:** Al^{3+}; Mn^{2+} and Fe^{2+}	mg/l
pH		**Organic substances** (OC and OM); HA and FA	mg/l
EC	mS/m		
TDS	mg/l		

c) Peat chemistry

The physical and chemical parameters for the peat chemistry assessment are shown in **Table 12**. The organic substances, CHN and trace elements were analysed at the University of Zululand, Department of Chemistry and Agriculture. Proximate analyses were analysed at Optimum Colliery Laboratory Proximate results were checked against Maputaland Peat Classification (as in **Table 1**). N and P composition were assessed to indicate the nutrient composition of the peat. CHNS and organic carbon (OC) and organic matter (OM) values were determined to indicate the level of peat decomposition. Humic acid (HA) and trace elements were assessed to indicate the extractable content for comparison against the dissolved HA.

Table 12: Peat chemistry analyses

Physical Parameters	Units	Chemical Parameters	Units
Peat profile		**Nutrients:** NO_3-N; NO_2-N; NH_4-N; TN and PO_4-P	mg/l
Depth	m	**Proximate analysis** (ash, volatile, moisture and fixed carbon)	%
pH		**Peat energy** using calorific value (CV)	MJ/kg
		Organic substances (OC and OM); HA and FA	mg/l
		Ultimate analysis (carbon, hydrogen, nitrogen, and sulphur (CHNS)	%
		Cations and trace elements (Al, B, Ca, Cr, Cu, Fe, K, Mg, Na and Zn)	g/kg

4.7 Instrumentation

The instruments used during the study for various analyses are shown in **Table 13**

Table 13: Instruments and analytical methods

Parameter	Instrumentation	Analytical method	Laboratory
Nitrogen		Kjeldahl method	Yanka Laboratories
Phosphorus	Inductively coupled plasma (ICP)		Yanka Laboratories
Trace elements	Inductively coupled plasma (ICP)		Yanka Laboratories
Cations and anions	Inductively coupled plasma (ICP)		Yanka Laboratories
Organic carbon and organic matter		Walkley and Black (1934)	University of Zululand Chemistry Department Laboratory
Humic and fulvic acids	Ultraviolet (U-vis) and infrared spectrophotometers (FTIR)	IHSS method and Malcolm 1981)	University of Zululand Chemistry Department Laboratory

CHAPTER 5

MGOBEZELENI POPULATION DEMOGRAPHIC

5. 1 Introduction

This chapter presents results and discussion on the socio-economic factors relating to the Mgobezeleni catchment area, such as population, existing basic services (tap water supply, solid waste disposal and sanitation practices) and the rate of new household establishment. The assessment of the population was based on permanent residents in the Mgobezeleni catchment. The assessment also provides the estimated nitrogen (N) and phosphorus (P) concentrations percolating to the groundwater system and indicates the increase that has occurred because of the population growth.

Leachate from the pit latrines which has increased along with the increase in population can contaminate the groundwater quality. This has resulted in eutrophication in other hydrological systems. This occurs especially in faecal sludge containing about 3 to 5 g/l of nitrogen and 20g/l to 50 g/l of carbon oxygen demand (COD) respectively (Montagero and Strauss, 2002; Lu and Huang, 2010; Cheng *et al*., 2011). As leachate moves through the soil, the biodegradable organic compounds and nitrogen concentrations in the leachates are affected by natural biological processes (Babel *et al*., 2009). During this process, the COD is reduced but nitrogen concentration (especially nitrates) remain elevated in the groundwater near pit latrines (Tredoux *et al*., 2000; Still and Nash, 2002; Zingoni *et al*., 2005; Dzwairo *et al*., 2006; Okafor and Opuene, 2007; Chenini and Khemiri, 2009). The WHO (1992) reported that high nitrogen concentration causes eutrophication in surface water resources.

5.2 Mgobezeleni catchment population demographics

According to Taylor (in Bate *et al*., 2016), the Mgobezeleni catchment was undeveloped in the early 1950s. It was described as small game-guard outpost seldom visited by holidaymakers. The Natal Parks Board (now known as Ezemvelo KZN Wildlife) displayed interest in the Sodwana Bay area which was proclaimed as a nature reserve in December 1950. At the outset, the Reserve was equipped with limited infrastructure such as a thatched hut with a toilet. The first visitor facilities at Sodwana Bay were established in the early 1960s. The access road to the nature reserve passed around the southern edge of Lake Mgobezeleni, from which drinking water was sourced. The nature reserve at the time catered for offshore ski-boat recreation activity. In 1971, the access road to the nature reserve was improved with the construction of a small concrete bridge across the Mgobezeleni Estuary. The bridge structure restricted the flow of water to the estuary, however, which is reported to have led to the loss of several species of fish, crab and mudskippers; and caused the death of the mangrove forest upstream from the bridge (Bruton and Appleton, 1975). The design and structure of the bridge was later improved to allow water to flow freely and the new bridge was completed between 1976 and 1977.

Mbazwana and Manzengwenya timber forestry (19 000 ha) plantations were established by the KwaZulu-Natal Department of Forestry in 1960s and have been leased by the DWAF since 1994 (SA Forestry Online, 2012). The establishment of the plantation resulted in the expansion of the Mbazwana area as labour requirements increased. The forestry plantations in the Mgobezeleni area are causing fluctuations in the water table owing to evapotranspiration (Bate *et al*., 2016).

According to Taylor (Bate *et al.*, 2016), the Mgobezeleni area consisted of 470 homesteads with 1192 huts in 1999 and about 16 homesteads were observed within the boundary of the iSimangaliso Park. Assuming an average (of five people per hut in the whole area, the total population was estimated at approximately 6000 people. Based on a desktop study conducted in 2015, the total population in the Mgobezeleni area was estimated at approximately 15 000 people (**Table 14**), of which about 55% resided within the Mgobezeleni catchment. The population consists mainly of black Africans (>99%), while whites, Indians/Asians and coloured people constitute less than 1%.

Table 14: Information on residential areas (SSA, 2011; DWAF, 2011)

Area	Size (ha)	Population	Households	Female %	Male %	Black %	White %	Asian %	Coloured %	Other %	Pop. Density (population/ha)	Household	People/ Household
Olakeni	1857	1892	332	51	49	98.6	0.54	–	0.3	0.6	1.0	0.2	6.0
Qondwane	1031	3024	606	54	46	97.8	2.0	–	0.2	–	3.0	0.6	5.0
Thungwini	1578	1743	366	53	47	93.6	5.3	1.1	–	–	1.0	0.2	5.0
Mbazwana	1012	4930	1279	54	46	99.3	0.3	0.4	0.01	0.04	5.0	1.3	4.0
Hagaza	560	2344	478	52	48	99.5	0.5	–	–	–	4.0	0.9	5.0
Sodwana	410	105	41	39	61	74	26	–	–	–	0.3	0.1	3.0
Esiphahleni	478	419	66	55	45	99.6	0.3	–	–	–	1.0	0.1	6.0
Total	**6926**	**14457**	**3168**	**51**	**49**	**94.6**	**5.0**	**0.7**	**0.2**	**0.3**	**2.0**	**0.5**	**5.0**

Based on the population estimate provided by Taylor in Bate *et al*, 2016 (6000 people in 1999), the population in the Mgobezeleni area has increased by 8.3% p.a. in 17 years. This is higher than the estimated Local Municipality population growth rate of 0.3% per year (uMhlabuyalingana IDP, 2014/2015). It is also higher than the KwaZulu-Natal province and national population growth rates of 1.9% and 1.3% respectively (SAS, 2011).

According to **Table 14**, on average the Mgobezeleni catchment has a low a population density due to sparsely populated areas consisting of undeveloped lands (containing forests) such as Sodwana and Esiphahleni. Mbazwana is the most populated area, followed by Hagaza and Qondwane. On average, households in the Mgobezeleni catchment area comprise five people (including children) (**Table 14**).

5.2.1 Household demographics

The living conditions of people in the Mgobezeleni catchment are comprised out of semi-compact rural settlements. The housing structures are modern and freestanding with large plot sizes. Scattered amongst these modern houses are basic structures built with traditional material such as wooden poles, sticks and stones, and fitted with galvanised iron roofs. These structures appeared to be built as temporary shelters while permanent modern structures were under construction. The main structures are built with building blocks and then plastered and painted. The building blocks are manufactured by the local communities mainly from sand and cement material. This industry provides an income to locals. The living standard in the Mgobezeleni areas is classified as peri-urban.

According to the desktop survey, the Mgobezeleni area has a total number of 3168 households (**Table 14**). Based on the statistics and Taylor's information (in Bate *et al*, 2016 (of 470 households in 1999), the households in this area have increased dramatically by 33.8% p.a. in 17 years. According to the total extent of the area and the total number of households, the average household density is one household per half a hectare. The area has a close cluster of houses, with the highest household density being observed in Mbazwana (**Table 14**). Currently, people seem to be attracted to the area because of the proximity to schools, shopping centres, road access and public transport.

The second highest household density is in the Hagaza area. This area is the closest residential area to Mbazwana; therefore, as Mbazwana became highly populated, people started settling in Hagaza. The lowest household densities were observed at Esiphahleni and Sodwana Bay. These two areas are still underdeveloped and are mainly dominated by natural forest. The Sodwana Bay (Ezemvelo KZN Wildlife) area is not a public residential area but a residential area for tourists (visitors) and Ezemvelo KZN Wildlife employees.

5.2.2 Basic services

A total of 698 people were interviewed in the residential areas during the field surveys in 2014 to 2015 to establish the nature of the basic services in the area as reported by the residents.

(a) Potable water supply

The Mgobezeleni area has a reasonable supply of tap water. The tap water is sourced from Lake Sibaya, pumped and treated at the Mbazwana WTW and supplied through the reticulation system by the uMhlabuyalingana Local Municipality. The Sodwana Bay tourist camp and staff residences are supplied by Lake Mgobezeleni. The water is pumped and treated at Ezemvelo KZN Wildlife WTW.

Several households in the surveyed residential areas obtain their water supply from private boreholes. These seem to be afforded by household members with a relatively high income, as well as business enterprises and institutions. They were found mainly in the Qondwane and Thungwini residential areas (**Table 15).** The total water abstraction from these private boreholes was estimated at 0.1 Mm^3 per annum (Bate *et al*., 2016).

According to SSA (2011), access to water in South Africa was improved to 91% by 2011. It has also improved to 79% in rural areas by 2010 (WHO, 2009). The study indicated that about 55% and 35% of the households have access to tap water and groundwater supply respectively (**Table 15**). Therefore, the water supply in the Mgobezeleni area is below the water access mean level for a rural area in South Africa. According to SSA (2007), the tap water supply in the Local Municipality has improved by 18% between 2001 and 2007.

Table 15: The Mgobezeleni catchment social service and land developmental status (Survey, 2014/15)

Area	Population	Households	Children	Total people	Waste burning	Municipal waste site	Tap water users	Private well users	Available VIPs	Available long drops	Available septic tank	Bush users	New household
Olakeni	31	8	11	42	–	–	100%	–	50%	25%	–	25%	63%
Qondwane	68	16	22	90	50%	19%	19%	69%	31%	–	38%	–	44%
Thungwini	72	17	16	88	59%	24%	18%	41%	59%	–	47%	–	44%
Mbazwana	303	69	114	417	32%	1%	61%	20%	43%	16%	–	10%	36%
Hagaza	38	9	23	61	–	–	78%	11%	22%	33%	11%	44%	11%
Total	**512**	**119**	**186**	**698**	**47%**	**15%**	**55%**	**35%**	**41%**	**25%**	**32%**	**26%**	**40%**

The tap water system in the Mgobezeleni area suffers frequent supply cuts. This was also observed during the study period and is mainly due to illegal connections. During these periods, the water is supplied by the municipality using water carts or bowsers. Owners of private boreholes also assist their neighbours by providing alternative sources of water from their boreholes. At times, tap water supplied is reported to be unpalatable owing to the high dissolved salt content in the water. The water in some of the private boreholes especially in the Qondwane area was reported to develop a yellowish precipitate.

(b) General waste disposal

The general waste in Mgobezeleni households (15%) is removed by the Local Municipality to the Mbazwana landfill site. About 47% of households reported having their waste incinerated in small pits in their backyards (**Table 15**). According to uMhlabuyalingana IDP (2014/2015), about 87.6% of households in the Local Municipality dispose their own waste. It was also reported that access to solid waste disposal facilities in the Local Municipality has improved by 15% from 2007. The increase in individual waste disposal in the household pits/dumps in the Local Municipality is a major concern and contributes to atmospheric and groundwater pollution. The Local Municipality was reported by SAS (2007) to generate about 266 m^3 of waste per month of which 110 m^3 is recycled (SAS, 2007).

(c) Sanitation facilities

The Mgobezeleni area, which is a rural settlement, has no waterborne sanitation systems. Households have ventilated improved pit latrines (VIPs), long drops or septic tanks and some have no sanitation facilities at all. According to SAS (2007), in 2007 sanitation facilities had increased by 35% since 2001 in the Local Municipality. The South African Bill of Right states that everyone has a right to access basic sanitation. Access to basic sanitation in South Africa was improved to 91% in 2011 (SSA, 2011). The Local Municipality still has a sanitation facility backlog, as reported by SAS (2007). According to the survey conducted, most of the households (41%) in the Mgobezeleni area are equipped with VIPs and long drops (**Table 15**). High-income earners, business enterprises and institutions were equipped with septic tanks (32%). About 26% of the newly established houses for lower income earners have no sanitation facilities (people relied on bushes).

5.2.3 Mgobezeleni catchment livestock

Each household was surveyed for the type of farming practice. One objective was to establish the probability of animal waste contributing to nutrients leaching into the primary aquifer. Approximately 28% of households have dogs for protection purposes and 32% were farming with free-range chickens (**Table 16**). The area has a low number of households farming goats (5%) and cows (9%) as livestock.

Table 16: Mgobezeleni catchment demographics

Area	Father as family head	Mother as family head	Grandma as family head	Local relocation	Public transport users	Yard cropping	Use of manure	Chickens	Goats	Dogs	Cows
	%	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
Olakeni	75	17	17	100	87	75	75	35	13	38	13
Qondwane	-	-	-	-	-	-	-	6	0	19	6
Thungwini	-	-	-	-	-	-	-	6	0	12	12
Mbazwana	52	40	13	85	85	55	55	47	0	28	16
Hagaza	67	11	11	89	78	56	11	67	11	44	0
Total	**65**	**23**	**14**	**91**	**83**	**62**	**47**	**32**	**5**	**28**	**9**

5.2.4 Developmental and economic status of residential areas

The number of residential properties in the survey area is increasing because of new housing developments. However, some of these houses were still under construction. Approximately 91% of the people residing in the area have relocated from within the Maputaland region. In most of the households (65%) the father is considered the head of the family but generally worked outside the area. In addition, about 23% and 14% of the households were headed by the mothers and grandparents respectively (**Table 16**). It was also reported by SAS (2015) that approximately 45% of black African children in South Africa are living in households headed by a single parent.

Most of the people in the Mgobezeleni area do not own cars, with about 83% of the household members depending on public transport (**Table 16**). The common mode of public transport is taxis. The taxi rank is in Mbazwana next to the shopping centre and it supports all residential areas in the Mgobezeleni area.

5.3 Climatic conditions

The Mgobezeleni area has high annual average rainfall of 939 mm (Bate *et al*., 2016). The rainfall in this area is received throughout the year (Meadows, 1985). The high annual rainfall causes the leaching of waste from the sanitation facilities into the groundwater system, which is accelerated by the geological features (paleo dune sand) of the area. The total groundwater water storage capacity (at 20% porosity) in the Mgobezeleni area was estimated at 1414 Mm^3. The area has an average daily temperature of 21 °C. Approximately 80 Mm^3 of the total groundwater storage is lost through evapotranspiration by the forest plantations (Bate *et al*., 2016).

5.4 Groundwater nitrogen and phosphorus concentrations

In the Mgobezeleni catchment, the concentrations of N and P in the groundwater under normal conditions (absence of pollutants) will be approximately 0.05µg/l and 0.02 µg/l, respectively (De Villiers and Thiart, 2007). The same concentrations or less would be expected for the lakes and the estuary as the groundwater is the main source of recharge.

Urine and faecal sludge are very high in nitrogen. However, urine is the main contributor of the total nitrogen excreted by humans. It contributes 93% of total nitrogen, containing 84% of urea-nitrogen (Geigy, 1962). In South Africa, an average person produces 3.4 kg of nitrogen per year (WHO, 2006). An average person also excretes an amount of 0.8 to 1.6 l of water per day, depending on the climatic conditions, amount of water consumed and excreted, and the level of activity per individual (WHO, 2006). The average nitrogen concentration in urine ranges from 3 to 7 g/l

Assuming that 1.4 l of urine containing 5 g/l of nitrogen concentration is produced by the average person per day and the surface area of the pit latrine is 0.25 m^2, the rate of nitrogen mass load into a pit latrine is estimated at 140 g/m^2 per day (using an average of 5 persons per household, **Table 17**), and was calculated as follows:

$$\text{Estimated mass load per pit latrine} = \frac{1.4\ l \times 5\ g/l \times 5}{0.25\ m^2} = 140\ g/m^2 \qquad 5.5.1$$

Based on the total population, the total volume of urine excreted into sewage systems within the Mgobezeleni area was estimated to be 7.39 Ml/a (assuming that every permanent resident produces 1.4 l of urine of 5.0 g/l N concentration, **Table 16**). The estimated annual nitrogen mass load in the pit latrines was estimated at 37 tons and was calculated as follows:

$$\text{Estimated total annual urine volume excreted in pit latrines} = 1.4l \times 14457 \times 365 \times 10^{-6} = 7.39\ Ml \qquad 5.5.2$$

$$\text{Estimated total annual nitrogen mass} = 1.4\ l \times 5\ g/l \times 14457 \times 365 \times 10^{-6} = 37\ \text{tons N} \qquad 5.5.3$$

Based on the total estimated volume of the water in the groundwater at 20% porosity (1414 Mm^3), the dissolved nitrogen concentration in the groundwater is estimated at 0.026 mg/l (assuming all urine from the population percolates to the groundwater at 20% porosity, **Table 17**) and was calculated as follows:

$$\text{Estimated N concentration} = \text{estimated total nitrogen mass/groundwater volume} \quad 5.5.4$$

$$= \frac{36\,937\,635 \times 10^3 \text{ mg}}{1414 \times 10^9 \text{ l}}$$

$$= 0.026 \text{ mg/l}$$

Table 17: Estimated amount of N and P percolating to the groundwater system

	Nitrogen	Phosphorus
Total annual urine excreted (Ml)	739	739
Mass load per pit latrine (g/m²)	140	24
Annual mass load to the pit latrines (ton)	37	6.2
Concentration in the groundwater (mg/l)	0.026	0.0044

Based on David and Gentry (2002), an average person produces 0.43 kg of phosphorus per annum. Therefore, approximately 6.2 ton of phosphorus is produce per annum by the Mgobezeleni population. Assuming the rate is applicable to everyone, the estimated phosphorus concentration in the groundwater is therefore 0.0044 mg/l (**Table 17**).

$$\text{Estimated total annual P mass} = 0.43\text{kg} \times 14457 \times 10^{-6} \quad 5.5.5$$

$$= 6.2 \text{ tons P}$$

$$\text{Estimated P concentration} = \text{estimated total phosphorus mass/groundwater volume}$$

$$= \frac{6217 \times 10^3 \text{ mg}}{1414 \times 10^9 \text{ l}} \quad 5.5.6$$

$$= 0.0044 \text{ mg/l}$$

5.5 Discussion

The Mgobezeleni catchment is a semi-rural settlement comprising modern and freestanding structures on large plots. Its population and households have increased by 8.3% p.a and 33.8% p.a respectively since 1999. The most densely populated residential areas are Mbazwana, Hagaza and Qondwane. The dominant inhabitants of the area are Zulus and Thonga-Thembe people.

The residential areas obtain water from the municipal supply through metered connections, raw water sourced from Lake Sibaya. However, this water supply scheme suffers frequent cuts owing to illegal connections. Businesses and institutions, especially in Qondwane and Thungwini, source water for domestic use from private boreholes, to supplement the water supplied by the municipality. The groundwater is generally pre-treated (chlorinated) prior to use in business enterprises and institutions. Complaints were received from Qondwane regarding the turbidity of the groundwater. Some residents also harvest rainwater for domestic use.

The catchment (excluding Sodwana Bay) has no waste water treatment plant. Sewage systems include the use of long drops (LDs), ventilated improved pit latrines (VIPs) and septic tanks. Septic tanks are mainly for business enterprises, institutions and high-income earners. Some of newly established households of low-income earners have no sanitation systems. Most of the nutrients in these systems end up in the groundwater system due to unconsolidated sediments and mean annual high precipitation (MAP). Based on the total population in the Mgobezeleni catchment, the groundwater in the shallow aquifers were estimated to consists of 0.026mg/l and 0.0044mg/l of N and P concentrations respectively

The solid waste is generally managed by individual households through burning. Business enterprises, institutions and high-income earners either dispose their solid water in the Local Municipal landfill site or Local Municipal landfill collects the waste on weekly basis. Waste disposal in this manner pose groundwater pollution through leaching of nutrients including toxic organic and inorganic compounds by the high annual rainfall.

The catchment area contains large-scale Mbazwana forestry plantations which are used for black economic empowerment and for providing employment. Because of the low nutrient soils, poor road access to local markets and lack of irrigation schemes, the area has low agricultural potential. Most of the subsistence farming activities in the area generally occur in the wetland soils and in the backyards of homesteads.

CHAPTER 6

GROUNDWATER QUALITY RESULTS

6.1 Introduction

This chapter discusses the quality of the Mgobezeleni catchment groundwater in terms of N and P concentrations and chemical composition. It also provides the tap water and rainwater qualities to establish their contribution to the water quality of the primary aquifer. N and P compositions were used to determine the levels of anthropogenic impacts on the groundwater quality.

6.2 Background

Sources and levels of groundwater contamination in the Mgobezeleni catchment were evaluated through an assessment of the shallow private boreholes in the residential areas. The sampled borehole locations are shown in **Figure 18.** The anticipated anthropogenic source of groundwater pollution in the Mgobezeleni catchment is domestic waste disposal (use of pit latrines and septic tanks by the residents). The tap water quality was evaluated to determine its impact on the groundwater quality owing to the frequent leakages. In addition, the natural impact is associated with vegetation and rainwater infiltration into the shallow aquifer.

6.3 Mgobezeleni groundwater quality composition

6.3.1 Nutrient composition

The results of the groundwater nutrient composition are as follows:

a) The shallow boreholes varied significantly in terms of N and P concentrations. The DWS boreholes sampled in 2014 and 2015 showed a significant difference these nutrients per given period (**Table 17)**

- SODA 1, SODA 15, and SODA 21 indicated a decrease while SODA 13, SODA 18 and SODA 20 showed an increase in nitrate (NO_3-N) concentration
- SODA 15, SODA 18 and SODA 20 indicated a decrease while SODA 1 SODA 13 and SODA 21 showed an increase in ammonium (NH_4-N) concentration
- SODA 13, SODA 15, and SODA 20 indicated a decrease while SODA 1, SODA 18 and SODA 21 showed an increase in phosphate (PO_4-P) concentration
- The SOD 15 groundwater samples were obtained after the water had already been treated; this was indicated by low nutrient values

b) The NO_3-N concentration was elevated above the TWQG and SANS 241 limits in some of the Qondwane (8.5mg/l) and Mbazwana (20mg/l) boreholes (**Table 18)**. However, the mean NO_3-N concentration (2.8 ± 3 mg/l) was within the TWQG and SANS 241 limits

Table 18: Groundwater qualities sampled twice during the study period

Year	Site		NO_3-N (mg/l)	NO_2-N (mg/l)	NH_4-N (mg/l)	PO_4-P (mg/l)	TN (mg/l)
2014	SODA 1		4.6	0.01	0.11	0.02	4.7
2015			4.1	0.01	0.45	0.03	4.6
		Mean	**4.4 ± 0.4**	**0.01 ± 0**	**0.28 ± 0.2**	**0.03 ± 0**	**4.7 ± 0.1**
2014	SODA 13		1.79	0.01	0.29	0.26	2.1
2015			4.1	0.01	0.45	0.03	4.5
		Mean	**2.9 ± 2**	**0.01 ± 0**	**0.37 ± 0.1**	**0.15 ± 0.2**	**3.3 ± 2**
2014	SODA 15		0.43	0.01	0.45	0.03	0.89
2015			0.13	0.02	0.19	0.02	0.33
		Mean	**0.28 ± 0.2**	**0.01 ± 0**	**0.32 ± 0.2**	**0.02 ± 0**	**0.61 ± 0.4**
2014	SODA 18		3.4	0.01	0,45	0.03	3.8
2015			3.7	0.01	0.05	0.17	3.7
		Mean	**3.5 ± 0.2**	**0.01 ± 0**	**0.25 ± 0.3**	**0,10 ± 0.1**	**3.8 ± 0.1**
2014	SOD A 20		5.8	0.01	0.45	0.030	6.3
2015			6.3	0.01	0.08	0.16	6.4
		Mean	**6.1 ± 0.4**	**0.01 ± 0**	**0.26 ± 0.3**	**0.09 ± 0.1**	**6.4 ± 0.1**
2014	SODA 21		3.5	0.01	0.25	0.05	3.8
2015			3.4	0.01	0.45	0.03	3.8
		Mean	**3.5 ± 0.1**	**0.01 ± 0**	**035 ± 0.1**	**0.04 ± 0**	**3.8 ± 0**

c) NH_4-H concentration was elevated above both limits in most of the boreholes. The mean NH_4-N concentration (0.66 ± 2 mg/l) was above both limits. The highest NH_4-N concentration of 12 mg/l was observed in the Qondwane borehole

d) Based on the mean total groundwater inorganic nitrogen (TN) concentration (3.4 ± 3 mg/l) the groundwater in the Mgobezeleni catchment was classified as being eutrophic (rich in nitrogen, DWAF, 1996, **Table 18**)

e) The PO_4-P concentration was generally elevated above the TWQG limit. The mean PO_4-P concentration (0.23 ± 1 mg/l) was also above the TWQG limit. The highest PO_4-P concentration of 3.1 mg/l was observed in the Thungwini borehole

Table 19: Mgobezeleni catchment mean groundwater, tap water and rainwater nutrient composition

Parameters	SANS 241:11	TWQR	Units	Groundwater	Tap water	Rainwater
Mean NO_3-N	≤ 10	≤ 6.0	mg/l	**2.8 ± 3**	**0.35 ± 0.3**	**0.68 ± 0.2**
Min				0.08	0.02	0.53
Max				20	2.6	0.83
Mean NO_2-N	0	Unspecified	mg/l	**0.01 ± 0.001**	**0.12 ± 0.1**	**0.01 ± 0**
Min				0.00	0.00	0.01
Max				0.06	0.38	0.01
Mean NH_4-N	0.45	0.007	mg/l	**0.66 ± 2**	**0.41 ± 0.1**	**0.13 ± 0.1**
Min				0.04	0.05	0.06
Max				12	0.45	0.19
	Unspecified	0.500	mg/l	**3.4 ± 3**	**0.85 ± 0.3**	**0.82 ± 0.5**
				0.13	0.00	0.60
				0.21	2.7	0.90
Mean PO_4-P	Unspecified	0.025	mg/l	**0.23 ± 1**	**0.05 ± 0.6**	**0.08 ± 0.1**
Min				0.02	0.0	0.01
Max				22	0.48	0.15

6.3.2 Groundwater physical and chemical composition

6.3.2.1 Physical parameters

The results are shown in **Table 19**.

a) The groundwater was acidic, characterized by a mean pH value of 5.29 ± 0.9, which was below the TWQG limit. The lowest pH value observed in the groundwater was 4.28, which was below limits
b) The groundwater was characterized by a mean temperature of 26.1 ± 3 °C.
c) It was very turbid (mean 97 ± 3 NTU) with suspended solids. The turbidity problem was also reported by the private borehole owners especially in the Qondwane area. The turbidity and suspended soils were above the SANS 241 and TWQG limits
d) It was low in salinity with a mean salinity value of 0.14 ± 0.1 ppt
e) The TDS and EC values averaged to 193 ± 69 mg/l and 30 ± 11 mS/m, respectively, and were within the SANS 241 and TWQG limits. The TDS values ranged from 53 mg/l to 394 mg/l,

Table 20: Physical and chemical properties of groundwater, tap water and rainwater (Red highlight indicating values above the TWQG limits; blue values above SANS 241; yellow above both limits)

		pH	TDS(mg/l)	EC(mS/m)	Turb (NTU)	SS(mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	Na (mg/l(	SO_4 (mg/l)	Fe (mg/l)	Al(mg/l) mg/L	K(mg/l)	HCO(mg/l)	Mn(mg/l)	Tot. Hardness(mg/l)
TWQG		**6.5-8.5**	**<450**	**<40**	**<1**	**<5**	**<32**	**<30**	**<100**	**<70**	**<200**	**<0.1**	**<0.15**	**<50**	**<50**	**<0.02**	**<40**
SANS 241: 2011		**5.0-9.7**	**<1200**	**<70**	**1-5**	**<1**	**<250**	**<70**	**<250**	**<200**	**<400**	**<2**	**<0.3**	**<50**		**<0.5**	
Groundwater	Mean	5.29 ± 0.9	143 ± 57	29 ± 11	4.1 ± 11	1.3 ± 3	12 ± 14	4.0 ± 2	57 ± 20	34 ± 12	3.8 ± 4	0.16 ± 0.2	0.22 ± 0.7	3.1 ± 2	28 ± 37	0.02 ± 0.02	74 ± 60
	Min	4.28	53	15	0.14	0	0.93	1.7	25	12	0.42	0.01	0.01	0.88	1.2	0.01	12
	Max	6.07	394	77	66	21	53.4	13	150	100	29	1.1	3.7	10	152	0.08	226
Tap water	Mean	7.7 ± 0.5	394 ± 8	78 ± 1	0.78 ± 0.5	1.9 ± 3	25 ± 1	13 ± 1	154 ± 5	95 ± 3	23 ± 2	0.04 ± 0.03	0.11 ± 0.2	11 ± 0.2	117 ± 3	0.01 ± 0.0	117 ± 4
	Min	6.1	382	76	0.10	0.10	23	12	145	92	16	0.01	0.04	11	113	0.01	110
	Max	8.3	405	79	2.0	9.0	26.5	15	161	99	26	0.10	0.66	12	123	0.01	127
Rainwater	Mean	6.7 ± 0.9	45 ± 38	9.4 ± 9			2.3 ± 1	1.4 ± 1	21 ± 24	11 ± 12	2.4 ± 2	0.05 ± 0.04	1.1 ± 0.3	0.02 ± 0.3	3.9 ± 3	0.03 ± 0.01	11 ± 7
	Min	6.1	18	3.4			1.3	0.68	4.1	2.7	1.0	0.02	0.92	0.02	2.0	0.02	6.0
	Max	7.3	73	16			3.3	2.0	38	20	3.8	0.08	1.3	0.02	5.8	0.03	17

while the EC values ranged from 15 mS/m to 77 mS/m. The highest value was observed in the Mbazwana borehole

6.3.2.2 Chemical composition

The results are shown in **Table 19**.

a) Groundwater was found to have low Ca, Mg, K and SO_4 concentrations. The highest Ca concentration of 11 mg/l was observed in Qondwane. The higher Mg, K and SO_4 concentrations were all observed in the Mbazwana boreholes. Ca^{2+} ions were more dominant than Mg^{2+} ions with a Ca: Mg ratio of 3: 1, which was normal
b) The groundwater was dominated by Na and Cl concentrations averaging 36 ± 12 mg/l and 60 ± 21 mg/l respectively. The highest Na (40 mg/l) and Cl (67 mg/l) concentrations were observed in the Thungwini boreholes. The Na: Cl ratio was 1: 2, indicating dominance of chloride ions over sodium ions
c) Owing to low pH values in most of the catchment boreholes, ferrous iron (Fe^{2+}), aluminium (Al^{3+}) and manganese (Mn^{2+}) ions were mobilised from the sediments into the groundwater. The highest levels of the mobilised trace elements were observed in Mbazwana boreholes. The Fe^{2+}, Al^{3+} and Mn^{2+} concentrations averaged to 0.16 ± 0.2 mg/l, 0.22 ± 0.7 mg/l and 0.02 ± 0.02 mg/l respectively. These values were all above the TWQG limits

6.4 Tap water quality

6.4.1 Nutrient composition

The results are shown in **Table 18**.

a) The tap water nutrient composition did not vary significantly regarding the sources and the time of sampling
b) NO_3-N concentration was generally low and mostly elevated in processed water. The mean NO_3-N concentration was 0.35 ± 0.3 mg/l
c) NH_4-N concentration was generally above the TWQG limit and the mean NH_4-N concentration (0.41 ± 0.1 mg/l) was above the TWQG limit. The highest concentration was observed in raw water
d) The tap water had an elevated TN concentration. The mean TN concentration of 0.85 ± 0.3 mg/l was used to classify the tap water quality as mesotrophic (moderate in amount of nutrients, DWAF, 1996)

e) The tap water had a mean PO_4-P concentration of 0.05 ± 0.6 mg/l, which was above the TWQG limit. The highest concentration was observed in processed water

6.4.2 Physical and chemical composition

6.4.2.1 Physical composition

The results are shown in **Table 19**.

a) The tap water was characterized by a mean pH value of 7.65 ± 0.3
b) It was relatively elevated in suspended solids (mean 1.9 ± 3 mg/l) above the SANS 241 limit. The processed water was low in turbidity from the treatment process
c) The TDS and EC values averaged to 394 ± 8 mg/l and 78 ± 1 mS/m respectively

6.4.2.2 Chemical composition

The results are shown in **Table 19**.

a) The tap water was characterized by relatively higher Ca, Mg, K and SO_4 concentrations in relation to the groundwater quality. Ca^{2+}, Na^{2+} and SO_4^{2-} ions were elevated in raw water. These ions resulted in tap water having higher total hardness. The processed water was also higher in Mg, Cl and K concentrations. Ca^{2+} ions dominated over Mg^{2+} ions. The Ca: Mg ratio was 2:1
b) The water was dominated by Na, K, Cl and HCO_3^- ions, as reported by Weitz and Demlie (2013) for Lake Sibaya water quality composition
c) It was also dominated by Na^+ and Cl^- ions. The Na: Cl ratio was 1:2 indicating Cl^- ion dominant over Na^+ ions
d) The mean trace elements in the tap water were all within the SANS 241 and the TWQG limits. Al^{3+} ions were elevated in the processed water due to use of aluminium sulphate flocculant. The Fe concentration was elevated in the raw water as observed by Weitz and Demlie (2013) for Lake Sibaya water

6.5 Rainwater composition

6.5.1 Nutrient composition

The results are shown in **Table 18**.

a) The mean NO_3-N concentration of rainwater was 0.68 ± 0.2 mg/l, which was higher than the tap water nitrate content
b) The mean NH_4-N concentration was 0.13 ± 0.1 mg/l which was higher than the TWQG limit.

c) The TN concentration averaged to 0.82 ± 1 mg/l, thus indicating that the rainwater was mesotrophic (DWAF, 1996)
d) The mean PO_4-P concentration (0.08 ± 0.1 mg/l) was above the TWQG limits

6.5.2 Physical and chemical composition

6.5.2.1 Physical composition

The results are shown in **Table 19**.

a) Rainwater was found to be slightly acid to neutral and characterized by a mean pH value of 6.65 ± 0.9. The pH was assumed to be influenced by sample bottle storage, biological activities and temperature prior to analysis. It was not analysed in the field
b) The TDS and EC values averaged to 45 ± 9 mg/l and 9.4 ± 7 mS/m respectively

6.5.2.2 Chemical composition

The results are shown in **Table 19**.

a) The rainwater was found to be low in Ca, Mg, K and SO_4 concentrations. Calcium ions dominated magnesium ions with a Ca:Mg ratio of 2:1
b) The water was found to be elevated in sodium and chloride ions concentration. Cl^- ions dominated Na^+ ions with an Na:Cl ratio of 1:2
c) The Fe concentration was found to be low, but water was elevated in Al and Mn concentrations above the TWQG limits

6.6 Comparison of groundwater quality with tap water and rainwater quality

The N and P concentrations were elevated in the groundwater due to leaching of nutrients from the sanitation systems owing to the growing population; slow groundwater movement and that fact that there is confining layer restricting nutrients in the shallow aquifers (**Figure 28**). This indicates that the tap water and the rainwater have insignificant impacts on the groundwater nutrients composition.

Cations and anions concentrations were elevated in tap water owing to the nature of the water quality of the Lake Sibaya (**Figure 29)**. Lake Sibaya is a close system, causing the water to saturate in the Lake. A significant drop in water level over last decade (Weitz and Demlie, 2013) also contributes to the salinity levels of the water. The similar quality was also identified by Weitz and Demlie (2013). Although the tap water pipelines have constant leaks due to illegal connection, the has not significantly impacted on the groundwater quality in terms of these above-mentioned concentrations.

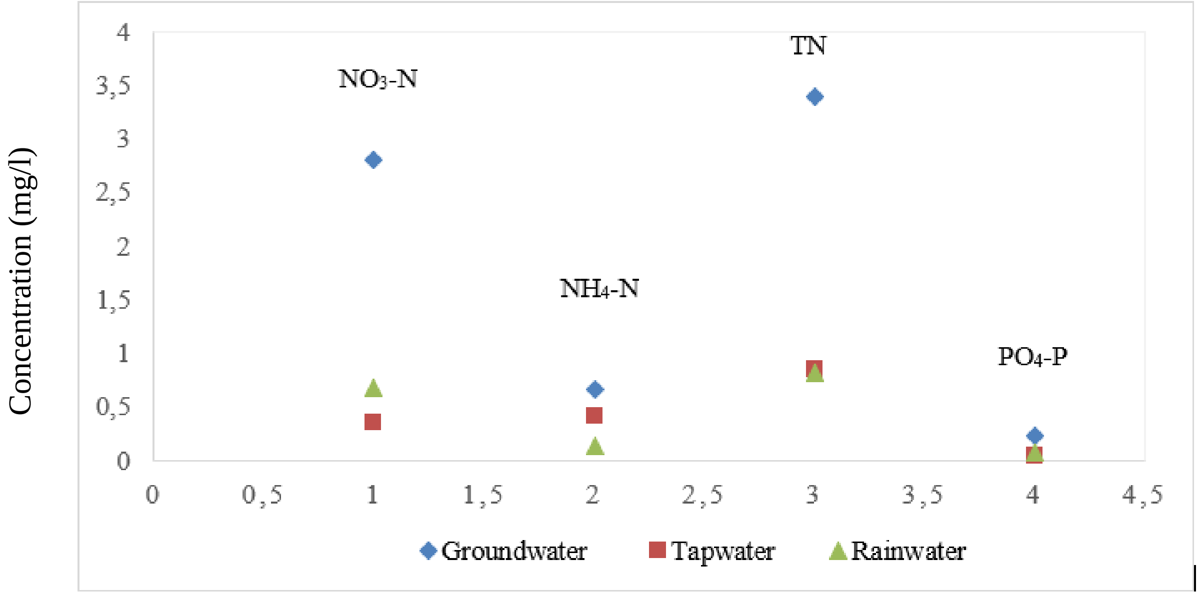

Figure 28: Groundwater, tapwater and rainwater **n**utrient composition comparison

The Fe and Al concentrations were elevated in the groundwater due to low pH values (acidity was also assumed to be a result of organic acids from domestic waste decomposition) which caused mobilization of heavy minerals ions from sediments (**Figure 30**). The Mn concentration was elevated in rainwater which could indicate contamination of the source of the water or from particulate matter.

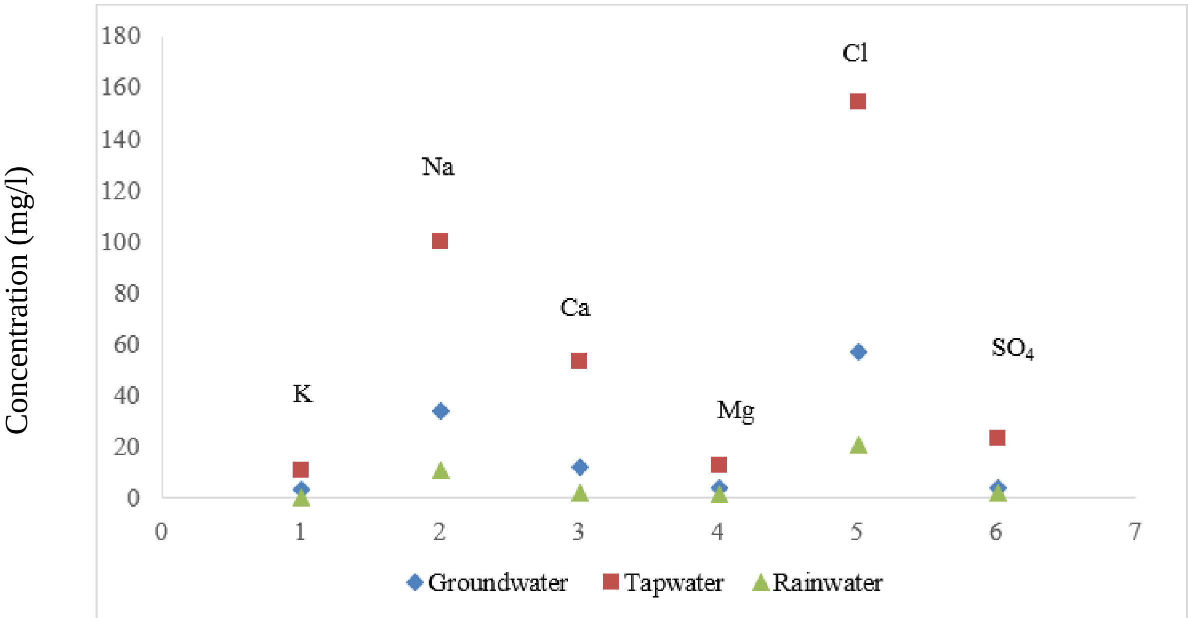

Figure 29: Groundwater, tapwater and rainwater cations and anions concentrations comparison

6.7 Discussion

a) Groundwater

The nutrient composition in the groundwater appears to be influenced by the sewage effluent from the sanitations systems especially in the high dense population residential areas such Mbazwana as indicated by Still and Nash (2002). The nitrate concentration currently pose no health threat for drinking purposes in most of the boreholes except for MBAC 18 (20 mg/l), which was above the SANS 241:11. The NO_3-N concentration is within the TWQG limit except for three Qondwane boreholes SODA 7 (6.19 mg/l), SODA 20 (6.34 mg/l) and SODA 25 (8.48 mg/l) and Mbazwana borehole MBAC 18. The NH_4-H concentration is mostly above the TWQG limit, indicating that the base flow groundwater recharge to the surface water system can cause eutrophication of the surface water systems. The highest values are observed in Thungwini borehole SODB 16 (12 mg/l). The TN concentration was indicative of eutrophic condition. The high N levels were observed particularly in most densely populated residential areas such as Qondwane and Mbazwana.

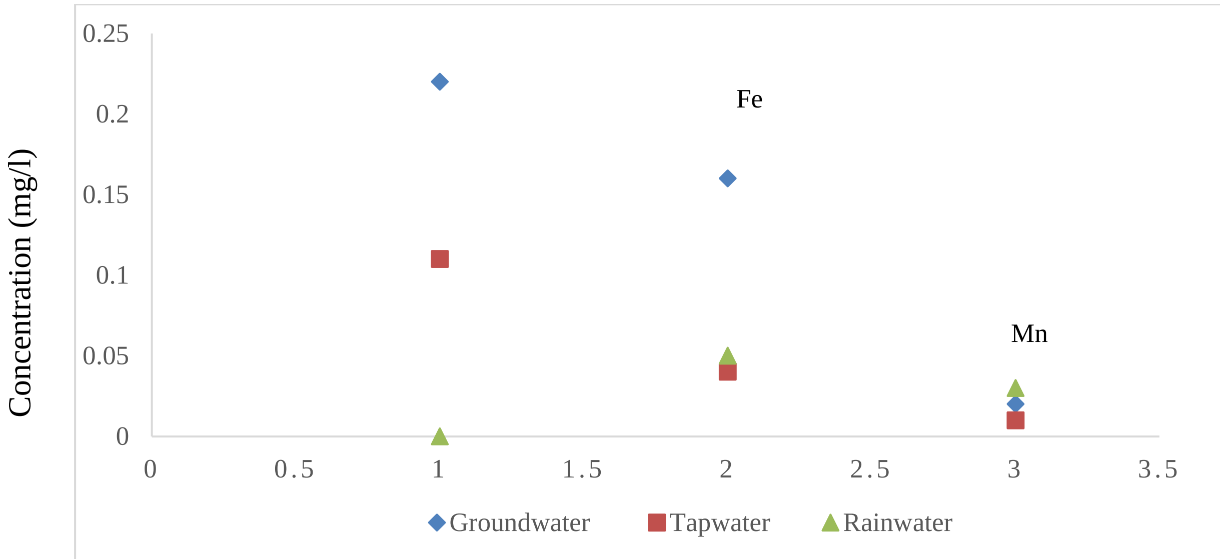

Figure 30: Groundwater, tapwater and rainwater trace elements concentrations comparison

As reported by Kelbe (in Bate *et al.*, 2016), the high N concentration indicates nutrient are accumulating in the groundwater in the shallow boreholes because of a large number of pit latrines and a slow groundwater movement. The actual groundwater TN concentration is 130 times more than the estimated value from the number of people in the catchment. Therefore, the base flow discharge of the groundwater into the surface water resources contributes to eutrophication.

The PO_4-P concentration is also elevated above the TWQG limit, indicating a similar effect as the NH_4-N concentration. The highest PO_4-P concentration is observed in the Qondwane boreholes SODA 7 (3.12 mg/l) and SODA 14. The actual groundwater PO_4-P concentration is 56 times higher than the estimated PO_4-P concentration from the population in the catchment.

The groundwater is generally acidic and in other boreholes not suitable for drinking purposes (due to pH values below 5.0) and the mean pH value is below the TWQG limit. The water is very turbid, turbidity is above the SANS 214 and TWQG limit.

The groundwater is relatively low Ca, Mg, K and SO4 concentrations, however elevated in Na and Cl concentrations. It was therefore characterized by a sodium-chloride ion signature, which is a common groundwater signature in some of the shallow boreholes in the Maputaland region, owing to recent cyclic salt input from the sea or from fossilised material in the Tertiary sediments of the underlying basin (Allan and Van Wyk, 1969). It is elevated in trace elements such as Fe^{2+}, Mn^{2+} and Al^{3+} concentrations, above the TWQG limits owing to the low pH values causing the mobility of these ions from sediments.

b) Tap water

The tap water is lower in N and P concentrations in relation to the groundwater quality. It is, however, elevated in cations and anions concentration above the groundwater. The EC values are above the SANS 241 and TWQG limits, which is associated with Lake Sibaya hydrochemistry. The water chemistry of the Lake is influenced by the lack of surface water outflow and the fact that the water level in the Lake has dropped significantly affecting the salt contents of the lake resulting in the saturation of cations and anions. The processed water is elevated in aluminium ions due to use of flocculants at the Mbazwana WTW. The raw water is elevated in ferrous iron concentration, as reported by Weitz and Demlie (2013) in Lake Sibaya.

c) Rainwater (RW)

The rainwater is relatively low in N and P concentrations in relation to the groundwater quality. It is, however, elevated in NO_3-N and PO_4-P above the TW quality, which is assumed to be associated with the particulate matter because the water was collected from rainwater harvesters. It is, however, relatively low in NH_4-N concentration, but elevated in Al above the TWQG limits and in Mn above bothlimits

CHAPTER 7

SURFACE WATER QUALITY RESULTS

7.1 Introduction

This chapter discusses the surface water quality results of the lakes and estuary of the Mgobezeleni catchment in terms of the nutrient (N and P), physical and chemical composition (including organic substances). The main objective was to establish the quality of these systems to determine the impact of the groundwater and the levels of eutrophication due to the groundwater recharged.

7.2 Lake Mgobezeleni water quality

7.2.1 Nutrient composition

a) The Lake water was relatively low in NO_3-N concentration at the surface and subsurface levels. The mean NO_3-N concentration was vertically the same throughout the Lake water column and averaged to 0.20 ± 0.2 mg/l. The highest NO_3-N concentration of 0.35 ± 0 mg/l was observed in the sludge sample (indicating the nutrients near the base of the Lake) (**Table 21**)

b) It was also low in NO_2-N concentration especially in the subsurface levels, averaging 0.03 ± 0.03 mg/l

c) It was relatively elevated in NH_4-N concentration above the TWQG limit (**Table 21**). The highest concentration of 0.20 ± 0.2 mg/l was observed in the surface level, averaging 0.18 ± 0.2 mg/l. The elevated NH_4-N concentration of 0.45 ± 0 mg/l was observed in the sludge sample

d) The TN concentration of the Lake averaged to 0.41 ± 0.2 mg/l, thus indicating that the Lake is oligotrophic (low in nutrients), but the concentration was slightly elevated in the upper region of the lake water column (**Table 21**). The higher TN concentration was observed in the sludge (0.81 ± 0 mg/l), thus indicating potential mesotrophic conditions (slightly higher in nitrogen) at the base of the lake. The mean TN concentration of the two boreholes (SODA 29 and 32) assessed for groundwater quality near the Lake was 5.81 ± 0.03 mg/l (**Figure 17)**

Considering the steady state annual net groundwater inflow into the Lake of 540 565 m^3 and the total Lake water storage volume of approximately 11.4 Mm^3 (Bate *et al*., 2016), the annual groundwater dilution factor was estimated at 1:21. The TN concentration after groundwater dilution in the Lake was then estimated at 0.28 mg/l and calculated as follows:

TN after groundwater dilution = 5.82 mg/l x 540565 x 10^3 l / (11.4 x 10^9) l (7.3.1.1)

= 0.28 mg/l

Table 21: Lake Mgobezeleni nutrient and organic composition

Parameters		TWQR	Units	Shallow levels (15 cm)	Deep levels (0.5 to 3m)	Mean values	Sludge
NO_3^-	Mean	≤ 6.0	mg/l	0.20 ± 0.1	0.20 ± 0.2	0.20 ± 0.2	0.35 ± 0
	Min			0.07	0.20	0.03	0.35
	Max			0.47	0.37	0.47	0.35
NO_2^-	Mean	Unspecified	mg/l	0.03 ± 0.03	0.01 ± 0	0.03 ± 0.03	0.01 ± 0
	Min			0.01	0.01	0.01	0.01
	Max			0.08	001	0.08	0.01
NH_4^+	Mean	<0.007	mg/l	0.20 ± 0.2	0.12 ± 0.12	0.18 ± 0.2	0.45 ± 0
	Min			0.01	0.12	0.01	0.45
	Max			0.45	0.20	0.45	0.45
TN	Mean			0.43 ± 0.2	0.33 ± 0.2	0.41 ± 0.2	0.81 ± 0
	Min	<0.500	mg/l	0.15	0.33	0.07	0.81
	Max			0.81	0.58	0.81	0.81
PO_4^{3-}	Mean	<0.025	mg/l	0.01 ± 0.01	0.01 ± 0	0.01 ± 0.01	0.03 ± 0.04
	Min			0.01	0.01	0.01	0.03
	Max			0.01	0.01	0.03	0.10
OC	Mean		mg/l			20 ± 13	
	Min					12	
	Max					35	
OM	Mean	20	mg/l			46 ± 31	
	Min					27	
	Max					82	

The Lake mean TN concentration was approximately twice as high as the estimated values. It can therefore be concluded that the groundwater was not the only source of nitrogen concentration in the Lake. The decomposing vegetation around the lake as well as the peat underlying the lake's basin and the stream water all influence the nitrogen composition in the Lake.

The PO_4-P concentration of the lake was within the P concentration range of South Africa's surface water resources but was above the TWQG limit, averaging 0.01 ± 0.01 mg/l, and did not vary significantly throughout in the lake water column. However, an elevated concentration was observed in the sludge sample (**Table 21**). Phosphorus was a limiting nutrient in the lake.

7.2.2 Organic composition

The dissolved organic composition of the surface water resources was characterized using organic carbon (OC) and organic matter (OM) contents. The infrared (IR) and ultra-violet light (UV-Vis) spectra were also used to characterize the organic composition of the water in the lakes and the Estuary based on the absorption bands and the colour rate to determine the saturation of dissolved organic compounds [differential between aliphatic (fulvic acid) and aromatic compounds (humic acid].

The results of the organic composition are as follows:

a) The Lake was relatively high in organic carbon (OC) and organic matter (OM) above the range (0.10 to 20mg/l of OM) suggested by Volk (2001), averaging 20 ±13 mg/l and 46±31mg/l respectively (**Table 21**)
b) The humic acid (HA) Infrared (IR) spectrum obtained for Lake water and sludge samples indicated principal absorption bands of relative strong intensities (**Figure 31 and Figure 32**) characterized by the following absorption bands (Haworth, 1971 Garcia *et al.*, 1992; Stevenson, 1994; Ayuso *et al.*, 1996; Dorado *et al.*, 2003)
    (i) O-H, free O-H or intermolecular bonded O-H a stretching around 3383cm^{-1} and 3318 cm^{-1} regions ((**Figure 31 and Figure 32**)

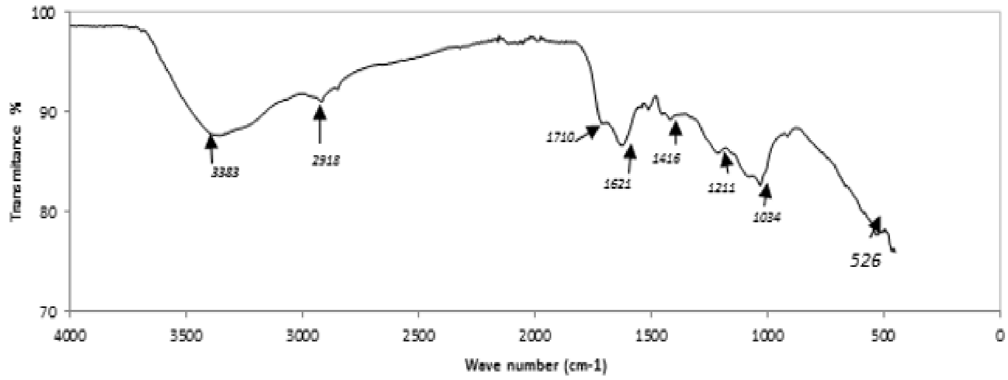

Figure 31: Lake Mgobezeleni humic acid IR spectrum

(ii) Aliphatic C-H, C-H_2-CH_3 stretching around 2918 cm^{-1} and 2930 cm^{-1} regions ((**Figure 31 and Figure 32)**. These bands were completely distorted in the sludge sample, thus indicating decomposition of the C-H, C-H_2-CH_3 bands

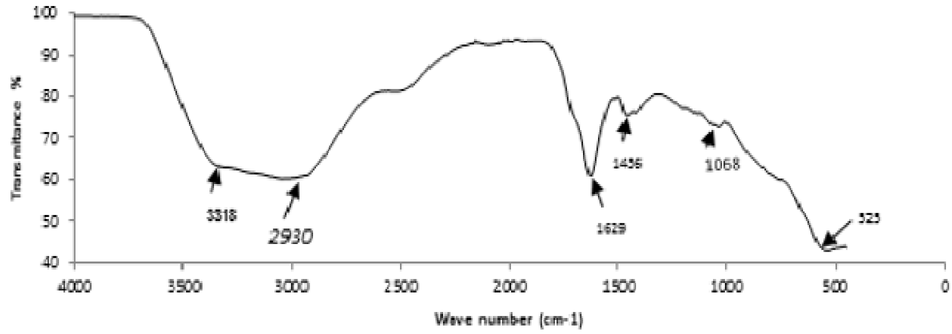

Figure 32: Lake Mgobezeleni sludge sample humic acid IR spectrum

(iii) Protonated carboxylic acid (C=O) stretching, cyclic and acyclic aldehydes, ketones, quinones; and C-O stretching of phenols, carboxylic acids, ethers and -COOH groups around 1717 cm^{-1} and 1211 cm^{-1} (Haworth, 1978; Stevenson, 1994). These bands were not observed in sludge samples due to the degree of decomposition ((**Figure 31 and Figure 32**)

(iv) Strong bands of C=C stretching vibration of the double bonds of the cyclic and acyclic compounds and benzene ring substitutions around 1621 cm^{-1} and 1629 cm-1 respectively (Dorado *et al*., 2003)

(v) Weak absorption bands of aliphatic C-H deformation around 1416 cm^{-1} and 1456 cm^{-1}.

(vi) Si-O stretching and bending, metal-oxygen stretching bands around 1034 cm^{-1}; 1086 cm^{-1} and at 526 cm^{-1}; 525 cm^{-1} respectively.

(c) The fulvic acid (FA) IR spectra were obtained for the Lake and the sludge sample. The bands of absorption are shown in **Table 22**

(d) The ultra-violet light (UV-Vis) spectra obtained for the Lake and the sludge sample were featureless and appeared to decrease with increasing wavelength (**Figure 33)**. The more pronounced shoulder bands were observed between 205 nm to 260 nm, which was attributed to the structural conjugation of quinone and ketones indicative of aromatic systems (Canellas, 1999). Based on the colour ratio (E4/E6), Lake Mgobezeleni reflected a high degree of condensed structures of aromatic compounds indicating the presence of humic acid (Chin *et al*., 1994, **Table 23**)

Table 22: Surface water fulvic acid infrared absorption bands

Absorption bands	**Lake Mgobezeleni**	**Sludge sample**	**Lake Shazibe**	**Mgobezeleni Estuary**
Stretching of hydrogen bonded O-H, free O-H or intermolecular bonded O-H.	3356 cm^{-1}	3350 cm^{-1}	3282 cm^{-1}	3351 cm^{-1}
C=C stretching vibration of the double bonds of the cyclic and acyclic compounds, benzene rings substitutions	1635 cm^{-1}	1630 cm-1	1635 cm-1	1626 cm^{-1}
Si-O stretching bands	-	1106 cm^{-1}	-	1132 cm^{-1}

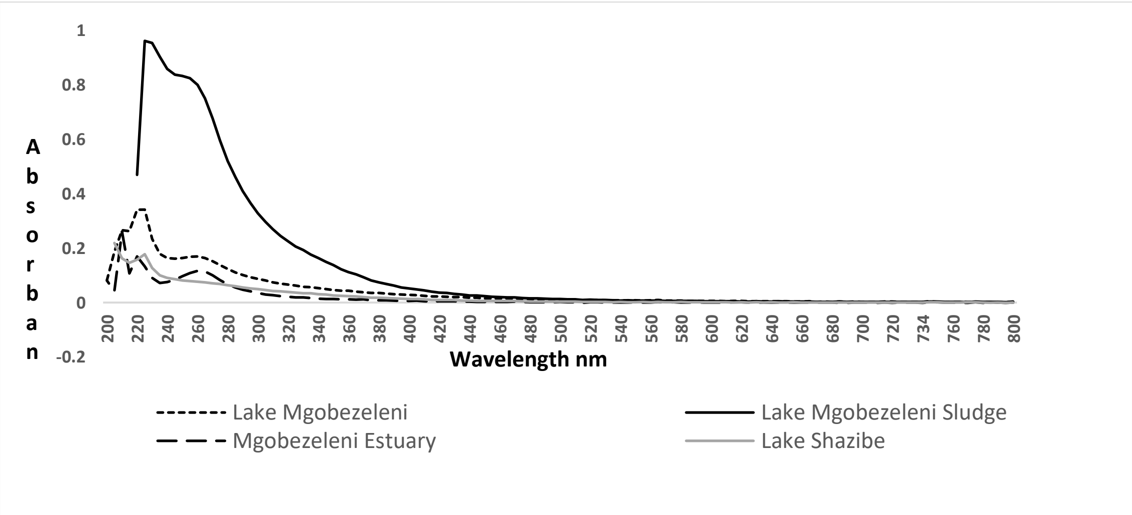

Figure 33: Mgobezeleni catchment water resources ultra-violet spectra

7.2.3 Physical and chemical composition

The physical composition of the lake water was analysed in the field using a multi-probe. The results of the physical composition are as follows:

a) The water was slightly acidic to slightly alkaline with pH values ranging between 6.20 and 8.38. It was characterized by a mean pH value of 8.04 ± 0.7. The pH values increased slightly towards the bottom region of the Lake (**Table 24**)
b) The temperature averaged to 22.5 ± 0.8 °C, generally decreasing by approximately 2.4 °C towards the bottom of the lake
c) The water was very turbid with high suspended solids. The turbidity and suspended solids averaged to 7.5 ± 4 NTU and 9.6 ± 8 mg/l respectively and were all above the TWQG limits
d) The water was low in salinity, averaging 0.18 ppt, and was found to be the same throughout the Lake
e) The dissolved oxygen (DO) concentration in the Lake ranged from 7.79 to 9.34 mg/l and averaged to 8.45 ± 1 mg/l, which was within the TWQG limit
f) The TDS and EC values averaged to 242 ± 3mg/l and 37.3 ± 0.4 mS/m respectively. Both values decreased towards the deeper region of the Lake (**Table 24**)

Table 23: Mgobezeleni catchment water resources colour ratios (E4/E6)

Area	E4	E6	E4/E6
Lake Mgobezeleni	0.015208	0.004441	3.42
Mgobezeleni Lake Sludge sample	0.019412	0.003117	6.23
Mgobezeleni Estuary	0.002611	0.000554	4.71
Lake Shazibe	0.005589	0.000652	8.57

The chemical composition of the lake was analysed in the laboratory. The results of the chemical composition are as follows:

a) The Lake water fluctuated in alkalinity, ranging from 1.2 to 152 mg/l and averaging 52.4 ± 10 mg/l. This was relatively higher in the upper layers of the lake profile

Table 24: Surface water chemistry (red highlights indicate values above the TWQG limits)

		pH	TDS(mg/l)	EC(mS/m)	Turb (NTU)	DO(mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	Na (mg/l(	SO_4 (mg/l)	Fe (mg/l)	Al(mg/l)	K(mg/l)	HCO_3(mg/l)	Mn(mg/l)	Tot. Hardness(mg/l)
TWQG		**6.5-8.5**	**<450**	**<40**	**<1**	**8-12**	**<32**	**<30**	**<100**	**<70**	**<200**	**<0.1**	**<0.15**	**<50**	**<50**	**<0.02**	**<40**
SANS 241		**5.0-9.7**	**<1200**	**<70**	**1-5**		**<250**	**<70**	**<250**	**<200**	**<400**	**<2**	**<0.3**	**<50**		**<0.5**	
Lake Mgobezeleni	Mean	8.04 ± 0.7	242 ± 3	37.3 ± 0.4	7.5 ± 4	8.45 ± 0.6	14.0 ± 3	5.20 ± 1	70.7 ± 7	40.9 ± 5	4.57 ± 1	0.14 ± 0.1	0.05 ± 0.03	2.88 ± 0.5	52.4 ± 10	0.01 ± 0.01	57.8 ± 15
	Min	6.20	240	36.9	0.45	7.79	5.80	2.59	52.7	33.9	2.35	0.06	0.02	1.82	1.2	0.01	25.1
	Max	8.38	248	38.2	10.0	9.34	17.7	6.15	76.3	46.9	6.19	0.21	0.12	3.61	152	0.03	69.1
Sludge sample	Mean	6.20 ± 0.9	167 ± 48	33.2 ± 10	516 ± 304		12.7 ± 3	5.22 ± 0.7	69.9 ± 0.7	38.8 ± 10	11.8 ± 2	0.03 ± 0.03	0.27 ± 0.4	3.63 ± 0.2	39.9 ± 32	0. 14 ± 0.14	31.7 ± 21
	Min	5.13	112	21.8	201		3.20	4.46	52.2	27.6	5.80	0.01	0.01	3.44	3.00	0.01	8.00
	Max	6.84	198	39.3	808		17.5	5.68	79.7	45.0	17.5	0.07	0.71	3.85	59.6	0.29	43.7
Lake Shazibe	Mean	7.46 ± 0.6	252 ± 5	38.0 ± 3	1.13 ± 0.6	7.38 ± 2	15.7 ± 4	6.36 ± 3	92.9 ± 26	53.3 ± 19	5.46 ± 9	0.11 ± 0.01	0.05 ± 00.2	3.94 ± 3	50.3 ± 13	0.04 ± 0.04	68.4 ± 25
	Min	6.37	240	31.1	0	3.68	8.80	3.35	75	41.5	0.01	0.01	0.01	1.80	38.1	0.01	40.6
	Max	8.10	258	39.7	1.87	9.65	24.6	12.4	152	96.7	24.7	0.21	0.08	11.7	77.5	0.09	112
Mgobezeleni Estuary	Mean	7.53 ± 0.4	15800 ± 9	258 ± 1322	9.53 ± 18	7.80 ± 1	15.9 ± 1	12.0 ± 8	157 ± 95	87.4 ± 95	14.0 ± 15	0.09 ± 0.	0.05 ± 0.03	6.00 ± 3	60.1 ± 13	0.03 ± 0.04	80.1 ± 15
	Min	6.89	3400	349	0.95	6.37	13.6	2.83	50.7	32.2	4.64	0.04	0.01	2.53	45.9	0.01	49.6
	Max	7.92	22700	3495	72.9	9.63	18.0	38.8	456	254	68.5	0.50	0.14	15.0	107	0.09	113

b) It was relatively low in cations and anions such as Ca, Mg, K and SO_4 concentrations, especially in the lower layers of the water column
c) Calcium concentration decreased towards the bottom of the lake. The Ca:Mg ratio was 3:1, indicating dominance of calcium ions over magnesium ions
d) The water was characterized by high sodium (40.9 ± 5 mg/l) and chloride (70.7 ± 7 mg/l) concentrations. The Na: Cl ratio was 1:2, indicating dominance of chloride ions over sodium ions
e) It was low in Al^{3+} concentration and elevated in Fe^{2+} and Mn^{2+} concentrations, especially in the sub-surface levels of the lake (**Table 24**)

7.3 Lake Shazibe water quality

7.3.1 Nutrient composition

a) The NO_3-N concentration was relatively higher in the shallow region of the Lake averaging to 0.27 ± 0.1mg/l (**Table 25**). Nitrate ions are likely consumed by micro-organisms in the Lake. NO_2-N concentration was slightly elevated in the shallow region of the Lake.
b) NH_4-N concentration was higher in the bottom of the Lake, averaging 0.51 ± 0.7mg/l, which was above the TWQG limit
c) The TN concentration averaged to 0.81 ± 0.7 mg/l, indicating that the Lake was mesotrophic. Higher TN values were observed in the shallow region of the Lake. The mean TN concentration of the borehole assessed for water quality near the Lake was 5.38 mg/l. Considering a steady state annual net groundwater inflow into the lake of 456 250 m^3 and total lake water storage volume of approximately 1.83 Mm^3, the annual groundwater dilution factor was estimated at 1:4. Therefore, the TN concentration in the Lake was estimated at 1.34 mg/l. The mean concentration was 1.7 times lower than the estimated value. It was therefore assumed that nitrogen in the Lake are used up by plant material causing the eutrophication in Lake. Lake Shazibe was higher in the number of macrophytes species compared to Lake Mgobezeleni. Due to the lower level of nutrients in the deeper region, the Lake was low in microalgal species.
d) The PO_4-P concentration was mostly elevated in the subsurface levels, averaging 0.49 ± 2 mg/l and was above the TWQG limit

7.4.2 Organic composition

The results of OC and OM are as follows:

a) The dissolved organic substances were above the range suggested by Volk (2001).

b) The OC and OM contents averaged to 29 ± 10 mg/l and 65 ± 24 mg/l respectively (**Table 25**).
c) The HA IR spectrum was not obtained for Lake Shazibe, just the FA spectrum absorptions bands
d) The UV-Vis spectrum obtained for the lake was also featureless, indicating quinone and ketone bands of aromatic compounds around 205 to 260 nm
e) Based on the colour ratio (E4/E6), Lake Shazibe reflected a large composition of aliphatic structures and low quantities of condensed aromatic structures indicating the presence of fulvic acid components (Chin *et al*., 1977, **Table 25**)

Table 25: Lake Shazibe nutrient and organic compositions

Parameters		**SANS 241:11**	**TWQR**	**Units**	**Shallow levels (15 cm)**	**Deep levels (0.5-2.0m)**	**Mean values**
NO_3^-	Mean	≤ 10	≤ 6.0	mg/l	0.30 ± 0.1	0.10 ± 0.01	0.27 ± 0.1
	Min				0.15	0.09	0.09
	Max				0.52	0.11	0.52
NO_2^-	Mean	0	Unspecified	mg/l	0.04 ± 0.01	0.01 ± 0	0.03 ± 0.05
	Min				0.01	0.01	0.00
	Max				0.17	001	0.17
NH_4^+	Mean	0.45	0.007	mg/l	0.48 ± 0.7	0.70 ± 0.9	0.51 ± 0.7
	Min				0.03	0.05	0.03
	Max				2.44	1.34	2.44
TN	Mean		0.500	mg/l	0.82 ± 0.7	0.80 ± 0.9	0.81 ± 0.7
	Min				0.26	0.17	0.17
	Max				2.72	1.43	2.72
PO_4^{3-}	Mean		0.025	mg/l	0.02 ± 0.02	3.31 ± 5	0.49 ± 2
	Min				0.01	0.01	0.01
	Max				0.17	6.61	6.61
OC	Mean			mg/l			29 ± 10
	Min						21

	Max			36
OM	Mean	20	mg/l	65 ± 24
	Min			49
	Max			82

7.3.3 Physical and chemical composition

The physical composition was analysed in the field using the multi-probe. The results of physical composition of the Lake water are as follows:

a) The water in Lake Shazibe was slightly acid to slightly neutral, characterized by a mean pH value of 7.46 ± 0.6 (**Table 25**). The pH values appeared slightly higher at the surface levels (15 cm)
b) It was cool to warm in temperature; averaging 22.1 ± 0.9 °C and the temperature appeared to drop towards the deeper region of the lake by 1.3 °C
c) It was turbid with high suspended solids averaging to 1.13 ± 0.6 NTU value was above the TWQG limits
d) It was low in salinity averaging to 0.19 ± 0.01 ppt which appeared to decrease slightly towards the bottom part of the Lake
e) The DO levels in the Lake ranged from 3.68 to 9.65 mg/l averaging to 7.38 ± 2 mg/l, which was below the TWQG limit. It appeared to decrease by 3.2 mg/l towards the deeper region of the Lake
f) The TDS and EC values averaged to 252 ± 5 mg/l and 38.0 ± 3 mg/l respectively and appeared to decrease towards deeper part of the lake (**Table 25**).

The chemical composition was analysed in the laboratory and were found to be as follows:

a) The Lake water fluctuated in alkalinity, ranging from 38.1 to 77.5 mg/l, with an average of 50.3± 10 mg/l
b) It was low in most cations and anions such as Ca, Mg, K and SO_4 concentrations. The Ca: Mg ratio was 2:1.
c) It was elevated in sodium and chloride concentrations, averaging to 53.3 ± 19 mg/l and 92.9 ± 26 mg/l respectively. The Na: Cl ratio of the lake water was 1:2
d) It was relatively low in aluminium concentration. The mean ferrous iron (0.11 ± 0.01 mg/l) and manganese (0.04 ± 0.04 mg/L) concentrations were all above the TWQG limits

7.4 Mgobezeleni Estuary water quality

7.4.1 Nutrient composition

a) The NO_3-N concentration was higher in the shallow region, averaging 0.42 ± 0.5 mg/l. The average NO_3-N concentration of the estuary was 0.41 ± 0.1 mg/l (**Table 26**)
b) It was low in NO_2-N concentration in all levels averaging to 0.01 ± 0.01 mg/l
c) The NH_4-N concentration was higher in the deeper region of Estuary, similarly to Lake Shazibe, due to decomposing organic matter. The average concentration of the estuary was 0.41 ± 0.2 mg/l which was above the TWQG limit
d) The TN concentration was also relatively higher in the deeper levels, averaging 0.83 ± 0.3 mg/l which indicates that the Estuary is mesotrophic
e) The PO_4-P concentration was also relatively higher in the deeper levels, similarly to Lake Shazibe, and was above the TWQG limit, with an average of 0.03 ± 0.3mg/l

7.4.2 Organic composition

The organic composition of the estuary covers the OC, OM, HA, FA components. The HA and FA components were characterized using infrared (IR) and UV-Vis spectrophotometers.

The results of the organic carbon (OC) and organic matter (OM) are as follows:

a) The Estuary water was relatively high in organic substances above the range suggested by Volk (2001). The dissolved OC and OM contents averaged 40 ± 13 mg/l and 91 ± 24 mg/l respectively (**Table 26**). Accumulation of organic material fragments was observed at the base of the Estuary especially when its mouth was closed

Table 26: Mgobezeleni Estuary nutrient and organic composition

Parameters		SANS 241:11	TWQR	Units	**Shallow levels**	**Deep levels**	**Mean values**
NO_3^-	Mean	≤ 10	≤ 6.0	mg/l	0.42 ± 0.5	0.40 ± 0.2	0.41 ± 0.1
	Min				0.01	0.26	0.01
	Max				1.55	0.97	1.55
NO_2^-	Mean	0	Unspecified	mg/l	0.01 ± 0.001	0.01 ± 0.001	0.01 ± 0.001
	Min				0.01	0.01	0.00

	Max				0.0.0	001	0.01
NH_4^+	Mean	0.45	0.007	mg/l	0.32 ± 0.2	0.49 ± 0.2	0.41 ± 0.2
	Min				0.09	0.16	0.09
	Max				0.45	1.07	1.07
TN	Mean		0.500	mg/l	0.75 ± 0.4	0.90 ± 0.2	0.83 ± 0.3
	Min				0.14	0.80	0.14
	Max				1.62	1.34	1.65
PO_4^{3-}	Mean		0.025	mg/l	0.02 ± 0.01	0.03 ± 0.01	0.03 ± 0.3
	Min				0.01	0.01	0.01
	Max				0.03	0.03	0.03
OC	Mean			mg/l			40 ± 13
	Min						30
	Max						59
OM	Mean		20	mg/l			91 ± 24
	Min						69
	Max						135

b) The HA IR spectrum was not obtained for the estuary. The FA IR absorption bands and spectrum are shown in **Table 22**

c) The E4/E6 (the ratio absorbance at 465 nm/665 mn) relationship relates to the degree of condensation and aromaticity of the chain of aromatic carbons of humic acids. This was used for the humification index (Kononova, 1966; Stevenson and Schnitzer, 1982). The low E4/E6 ratio relates to a high degree of condensation in the structures, while the high ratio reflects the large aliphatic structures and low quantities of condensed aromatic structures (Chin *et al*., 1971). The ratio is larger for non-humified material owing to the presence of protein and carbohydrates, which increases the absorptivity at the UV region of the spectrum (Vieyra *et al*., 2009). The UV-Vis spectrum obtained was also featureless; indicating quinone and ketone bands of aromatic compounds around 205 to 260 nm (**Figure 34**). Based on the colour ratio (E4/E6), the estuary reflected the highest degree of condensed structure of aromatic compounds, thus indicating the presence of aliphatic compounds due to the presence of FA (**Table 22**).

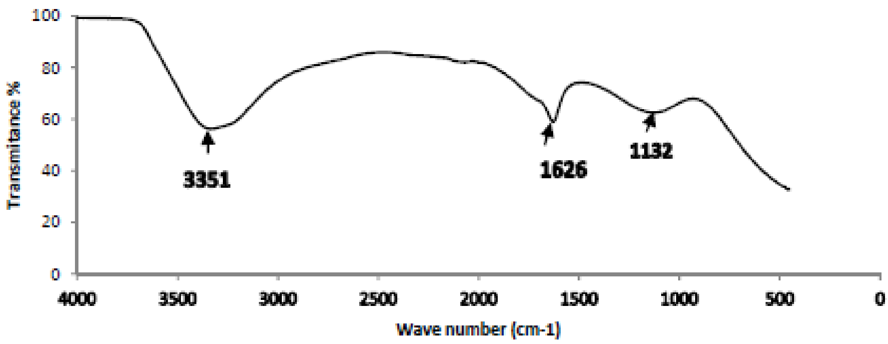

Figure 34: Mgobezeleni Estuary fulvic acid IR spectrum

7.4.3 Physical and chemical composition

The physical composition was analysed in the field using a multi-probe. The results of the physical composition of the estuary water are as follows:

a) The water was neutral to slightly alkaline characterized by a mean pH value of 7.53 ± 0.4 (**Table 24**). The pH values were slightly higher in the deeper region of the estuary due to the influence of sea intrusion into the estuary
b) It was cool in temperature, averaging 20.7 ±0.2 °C; the temperature appeared to decrease slightly towards the bottom of the estuary
c) The water in the Estuary was black in colour and very turbid. The turbidity and suspended solids concentrations were above the TWQG limits (**Table 24**)
d) The DO concentration in the Estuary ranged from 6.37 to 9.63 mg/l, averaging 7.80 ± 1 mg/l. The mean DO values were below the TWQG limit. The DO levels appeared to decrease by 2 mg/l towards the bottom of the Estuary
e) It contained high TDS and EC due to sea influx influence, especially at the bottom part of the Estuary. The TDS and EC values averaged to 15800± 9 mg/l and 258 ± 1322 mS/m respectively.
f) It was high in salinity levels due to the sea influx, especially in the bottom part of the Estuary, averaging 12 ± 9 ppt

The chemical composition of the Estuary water was analysed in the laboratory. The results were as follows:

a) Estuary water fluctuated in alkalinity, ranging from 45.9 to 107 mg/l, with an average of 60.1 ± 13 mg/l
b) It was low in Ca, Mg, and K and SO_4 concentrations. The Ca: Mg ratio was approximately 1:1.

c) It was dominated by sodium and chloride ions, averaging to 87 ± 95 mg/l and 157 ± 95 mg/l respectively, which were above the TWQG limits. The Na: Cl ratio was 1:2, indicating the dominance of sodium ions especially in the deeper region of the Estuary because of sea water influx

d) The mean Fe^{2+} and Al^{3+} concentrations were within the TWQG limits. The estuary did, however, have an elevated Mn^{2+} concentration averaging 0.03 ± 0.04 mg/l

7.5 Comparison of groundwater quality with lake and estuary water quality

The N and P cnutrient composition is all elevated in the groundwater above the lakes and the estuary due to leaching of nutrients from the sewage systems, except for phosphate ions which are elevate in Lake Shazibe owing to the decomposition of fringing macrophytes (**Figure 35**). This indicates that the groundwater is causing the surface water resources to be eutrophic, resulting in growth of macrophytes.

Most of the cations and anions concentrations are elevated in the Estuary due to the influx of the sea water which increases the salinity of estuary especially in the deeper region (**Figure 36**). All systems were relatively low in Ca, Mg, K and SO_4 concentrations.

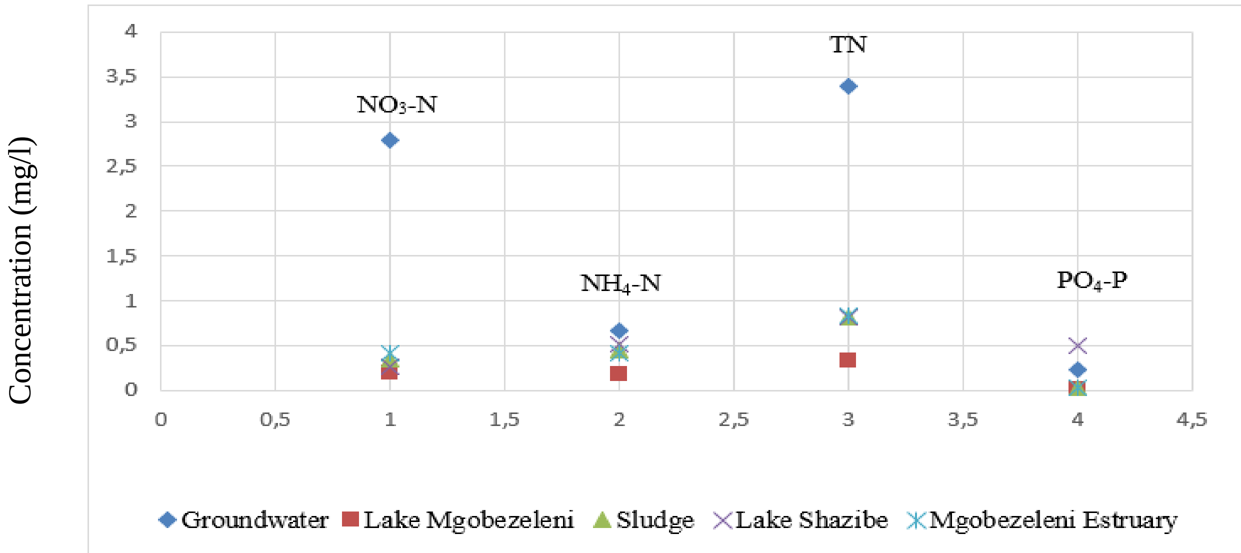

Figure 35: Groundwater quality comparison to lakes and estuary nutrient composition

Owing to high levels of decomposing vegetation in the deeper region of the Lake Mgobezeleni, the sludge sample indicated a relatively high level of Al and Mn concentrations. it was observed that the groundwater was also elevated in these concentration above lake and the estuary. The was elevated in Estuary and Lake Shazibe.

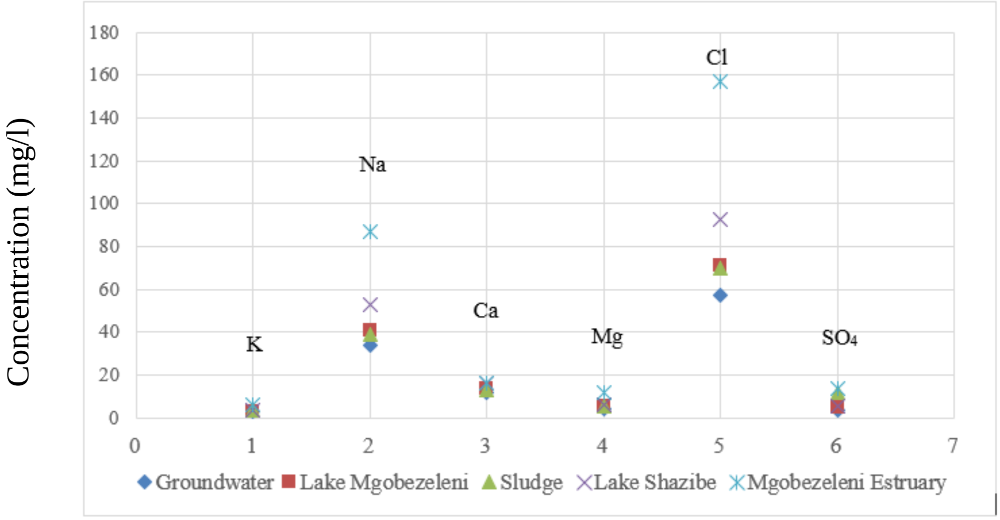

Figure 36: Groundwater quality comparison to lakes and estuary cations and anions compositions

7.6 Discussion

a) Lake Mgobezeleni

Lake Mgobezeleni is recharged by groundwater as base flow, which is elevated in N and P concentrations. The large volume water in the lake dilutes the groundwater quality and some of the groundwater nutrients are assimilated by the vegetation causing increasing the growth of macrophytes. However, the biodegradation of peat surrounding the Lake basin and organic material (leaves) caused by microorganisms and water recharge from the streams (rich in peat deposits) are increasing the N and P concentrations in the Lake water column.

Owing to a large amount of suspended organic material in the water column, the water is high in NH_4^+ ions in the surface region of the Lake (ammonium ions are normally the first inorganic nitrogen species produced by the biodegradation of nitrogenous compounds). Nitrate ions are produced by an oxidation process in this layer but immediately assimilated by plants. The NH_4^- ions are the major contributor to the Lake TN concentration.

The low nutrient concentration in the water column of the Lake resulted in a lower number of macrophyte species but, owing to the high levels of nutrients at the base of the Lake, it was higher in microalgal species (Bate *et al*, 2016). Biodegradation of organic material produces high levels of dissolved organic matter in the Lake, resulting in the formation of humic substances. Due to high levels of humic substances in the Lake water column results in the formation of *blackwater* (Kortelainnen, 1999). Humic substances bind organic and inorganic nutrients resulting in nutrients in the Lake.

Deducing from the sludge sample nutrient composition and organic substances are accumulating at the base of the Lake. Accumulation of brownish organic material in the form of colloidal particles was also observed at the base of the shallow region of the Lake. The accumulation of high nutrients at the base of the Lake results in high growth of microalgal species.

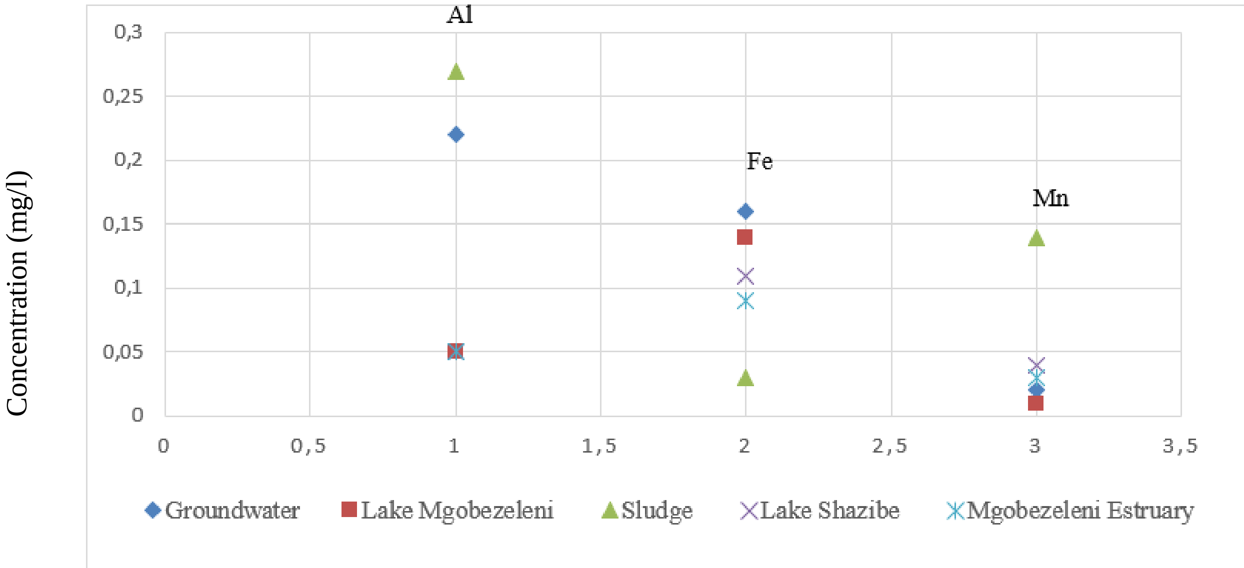

Figure 37: Groundwater quality comparison to lakes and estuary trace elements composition

The study by Bate *et al*. (2016) indicated that Lake Mgobezeleni is elevated in microalgal species. The dominant species are cyanophytes dominated by toxic *Microcystic aeruginosa*. The Lake also contains populations of flagellates and diatoms, with flagellate population being larger than the diatom population. Flagellates are an indication of relatively high dissolved organic material in the lake water column. A high population of dinophytes was also found. The significant slow water movement and retention time of water in Lake Mgobezeleni is the cause of the growth of cyanobacteria in the lake. Dominant toxic *Microcystic aeruginosa* can affect domestic and wild animals and may also threaten the water supply to Ezemvelo KZN Wildlife residential area (Scott, 1999; van Ginkel, 2004).

The dissolved OM content in the lake contains both HA and FA. The base of the lake contains mostly the humified organic material due to decomposed plant material. According to the colour ratio E4/E6, although the samples were crude, Lake Mgobezeleni reflected a high degree of condensed structures of aromatic compounds, thus indicating the presence of humic substances.

The water is characterized by a mean pH value of 8.04 ± 0.7, which is controlled by the HCO_3^- species, probably from the dissociation of CO_2 from the atmosphere and from the decayed organic matter. The suspended organic material and water turbulence results in high water turbidity and suspended solids. Although the water is high in dissolved organic matter, owing to the water turbulence and the photosynthetic function of algae at the base of the lake, the water is high in DO levels, although it appeared to decrease slightly towards the deeper region of the Lake. The high levels of DO and temperature in the deeper region (around 3 m depth) of the Lake indicate a lack of stratification (water mixing).

Owing to the presence of humic substances forming complexes with cations, the water is low in most cations and anions. It is, however, elevated in sodium and chloride ions. Because the water is high in DO (aerobic).

a) Lake Shazibe

Similarly, to Lake Mgobezeleni, Lake Shazibe receives water recharge from the groundwater system as base flow, which has an elevated N and P compositions. The smaller capacity of the Lake is assumed to have little dilution of the groundwater quality. The submerged macrophytes seem to be assimilating most of the nutrients in the Lake.

However, biodegradation of the peat and organic matter by microorganisms at the base of the Lake appears to increase the N and P concentrations in the Lake water column. This is evident from the high levels of NH_4^+ ions in the subsurface region of the Lake. Because of the anaerobic conditions at the base of the Lake, nitrate ions are low and only elevated in the subsurface level. This indicates that NO_3^- ions are assimilated by submerged macrophytes.

Lake Shazibe is higher in dissolved organic substances than Lake Mgobezeleni. This is because the lake is shallow and has submerged macrophytes dying and decomposing at the base of the lake, resulting in high dissolved organic substances. The Lake is assumed to medium in the groundwater recharge with a small stream outlet. This results in nutrients and organic substance concentration in the lake because of the low flushing rate.

The levels of dissolved organic components in the catchment water resources indicate that there is a high consumption of dissolved oxygen and common anoxic conditions at the base of the Lake. The high dissolved organic matter content of the dystrophic lake water indicates that it is high in humic substances. The biodegradation of organic material produces high levels of dissolved organic matter in the Lake, including the humic substances. Owing to the high levels of these substances in the water column of the Lake, high levels of humic substances have resulted, thus forming the *blackwater* in the Lake (Kortelainnen, 1999). Based on the nutrient and dissolved organic matter content in Lake, the vegetation is decaying at the base of the Lake. The accumulation of high nutrients in the base of the lake results in the growth of microalgal species.

Lake Shazibe is relatively lower in populations of cyanophyte, flagellate and dinophyte species than Lake Mgobezeleni, while the diatom populations are similar in both lakes. The Lake is also found to have a large number of fringing macrophytes. The population of microalgal species in the Lake is due to water turbulence with a short water resident time.

The lake contains elevated concentration of OC and OM. The composition of these organic materials was characterized using IR and UV-Vis spectra. According to IR UV-Vis spectra, although the samples were crude, reflects high levels of aliphatic compounds thus indicating the presence of fulvic acid.

The water in Lake Shazibe is characterized by a mean pH value of 7.46 ± 0.6, which is controlled by the HCO_3^- species from the dissociation of CO_2 in the atmosphere and the decay of organic matter. The suspended organic matter and water turbulence results in high water turbidity and suspended solids.

The turbulence of the Lake does not have a major impact on the mixing of Lake water. Submerged vegetation photosynthesis and the biodegradation of plant material are the main factors affecting the DO levels in the lake. The Lake did not indicate any form of stratification. Owing to the presence of humic substances, the water was low in most cations but elevated in sodium and chloride ions. Because the water was high in DO (aerobic), it contained high suspended iron as Fe $(OH)_3$ and soluble iron in the form of the complex. Lake Shazibe was elevated above the groundwater quality in Na, Mg, Cl, HCO_3^- and Mn concentrations. High level of these in the Lake could indicate saline intrusion into the Lake or potential saturation of ions in the Lake.

b) Mgobezeleni Estuary

Similarly, to Lake Mgobezeleni and Lake Shazibe, the Mgobezeleni Estuary receives groundwater recharge as base flow with an elevated N and P concentrations. The smaller capacity of the Estuary does not have a significant impact on the dilution of groundwater quality.

The biodegradation of the peat and organic matter by micro-organisms at the base of the Estuary seems to increase the N and P concentrations in the Estuary water column. This was evident from the high levels of NH_4^+ ions in the subsurface region of the Estuary. Owing to slightly anaerobic conditions at the base of the Estuary, nitrate ions are lower and only elevated in the subsurface level, thus indicating aerobic conditions. NO_3^- ions are also assimilated by macrophytes.

The study by Bate *et al*. (2016) indicates that the Mgobezeleni Estuary is low in population of microalgal species owing to dominant macrophytes. Microalgae are normal in the estuary with lower numbers of *Microphytobenthos* species than expected. The estuary also contains lower population of cyanophytes. The Mgobezeleni Estuary is higher in organic substances than Lake Mgobezeleni and Lake Shazibe. This is because the Estuary is small and shallow, surrounded by macrophytes which are dying and decomposing at the base of the lake, thus resulting in high dissolved organic substances. Some of the organic matter is received from the surface water recharge from the stream and lakes. When the mouth of the estuary is closed, organic material accumulates at the base of the Estuary as brownish material (rendering the water black) until the mouth breaches.

The high levels of organic components in the base of the estuary result in low DO oxygen levels, which are found to be below the TWQG limit. The high organic content of the dystrophic estuary indicates high levels of humic substance. The biodegradation of organic matter produces high levels of dissolved organic matter in the lake, including the humic substances. The accumulation of high nutrients at the base of the Estuary results in high growth of microalgal species. According to the colour ratio E4/E6, although samples were crude, the Mgobezeleni Estuary reflects high levels of aliphatic compounds, thus indicating the presence of fulvic acid.

The water in the Estuary is characterized by a mean pH value of 7.53 ± 0.4, which is controlled by the HCO_3^- species from the dissociation of CO_2 in the atmosphere and the decay of organic matter. The suspended organic matter and water turbulence results in high water turbidity and suspended solids, but the turbulence of the estuary does not have a major impact on water mixing. Biodegradation of plant material is the main factor affecting the DO levels in the Estuary. The estuary does not indicate any form of stratification; high TDS, EC and salinity values are high due to the sea influx into the Estuary. Owing to the presence of humic substances, the water is found relatively low in most cations. It is, however, elevated in sodium and chloride ions. Mgobezeleni Estuary was also elevated above the groundwater quality in Na, Mg, Cl, HCO_3^- , SO_4 and Mn concentrations. These ions are likely to have been introduced by sea intrusion into the Estuary.

CHAPTER 8

WETLAND WATER QUALITY RESULTS

8.1 Introduction

This chapter provides the wetlands water quality results in the Mgobezeleni catchment. It covers N and P, physical and chemical composition (including organic substances). Factors responsible for the cause of the *blackwater* will also be discussed. The wetlands water quality is affected by the groundwater quality causing the eutrophication (growth and decomposition of vegetation increasing organic matter content)

The following four wetlands were investigated in the Mgobezeleni catchment for water quality:

a) Bhekaphandle Wetland
b) Thungwini Wetland
c) Culvert Wetland
d) Sangweni Pan

8.2 Bhekaphandle Wetland composition

8.2.1 Nutrient composition

The water quality of Bhekaphandle Wetland was assessed at two different wetland sites on the Bhekaphandle stream (**Table 27**). The results are as follows:

a) The Wetland water was found to be relatively low in NO_3-N concentration (mean 0.21 ± 0.2 mg/l), which was almost equivalent to that of Lake Mgobezeleni. This indicated a potential direct influence on the Lake water quality
b) It was slightly elevated in NO_2-N concentration, averaging 0.06 ± 0.1 mg/l
c) The NH_4-N concentration was above the TWQG limit and the NO_3-N concentration, averaging 0.29 ± 0.1 mg/l
d) The TN concentration was relatively high, averaging 0.51 ± 0.4 mg/l, which was classified as mesotrophic (productive systems, DWAF, 1996)
e) The PO_4-P concentration was above the TWQG limit and averaged 0.04 ± 0.1 mg/l

8.2.2 Organic composition

The organic matter of the wetlands was analysed to determine the levels of organic matter (OC and OM in the wetlands due to decomposing vegetation. The IR and UV-Vis spectra were used to be characterized the dissolved organic matter (humic substances) content in the lake to determine their saturation levels (aliphatic (fulvic acid) of aromatic (humic acid). It was assessed through understanding of the absorption bands

a) The Bhekaphandle Wetland water was found to be higher in organic substances than the Lakes and the Estuary. The organic carbon (OC) and organic matter (OM) contents averaged 47 ± 22 mg/l and 112 ± 53 mg/l respectively (**Table 27**)
b) The Humic acid (HA) infrared (IR) spectrum obtained for Bhekaphandle Wetland indicated the principal absorption bands of relatively strong intensities (**Figure 38**), which was characterized by the following absorption bands, as identified by Haworth (1978), Garcia *et al.* (1992), Stevenson (1994), Ayuso *et al*. (1996) and Dorado *et al*. (2003):

(i) Aliphatic C-H, C-H_2C-H_3 stretching and aliphatic C-H deformation around 1700 cm^{-1}
(ii) C-O stretching of the phenols, carboxylic acid, ethers and COOH groups around 1400 cm^{-1} 1400
(iii) C=C stretching vibration of the double bonds of the cyclic and acyclic compounds, benzene ring substitutions around 1230 cm^{-1}
(iv) Si-O stretching around 1030cm^{-1}

Table 27: Nutrient and organic composition

Parameters	TWQR	Units	Bhekaphandle	Thungwini	Culvert	Sangweni Pan
NO_3^-	≤ 6.00	mg/l	0.21 ± 0.2	0.35 ± 0	0.12 ± 0.2	0.19 ± 0.1
Min			0.01	0.35	0.01	0.03
Max			0.41	0.35	0.35	0.29
NO_2^-	Unspecified	mg/l	0.06 ± 0.1	0.01 ± 0	0.003 ± 0.01	0.02 ± 0.01
Min			0.01	0.01	0.00	0.01
Max			0.34	0.01	0.01	0.03
NH_4^+	0.007	mg/l	0.29 ± 0.1	0.45 ± 0	0.17 ± 0.2	9.35 ± 2
Min			0.01	0.45	0.02	6.76
Max			1.03	0.45	0.45	10.9
TN	0.500	mg/l	0.51 ± 0.4	0.81 ± 0	0.30 ± 0.4	9.55±2
Min			0.02	0.81	0.03	6.80
Max			1.45	0.81	0.81	11.22

PO_4^{3-}	0.0025	mg/l	0.04 ± 0. 1	0.03 ± 0	0.02 ± 0.01	0.02 ± 0.01
Min			0.01	0.03	0.01	0.01
Max			0.26	0.03	0.03	0.03
OC		mg/l	47 ± 22	71 ± 61	41 ± 20	
Min			12	12	21	
Max			78	143	62	
OM		mg/l	112 ± 53	164 ± 141	95 ± 45	
Min			27	27	47	
Max			179	328	143	

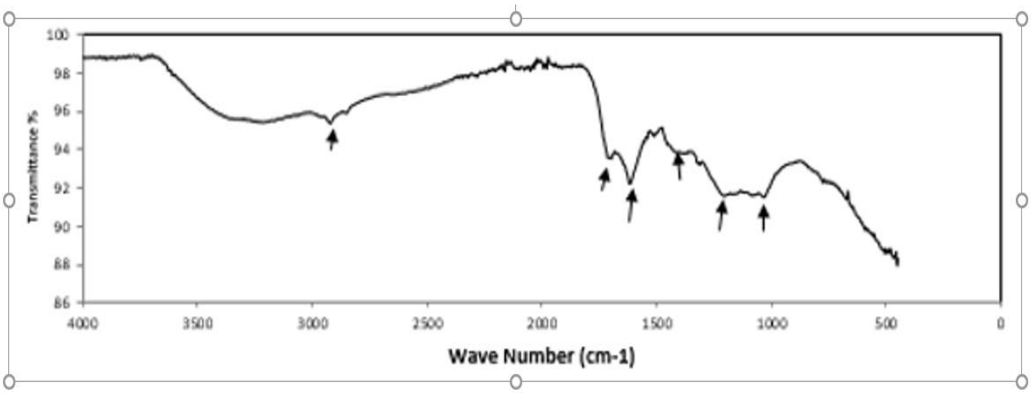

Figure 38: Bhekaphandle Wetland HA IR spectrum (arrows indicating associated absorption bands)

(c) The fulvic acid (FA) infrared (IR) spectrum was characterized by the following absorption bands:

(i) H-bonded O-H, free O-H, and intermolecular bonded O-H broad absorption bands around 3330 cm^{-1}

(ii) C=C stretching vibration of the double bonds of the cyclic and acyclic compounds, benzene ring substitutions around 1620 cm^{-1} (**Figure 39**)

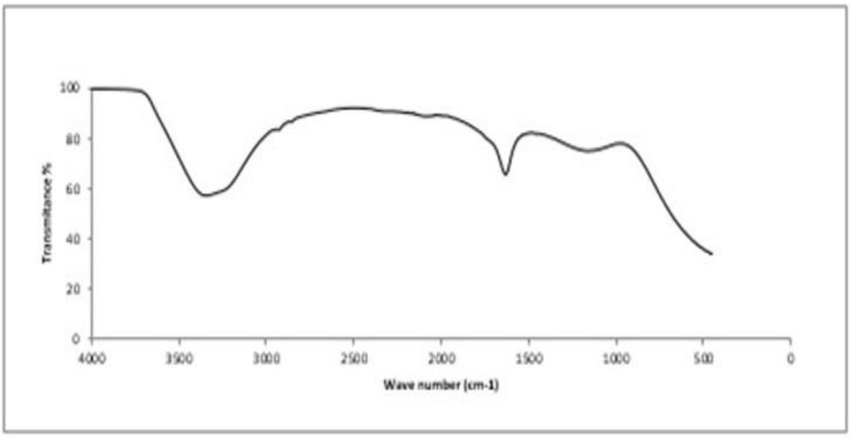

Figure 39: Bhekaphandle Wetland FA IR spectrum

The ultra-Violet visible region (UV-Vis) spectrum decreases with increasing wavelength (**Figure 40**). The more pronounced shoulder bands were observed between 205 nm and 265 nm and were attributed to the structural conjugation of quinones and ketones indicative of aromatic systems (Canellas, 1999; Chin *et al*., 1994).

8.3.3 Physical and chemical water composition

The results of the physical composition are as follows:

a) The water was acidic to neutral and characterized by a mean pH value of 6.08 ± 0.6. (water analysed in the laboratory).
b) The water was cool to warm in temperature, averaging 21.2 ± 1 °C
c) It was very turbid with high levels of suspended solids, averaging 918 ± 37 NTU and 845 ± 1724 mg/l respectively due to peat fragments (**Table 28**). These values were all above the TWQG limits
d) The TDS and EC values were within the TWQG limits, averaging 265 ± 120 mg/l and 40.9 ± 9 mS/m respectively (**Table 28**)

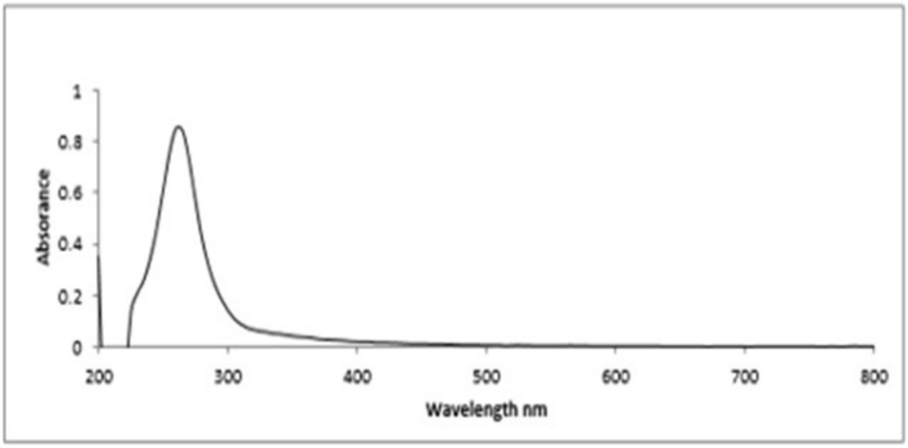

Figure 40: Bhekaphandle Wetland UV-Vis spectrum

The results of the chemical composition are as follows:

a) The water was low in most cation and anion compositions such as Ca, Mg, K and SO_4 concentrations. The Ca: Mg ratio was 3:1, thus indicating the dominance of calcium ions over magnesium ions
b) It was elevated in Na (41 ± 5mg/l) and Cl (71 ± 7mg/l) concentrations and comprised of Na: Cl ratio of 1:2
c) It was elevated above the TWQG limits in Al^{3+}, Fe^{2+} and Mn^{2+} concentrations (**Table 28**)

Table 28: Wetlands water chemistry (Red highlight indicating values above the TWQG limits)

		pH	TDS(mg/l)	EC(mS/m)	Turb. (NTU)	SS(mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	Na (mg/l)	SO_4 (mg/l)	Fe (mg/l)	Al(mg/l)	K(mg/l)	HCO(mg/l)	Mn(mg/l)	Tot. Hardness(mg/l)
TWQG		**6.5-8.5**	**<450**	**<40**	**<1**	**<1**	**<32**	**<30**	**<100**	**<70**	**<200**	**<0.1**	**<0.15**	**<50**	**<50**	**<0.02**	**<40**
Bhekaphandle Wetland	Mean	6.08 ± 0.6	265 ± 120	40.9 ± 19	918 ± 37	845 ± 1724	13.5 ± 12	4.93 ± 1	68.0 ± 17	38.6 ± 12	4.55 ± 1	0.16 ± 0.15	0.30 ± 0.62	3.88 ± 1	48.5 ± 52	0.03 ± 0.01	43.9 ± 16
	Min	5.42	105	55.3	892	0	1.42	3.61	49.5	26.6	0.33	0.01	0.01	2.94	4.6	0.01	18.4
	Max	6.93	359	16.2	944	5887	39.5	6.15	103	57.1	11.2	0.45	2.21	6.24	138	0.22	69.1
Thungwini Wetland	Mean	7.03 ± 0.01	149 ± 5	29.9 ± 0.4	4.53 ± 3	1.00 ± 1	17.5 ± 4	3.87 ± 0.04	60.9 ± 1	32.5 ± 1	0.16 ± 0	0.17 ± 0.01	0.16 ± 0	2.95 ± 0.3	46.0 ± 0.3	0.02 ± 0.01	59.5 ± 9
	Min	7.01	145	29.6	2.38	0.40	14.9	3.84	60.5	32.0	0.16	0.16	0.16	2.76	45.8	0.01	53.0
	Max	7.03	149	30.1	6.68	2.00	20.0	3.89	61.2	32.9	0.16	0.18	0.16	3.13	46.2	0.02	66.0
Culvert Wetland	Mean	6.32 ± 0.2	240 ± 6	36.6 ± 0.3	0.28 ± 0	1.20 ± 2	15.7 ± 1	5.85 ± 1	92.8 ± 1	43.7 ± 6	0.17 ± 0.3	0.02 ± 0.01	0.01 ± 00.2	2.30 ± 0.4	39.7 ± 1	0.01 ± 0.04	63.4 ± 5
	Min	6.17	236	36.4	0.28	0	14.7	5.36	91.4	40.2	0.01	0.01	0.01	2.05	38.8	0.01	58.8
	Max	6.47	245	36.8	0.28	3.20	17.1	6.27	94.2	96.7	0.50	0.05	0.02	2.75	40.8	0.01	68.5
Sangweni Pan	Mean	4.13 ± 0.6	807 ± 105	154 ± 20		14 ± 8	16.5 ± 3	47.6 ± 10	309 ± 19	186 ± 16	218 ± 56	0.64 ± 0.2.	0.69 ± 0.3	13.2 ± 0.3	2.60 ± 0.1	0.36 ± 0.06	237 ± 48
	Min	3.70	686	131		8	13.2	36.0	287	168	154	0.39	0.33	12.9	0	0.30	181
	Max	4.81	870	166		19	18.2	53.5	321	197	254	0.80	0.88	13.4	0.40	0.40	265

The water in the wetlands was characterized by acidic to neutral pH values and was slightly buffered against acidity. The presence of peat fragments resulted in high levels of suspended solids and turbidity in the water. Due to the active peat sites, most of the cations were assumed to have been attracted to active sites, resulting in low levels of cations. As a result of the reducing conditions (anaerobic) of the wetland, sulphate ions were low because of a reduction into hydrogen sulphide (H_2S). The reducing conditions of the wetlands resulted in elevated Al^{3+}, Fe^{2+} and Mn^{2+} concentrations above the TWQG limits.

8.3 Thungwini Wetland composition

8.3.1 Nutrient composition

The water quality of the Thungwini Wetland was assessed at the Tolla se Gat road crossing at two different wetland sites on the Thungwini stream. The results are as follows:

a) The NO_3-N concentration was relatively low, almost equivalent to that of Lake Shazibe, thus indicating a potential direct influence on the lake water quality
b) It was low in NO_2-N concentration, averaging 0.01 ± 0 mg/l (**Table 27**)
c) The NH_4-N concentration was above the TWQG limit and NO_3-N concentration, averaging to 0.45 ± 0 mg/l
d) The TN concentration was relatively high, averaging 0.81 ± 0.4 mg/l, and was therefore classified as mesotrophic (DWAF, 1996)
e) The PO_4-P concentration averaged of 0.03 ± 0 mg/l, and was above the TWQG limit

8.3.2 Organic composition

a) The organic carbon (OC) and organic matter (OM) content averaged to 71 ± 61 mg/l and 164 ± 141 mg/l respectively (**Table 27**)
b) The HA IR spectrum obtained for Thungwini Wetland is shown in **Figure 41**
c) The strong absorption bands were similar to those of Bhekaphandle wetland and resembled those identified by Haworth (1977), Garcia *et al.* (1992), Stevenson (1994), Ayuso *et al.* (1996) and Dorado *et al.* (2003)
d) The UV-Vis spectrum was also featureless and seemed to decrease with increasing wavelength. More pronounced shoulder bands were observed around 205 nm to 265 nm, which is attributed to structural conjugation of quinones and ketones (Chin *et al.*, 1994; Canellas, 1999)

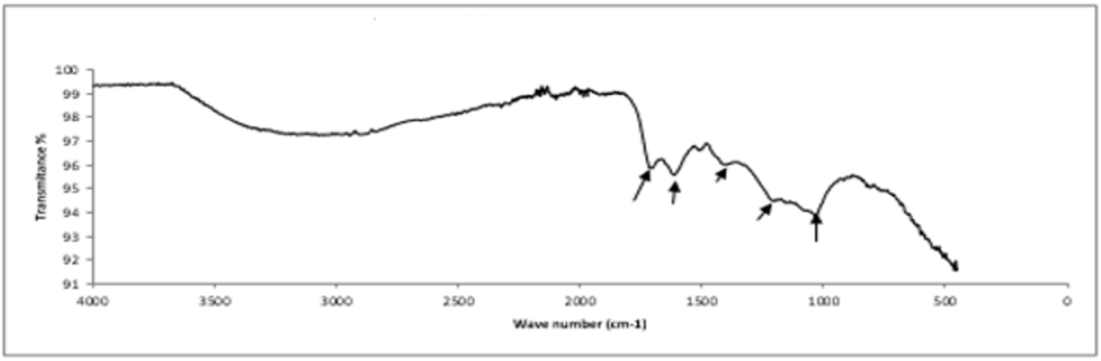

Figure 41: Thungwini wetland HA IR spectrum (arrows indicating associated absorption bands)

8.3.3 Physical and chemical composition

The results of the physical composition of the Thungwini Wetland water are as follows

a) The water was neutral, characterized by a mean pH value of 7.03 ± 0.01
b) It was relatively high in turbidity and suspended solids above the TWQG limits, averaging 4.53 ± 37 NTU and 1.0 ± 1 mg/l respectively (**Table 28**)
c) The TDS and EC values averaged 149 ± 5 mg/l and 29.9 ± 0.4 mS/m respectively (**Table 28**)

The results of the chemical composition are as follows:

(a) The water was relatively low in most cations and anions such as Ca, Mg, K and SO_4 concentrations. The Ca: Mg ratio was 5:1, indicating a lower concentration of magnesium ions in the Wetland. The water was dominated by Na (32.5 ± 1 mg/l) and Cl (60.9 ± 1 mg/l) concentration with the Na: Cl ratio of 1:2
(b) It was elevated in Al^{3+}, Fe^{2+} and Mn^{2+} concentrations above TWQG limits (**Table 28**)

8.4 Culvert Wetland composition

8.4.1 Nutrient composition

The water quality of the Culvert Wetland was assessed at Sodwana Bay culvert road crossing which is recharged by the Lake Shazibe outlet stream. The results are as follows:

a) The NO_3-N concentration was relatively low, averaging 0.12 ± 0.2 mg/l, which was lower than the Lake Shazibe concentration
b) The NO_2-N concentration was lower, averaging 0.003 ± 0.01 mg/l (**Table 27**)
c) The NH_4-N concentration was above the TWQG limit, averaging 0.17 ± 0 mg/l

d) The TN concentration averaged 0.30 ± 0.4 mg/l and the wetland was therefore classified as oligotrophic (DWAF, 1996)

e) The PO_4-P concentration was above the TWQG limit, averaging 0.02 ± 0 mg/l (**Table 27)**

8.4.2 Organic composition

a) The organic carbon (OC) and organic matter (OM) content averaged 41 ± 20 mg/l and 95 ± 45 mg/l respectively (**Table 27**)

b) The HA and FA IR spectrum obtained for the Culvert Wetland is shown in **Figure 42** and indicate strong absorption bands resembling those of the Thungwini Wetland and Bhekaphandle Wetland

c) The UV-Vis spectrum was also featureless with pronounced shoulder bands for the structural conjugation of quinones and ketones observed in the same region as above (Chin *et al.*, 1994; Canellas, 1999)

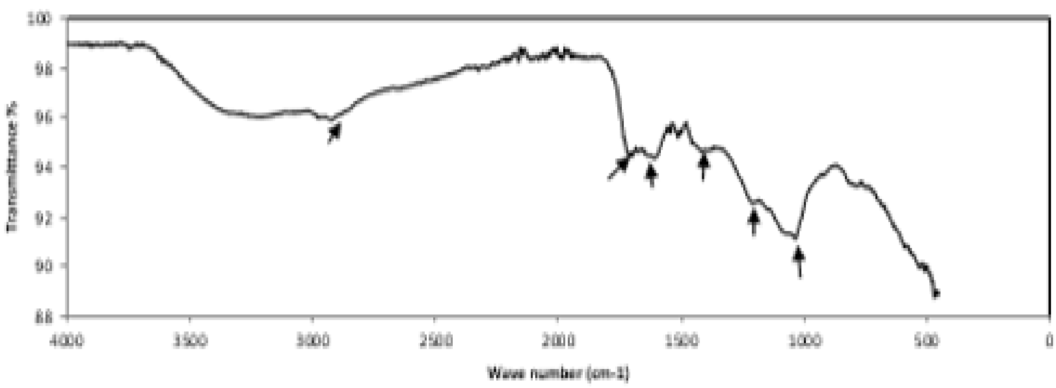

Figure 42: Culvert Wetland HA IR spectrum (arrows indicating associated absorption bands)

8.4.3 Physical and chemical composition

The results of the physical composition are as follows:

a) The water was slightly acidic with a mean pH value of 6.32 ± 0.2

b) It was cool in temperature, averaging 18.9 ± 0.4 °C

c) It was low in turbidity but higher in suspended solids above the TWQG limit (**Table 28**).

d) The TDS and EC values averaged 240 ± 6 mg/l and 36.6 ± 0.3mS/m respectively

The results of the chemical composition are as follows:

a) The water was characterized by low Ca, Mg, K and SO_4 concentrations. The Ca: Mg ratio was 3:1
b) It was dominated by Na (43.7 ± 6mg/l) and Cl (92.8 ± 1 mg/l) concentrations with an Na: Cl ratio of 1:2
c) It was low in Al^{3+}, Fe^{2+} and Mn^{2+} concentrations

8.5 Sangweni Pan composition

8.6.1 Nutrient composition

The water quality of the Sangweni wetland was assessed at the Sangweni Pan which is situated south of Lake Mgobezeleni. The results are as follows:

a) The NO_3-N concentration was found to be relatively low, resembling that of Lake Mgobezeleni and averaging 0.19 ± 0.1 mg/l (**Table 27**)
b) The NH_4-N concentration was very high, way above the TWQG limit, averaging 9.35 ± 2 mg/l.
c) The TN concentration averaged to 9.55 ± 2 mg/l and was therefore classified as hypertonic (highly productive systems, DWAF, 1996)
d) The PO_4-P concentration was also above the TWQG limit, averaging 0.02 ± 0.1 mg/l (**Table 27)**

8.5.2 Physical and chemical composition

The results of the physical composition are as follows:

a) The water was found to be acidic with a mean pH value of 4.13 ± 0.6 which was below the TWQG limit
b) The TDS and EC values averaged 807 ± 105 mg/l and 154 ± 20 mS/m respectively and were above the TWQG limit (**Table 28**)

The results of the physical composition are as follows:

a) The water was found to have elevated Mg (46.7 ± 10 mg/l), Na (186 ± 16 mg/l), K (13.2 ± 0.3 mg/l), Cl (309 ± 19 mg/l) and SO_4 (218 ± 105 mg/l) concentrations
b) It was characterized by low Ca concentration with a Ca: Mg ratio of 1:3
c) It was elevated in sodium and chloride concentrations. The Na: Cl ratio was 1:2
d) The Al^{3+}, Fe^{2+} and Mn^{2+} concentrations were elevated above the TWQG limits

8.6 Comparison of groundwater quality with lakes and wetlands water qualities

Similarly, to the lakes and the estuary, the groundwater is elevated in N and P concentrations above the wetlands (Figure 43). This indicated that groundwater is also introducing nutrients to the wetland water quality increasing the growth of macrophytes.

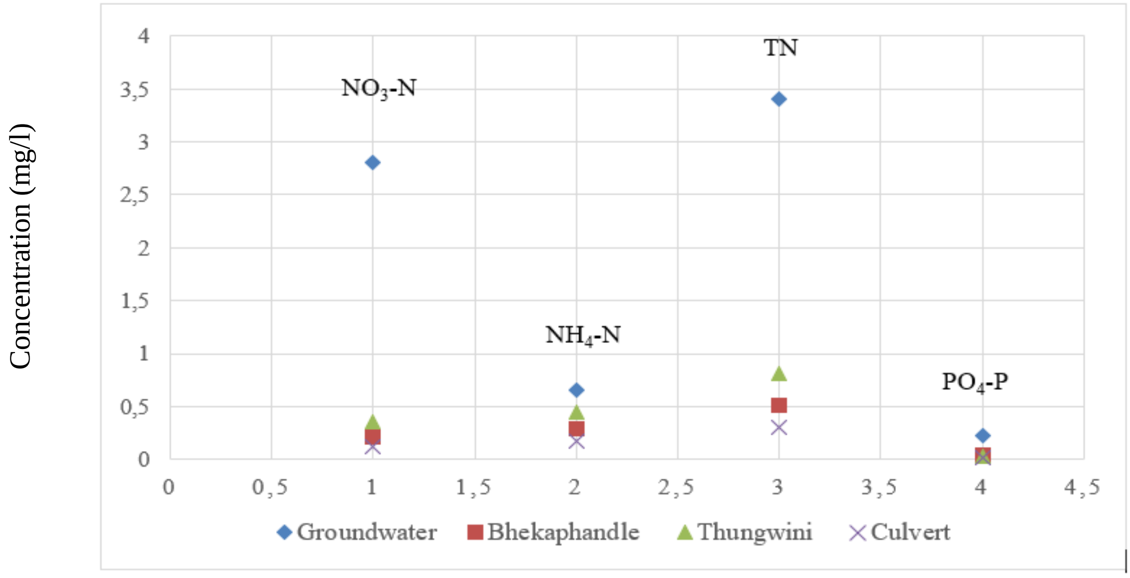

Figure 43: Groundwater quality comparison to wetland's nutrient composition

The groundwater is also elevated in N concentration above all surface water resources of the Mgobezeleni catchment due to the influence of the nutrients from the sewage facilities. The P concentration was elevated in groundwater systems above all other systems, in exception of Lake Shazibe (**Figure 44**).

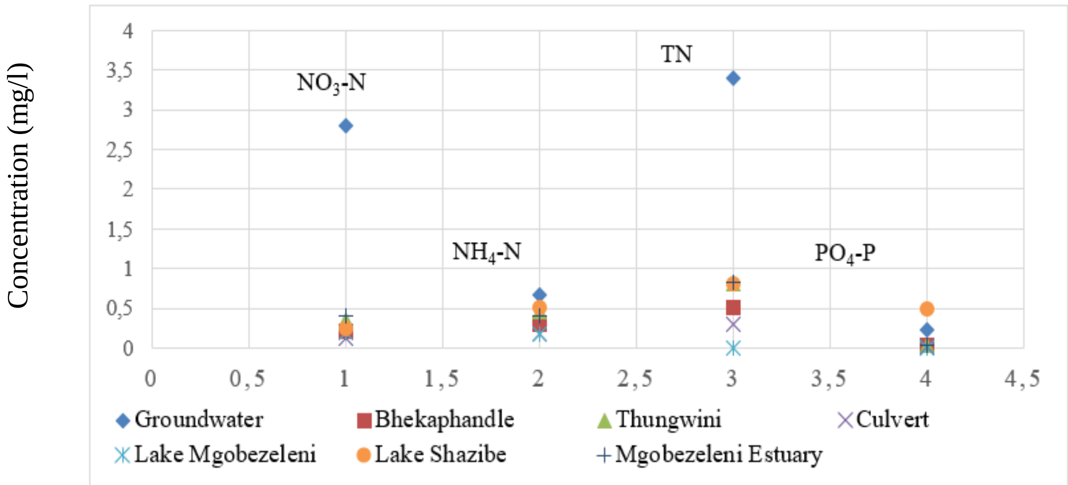

Figure 44: Groundwater quality comparison to wetlands, lakes and estuary nutrient composition

The groundwater quality is low in most cations and anion than most of surface water systems, except for elevated SO_4 concentration above wetland's water qualities. This indicated that sulphate ions are being reduced in the wetland systems due to anaerobic conditions (**Figure 45**). Most of the cations and anions concentrations (Na, K, Mg, Cl, SO_4 ions) are elevated in Mgobezeleni Estuary due to sea influx.

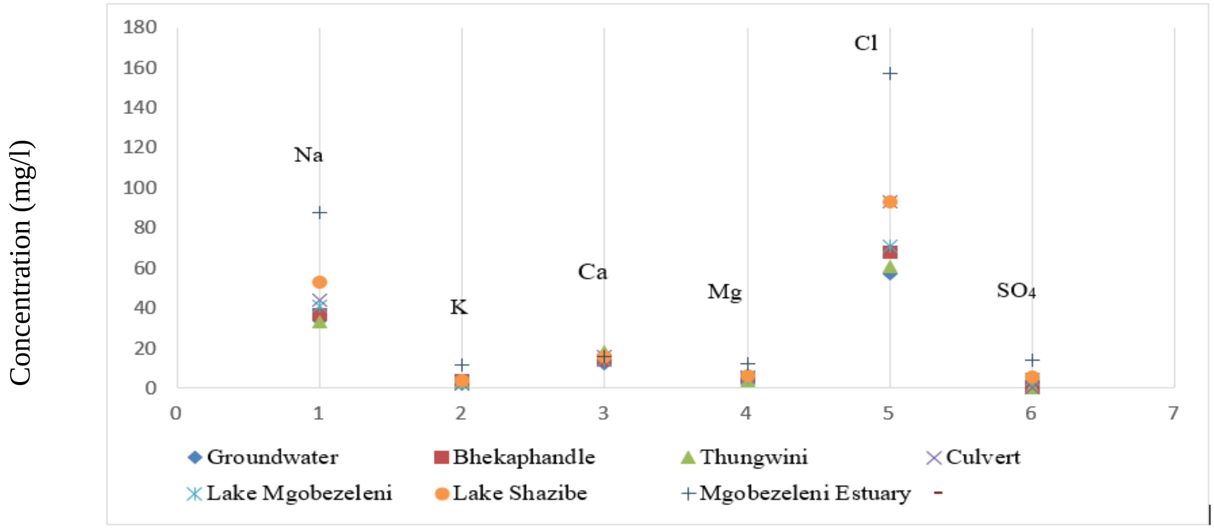

Figure 45: Groundwater comparison to wetlands, lakes and estuary cations and anions concentrations

The Culvert Wetland was elevated in Na, Mg, Cl ions similarly to Lake Shazibe water quality. The chloride ions appeared to increase from Thungwini Wetland (upstream) to Culvert Wetland (downstream)

The trace elements were mostly elevated in Bhekhaphandle Wetlands due high level organic material decomposition together with the peat material. The Wetland is also grazed, some of the nutrients could have been generated by the decomposing animal waste (cow-dung) deposited during grazing. The dissolved ferrous ion was mostly elevated in Thungwini Wetland.

8.7 Discussion

a) Bhekaphandle Wetland

It is relatively low in NO_3-N concentration averaging to 0.21±0.2mg/l. It is however, elevated in NH_4-N concentration (0.29±0.1mg/l) above the NO_3-N concentration and the TWQG limit. The N and P concentrations averaged to 0.51±0.4mg/l and 0.04±0.01mg/l respectively. Based on the TN concentration, the Wetland is classified as mesotrophic (DWAF, 1996).

The Wetland was high in dissolved OC and OM contents averaging to 47±22mg/l and 112±53mg/l respectively, owing to high organic material in the Wetland. The dissolved OM in the Wetland was characterized to contain humic substances (humic acid and fulvic acid components) which are contributing to the formation of *blackwater* in the Wetland.

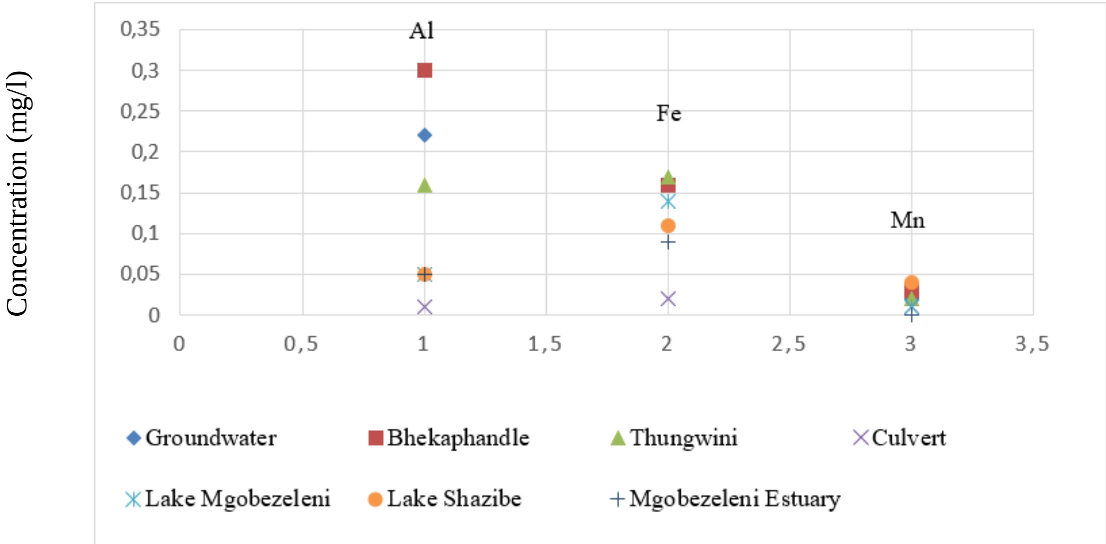

Figure 46: Groundwater comparison to wetlands, lakes and estuary trace elements concentrations

The water is characterized by a mean pH value of 6.08±0.6. Due to high suspended organic material in the water, it is high in turbidity (918±37NTU) and suspended solids (845±1724mg/l), which is contributed by peat decomposition and partially decomposed organic material (dead leaves). The TDS and EC values averaged to 265±120mg/l and 40.9±9mS/m respectively. The water is low in Ca, Mg, K, SO_4 concentrations however, elevated in Na and Cl concentrations. It is characterized by a sodium-chloride ion signature. It is also elevated in dissolved Al, Fe, and Mn concentrations. Cations, anions generally form organometallic complexes with humic substances, which remove them from solution.

b) Thungwini Wetland

It is relatively low in NO_3-N concentration averaging to 0.35±0mg/l. It is however, elevated in NH_4-N concentration (0.45±0.1mg/l) above the NO_3-N concentration and the TWQG limit. The N and P concentrations averaged to 0.81±0.4mg/l and 0.03±0mg/l respectively. Based on the TN concentration, the Wetland is classified as mesotrophic (DWAF, 1996).

The Wetland is high in dissolved OC and OM contents averaging to 71±61mg/l and 164±141mg/l respectively, owing to high plant organic material in the Wetland, which is characterized to contain humic substances (humic acid components) which are contributing to the formation of *blackwater* in the Wetland.

The water in Wetland is characterized by a mean pH value of 7.03±0.01. It is high in turbidity (4.53±37NTU) and suspended solids (1.0±1mg/l), which is contributed by peat decomposition and partially decomposed plant organic material (dead leaves). The TDS and EC values averaged to 149±5mg/l and 29.9±0.4mS/m respectively. The water is low in Ca, Mg, K, SO_4 concentrations however, elevated in Na and Cl concentrations. It s characterized by a sodium-chloride ion signature. It is also elevated in dissolved Al, Fe, and Mn concentrations.

c) Culvert Wetland

The Culvert Wetland is relatively low in NO_3-N concentration. It is however, elevated in NH_4-N concentration (0.17±0mg/l) above the NO_3-N concentration and the TWQG limit. The N and P concentrations averaged to 0.30±0.4mg/l and 0.02±0mg/l respectively. Based on the TN concentration, the Wetland was classified as oligotrophic (DWAF, 1996).

The Wetland is high in dissolved OC and OM contents averaging to 41±20mg/l and 95±45mg/l respectively, owing to high plant organic material in the Wetland, which is characterized to contain humic substances (humic acid components) which are contributing to the formation of *blackwater* in the Wetland.

The water is characterized by a mean pH value of 6.32±0.2. It is low in turbidity (0.28±0NTU) and relatively high in suspended solids (1.20±2mg/l), which is contributed by peat decomposition and partially decomposed plant organic material. The TDS and EC values averaged to 240±6mg/l and 46.6±0.3mS/m respectively. The water is low in Ca, Mg, K, SO_4 concentrations however, elevated in Na and Cl concentrations. It is characterized by a sodium-chloride ion signature. It is also elevated in dissolved Al, Fe, and Mn concentrations.

d) Sangweni Pan

The Sangweni Pan is relatively low in NO_3-N concentration. It is however, elevated in NH_4-N concentration (9.35±2mg/l) way above the NO_3-N concentration and the TWQG limit. The N and P concentrations averaged to 9.55±2mg/l and 0.02 ±0.1mg/l respectively. Based on the TN concentration, the Wetland is classified as hypertonic (DWAF, 1996).

The water is acidic, characterized by a mean pH value of 4.13±0.6. The TDS and EC values averaged to 807±105mg/l and 154±20mS/m respectively, indicating high levels of dissolved solids, contributing to electrical conductivity of the water. It is high in, Mg, K, $SO_{4,}$ Na, Cl concentrations and low in Ca concentration. It is characterized by a sodium-chloride-sulphate ion signature. It is also elevated in dissolved Al, Fe, and Mn concentrations.

CHAPTER 9

PEAT CHEMISTRY RESULTS

9.1 Introduction

This chapter presents the peat chemistry results of the Mgobezeleni catchment in terms of N and P, and physical and chemical composition (including organic substances). The main objective of the peat analysis was to establish whether the peat is humified (decomposed) and whether it causes the *blackwater* in the wetlands.

The following six peatlands were investigated in the Mgobezeleni catchment for peat chemistry:

a) Bhekaphandle peatland
b) Thungwini peatland
c) Culvert peatland
d) Qondwane peatland
e) KwaZikhali peatland
f) Sangweni Pan

KwaZikhali peatland and Sangweni Pan could not be analyzed for peat physical composition, elementary and cations and trace elements analysis because samples obtained were insufficient for these analyses. However, these peatlands are located on the southern side of the catchment and have not significant impacts on the lake and the estuary. Correction of peat to the water resources was based on the peatland in the vicinity of the lakes and the estuary.

9.2 Bhekaphandle peat chemistry

9.2.1 Physical composition

The physical composition of the peat in this study relates to peat thickness, fibre content, saturation status, organic matter and inorganic material.

The physical composition of the peat in Bhekaphandle peatlands was assessment at Site 1A (augured near the floodplain) and Site 2A (augured near the valley bottom channel). Both sites are grazed by cattle. In addition, Site 2A is cultivated (including banana trees) and drained by means a ditch or furrow.

The results of the physical analysis of the peat composition at the two sites are as follows:

a) Bhekaphandle peatland was saturated and high in brownish to black organic material. The peat thickness extended towards the centre of the peatland. The O-horizon of the uncultivated site was saturated and compacted and contained high fibrous organic material which was undecomposed. By contrast, the cultivated site contained decomposed organic material with low fibre content (of about 10%) (**Figure 47**)

b) The middle and bottom layers of the uncultivated site contained less fibre owing to high levels of inorganic material (sediments). By contrast, the cultivated sites were high in fibre content with no inorganic material (**Figure 47**).

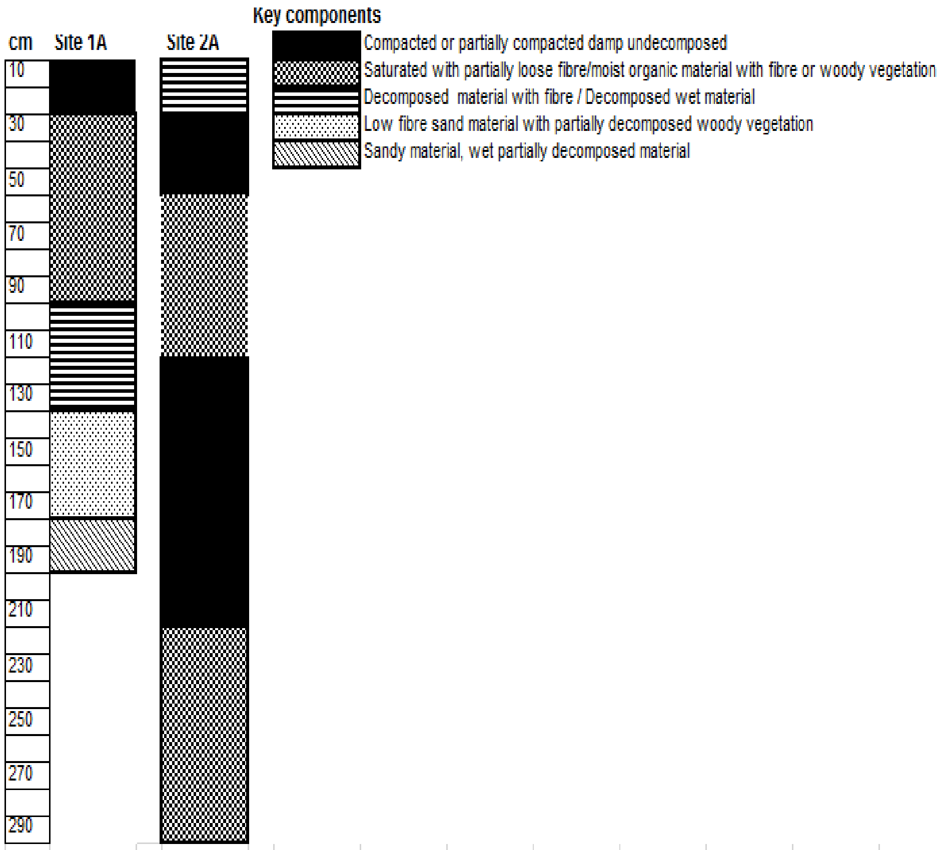

Figure 47: Bhekaphandle peat profile

9.2.2 Peat soil pH

The pH of the peat soils was assessed at Site 1, Site 2 and Site 3, at 0.5 m and 1 m depths by means of water extraction.

The results of the pH measurements are as follows:

a) Peat soils were found to be acidic and characterized by pH values ranging from 5.20 to 5.99, with a mean pH value of 5.50 ± 0.4. They were found to be more acidic in the upper layer at Site 2

9.3.3 Nutrient composition

The total (organic and inorganic) nitrogen (N) and phosphorus (P) composition of the peat soils were assessed at Site 1, Site 2 and Site 3, at 0.5 m and 1 m depths.

The results of the nutrient composition are as follows:

a) Peat soils in Bhekaphandle peatland were relatively low in total nitrogen (N) concentration. Nitrogen values ranged from 0.12 to 0.27%, averaging to 0.19 ± 0.1%, which was below the range of 0.3 to 4% suggested by the FAO (1998) (**Table 29**)
b) The phosphorus (P) concentration was relatively higher than N concentration. It averaged from 0.78 to 1.70%, averaging to 1.20 ± 0.3% (**Table 29**), was higher than the range (0.01 to 0.5%,) as suggested by the FAO (1998).

Table 29: Peatlands total N and P compositions and pH (range by FAO, 1988*)

Parameters	Range	Units	Bhekaphandle	Thungwini	Culvert	Qondwane
Total Nitrogen			0.19 ± 0.1	0.23 ± 0.2	0.19 ± 0.01	1.2 ± 0.03
Min	0.30	%	0.12	0.13	0.18	1.2
Max	4.0		0.27	0.49	0.19	1.2
Total Phosphorus			1.2 ± 0.3	1.4 ± 1	1.2 ± 0.1	4.4 ± 5
Min	0.01	%	0.78	0.82	1.0	1.1
Max	0.50		1.7	3.1	1.2	7.7
pH			5.50 ± 0.4	5.30 ± 0.3	5.78 ± 0.1	
Min			5.20	4.89	5.73	
Max			5.99	5.63	5.82	

9.2.4 Proximate composition

The proximate composition refers to ash, volatiles, inherent moisture, fixed carbon and calorific value content of the peat. The proximate composition of the peat soils was assessed at Site 1AA, Site 1, Site 2 and Site 3 at various depths.

The results of the proximate composition, as shown **Table 30**, are as follows:

a) The bottom layers of the peat profile and cultivated sites were high in ash content. Ash values ranged from 13 to 34%, averaging 23 ± 7% (**Table 30**)
b) The inherent moisture, volatiles and fixed carbon content averaged to 12 ± 5%, 44 ± 3% and 21 ± 2%, respectively

c) Peat soils were high in calorific values, ranging from 13 to 16 MJ/kg, with an average value of 14 ± 1 MJ/kg

d) The inherent moisture, volatiles, fixed carbon contents and calorific values corresponded to low and high ash peat soil classification (**Table 30**).

Table 30: Peatlands proximate analyses (Maputaland peat classification by Grundling and Mazus, 1998*)

Parameters	*Maputaland peat classification	Units	Bhekaphandle	Thungwini	Qondwane	Culvert	KwaZikhali	Sangweni
%Ash	16–29 (medium ash)	%	23±7	31±18	29±30	51±38	92±3	87±7
Min	30–50 (high ash)		13	16	12.	24	85	72
Max	<51 (inorganic)		34	48	74	78	96	96
% Inherent Moisture	11–9 (medium ash)	%	12 ± 5	7.4 ± 3	11 ± 5	7.0 ± 6	2.1 ± 1	3.7 ± 2
	8–6 (high ash)							
Min			7.4	5.4	3.3	2.7	0.40	0.90
Max	<5 (inorganic)		20	11	14	11	3.5	3.7
% Volatiles	**47–35** (medium ash)	%	44 ± 3	45 ± 7	30 ± 22	30 ± 18	3.3 ± 2	5.1 ± 3
Min	34–23 (high ash)		41	38	5.5	17	1.3	1.4
Max	<20 (inorganic)		49	52	50	42	7.4	9.8
% Fixed Carbon	23–17 (medium ash)	%	21 ± 2	17 ± 10	19 ± 9	12 ± 14	2.4 ± 2	4.0 ± 2
Min	16–12 (high ash)		17	4.9	6.5	2.5	0.50	0.50
Max	<11 (inorganic)		24	27	24	22	6.9	8.3
Calorific Value (CV, MJ/Kg)	16–13 (medium ash)	MJ/kg	14 ± 1	13 ± 4	13 ± 5	8.4 ± 7	1.8 ± 0.8	2.8 ± 1
Min	12–17 (high ash)		13	8.6	5.7	3.6	0.80	1.1
Max	<6 (inorganic)		16	17	17	13	3.6	5.5

9.2.5 Elementary and organic composition

The elementary composition of the peat soils was assessed at Site 1AA, Site 1, Site 2 and Site 3 at various depths.

The results of the elementary and organic compositions are shown in **Table 31**:

a) The organic carbon (C) content of the peat ranged from 35 to 42%, averaging 36 ± 3% (**Table 31**)
b) The hydrogen (H) and nitrogen (N) contents averaged to 4.8 ± 1% and 2 ± 0.3% respectively. The nitrogen values were generally higher in the upper layers of the peat profile
c) The CHN values were generally elevated in the bottom layers of the peat profile. Peat soils were decomposed, especially in the upper layers of the peat profile, which is indicated by an average C/N ratio of 19:1. Site 2 (22:1) and Site 3 (23:1) were higher in C/N ratios
d) Peat soils were higher in sulphur (S), organic matter (OM) and humic acid (HA) content averaging to 1.0 ± 0.4%, 52.3 ± 8% and 15.2 ± 6% respectively (**Table 31**).

Table 31: Elementary analysis and organic composition

Peatland	Depth (m)	C (%)	H (%)	N (%)	C/N Ratio	OM (%)	S (%)	HA (%)
Bhekaphandle Site 1	0.5	35	4.2	1.9	19:1	56	0.89	21
	1.0	35	5.5	1.9	19:1	55	1.2	6.7
Bhekaphandle Site 2	0.5	42	5.5	2.0	21:1	54	1.1	13
	1.0	36	4.2	1.6	23:1	55	1.0	22
Bhekaphandle Site 3	0.5	36	5.1	1.6	23:1	58	0.84	9.1
Bhekaphandle Site 1AA	0.2	33	4.0	2.2	15:1			20
	1.2	36	4.9	2.4	15:1	36	1.8	15
Thungwini Site 4	0.5	40	4.9	2.3	17:1	60	0.96	12
	1.0	44	4.3	2.3	19:1	62	1.2	14
Thungwini Site 5	0.5	23	3.5	1.3	17:1	55	0.52	3.2
	1.0	25	3.4	1.3	20:1	60	0.82	16
Culvert Site 6	0.5	14	1.4	0.80	17:1	23	0.17	7.2
Culvert Site 1	0.2	16	1.8	0.87	18:1			
	0.8	32	4.0	1.5	22:1	57	0.66	10
Qondwane Site 7	0.5	42	5.1	2.4	17:1	60	0.92	14

	1.0	43	5.5	2.2	20:1	54	1.1	4.2
Qondwane Site 1	0.2	36	4.6	2.2	16:1		0.86	5.6
	0.8	16	1.6	0.66	24:1	35	0.42	12

9.2.6 Cation and trace element composition

The elementary composition of the peat soils was assessed at Site 1AA, Site 1, Site 2 and Site 3 at various depths.

The results of cation and trace element composition are shown in **Table 32**:

a) Peat soils were found to be deficient in copper concentration at all sites in all layers of the peat profile. They were also deficient in potassium and zinc concentration at Site 1AA
b) They were relatively high in Al, Fe, Cr, Zn and Ca concentrations at all sites in the upper layers of the peat profile (**Table 32**).

Table 32: Cation and trace element composition

Area	**Depth**	**Units**	**Ca**	**Mg**	**Na**	**K**	**Al**	**Fe**	**Cr**	**B**	**Zn**
Bhekaphandle Site 1	0.5m	g/kg	87	10.	12	4.0	99	16	2.6	0.74	0.30
	0.1m	g/kg	52	7.5	5.4	3.1	98	13	0.20	0.54	0.15
Bhekaphandle Site 2	0.5m	g/kg	78	16	9.5	2.1	63	13	2.2	0.61	1.1
	0.1m	g/kg	30	7.0	2.6	1.8	50	6.5	0.14	0.51	0.40
Bhekaphandle Site 3	0.5m	g/kg	26	8.5	4.3	0.53	37	8.5	0.22	0.46	0.81
Site 1AA	0.20m	g/kg	115	8.8	4.7	-	30	11	0.08	0.45	-
	1.20m	g/kg	121	4.8	1.5	-	24	16	0.09	0.38	-
Thungwini Site 4	0.5m	g/kg	20	0.66	0.05	-	2.0	1.6	0.01	0.04	-
	0.1m	g/kg	108	15	4.0	-	32	31	1.6	0.82	0.03
Thungwini Site 5	0.5m	g/kg	13	3.5	0.65	4.6	149	15	0.12	0.35	0.05
	0.1m	g/kg	14	4.0	1.1	6.2	161	16	0.14	0.31	-
Culvert Site 6	0.5m	g/kg	10	1.4	-	-	11	4.2	1.1	0.27	-

Culvert Site 1	1.20m	g/kg	78	5.4	1.7	-	19	8.3	1.1	0.22	-
Qondwane Site 7	0.5m	g/kg	-	26	22	3.9	110	17	1.1	0.42	1.2
	0.1m	g/kg	-	1.2	5.1	-	31	5.5	1.2	0.31	0.08
Qondwane Site 1	0.2m	g/kg	-	17	9.3	0.72	62	11	-	0.32	0.49
	0.80m	g/kg	-	1.2	-	-	9.3	1.7	1.1	0.19	-

9.3. Thungwini peat chemistry

9.3.1 Physical composition

The physical composition of the peat in Thungwini peatland was assessed at Site 1 and Site 2 which were drilled in the Thungwini wetland. Both sites were cultivated and drained using ditches or furrows.

The results of the physical composition of the peat are shown in **Figure 48**:

a) The thickness of the peat soil was slightly deeper at Site 2
b) Peat soils in all layers of the peat profile were low in inorganic material without any fibre content. They were generally high in inorganic material
c) The upper layer of the peat profile contained partially decomposed woody material from banana trees
d) Peat soils at these sites were generally decomposed throughout the peat profile.

9.3.2 Soil pH

The soil pH was assessed at Site 4 and Site 5 at depths of 0.5 m and 1 m.

The results of the soil pH measurements are as follows:

a) Peat soils in Thungwini peatland were found to be acidic; pH values ranged from 4.91 to 5.56 with a mean pH value of 5.30 ± 0.3. The pH values seemed to fluctuate with the peat depth (**Table 29**).

9.3.3 Nutrient composition

The total N and P compositions in peat soils were assessed at uncultivated Site 4 and Site 5 at depths of 0.5 m and 1 m.

The results of the total N and P composition are as follows:

a) Peat soils were found to be relatively high in total P concentration, ranging from 0.82 to 3.08%, with an average of 1.44 ± 1%. P concentration was found to be higher in the bottom layers of the peat profile (**Table 29**)
b) Soils were generally low in total N, ranging from 0.13 to 0.49% and averaging 0.23 ± 0.2%. The total N concentration was found to be higher in the bottom layers of the peat profile
c) Significant high N and P concentrations were observed at Site 4.

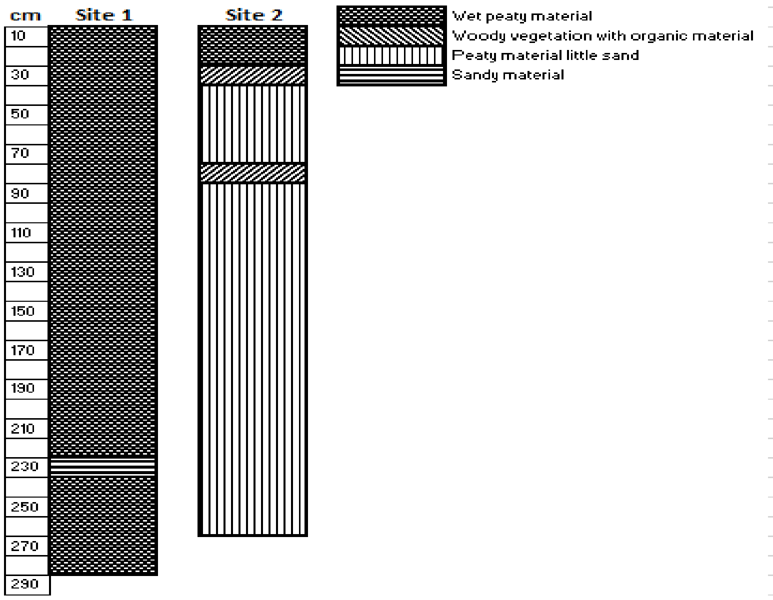

Figure 48: Thungwini peat profile

9.3.4 Proximate composition

The proximate composition of the peat soils was assessed at Site 4 and Site 5 at depths of 0.5 m and 1 m. The results of the proximate composition are as follows:

a) Peat soils at Site 4 were low in ash content, whereas those at Site 5 were elevated in ash content owing to high levels of inorganic material (sediments). The ash content averaged 31 ± 18%, and generally occurred in the bottom layers of the peat profile (**Table 30**)
b) The inherent moisture, volatiles and fixed carbon contents were lower in sites with high inorganic material (sand). They averaged to 7.4 ± 3%, 30 ± 22% and 19 ± 9% respectively
c) The calorific values ranged from 5.7 to 17 MJ/Kg, averaging 13 ± 4 MJ/kg. These decreased with the peat depth.

9.3.5 Elementary and organic composition

The elementary composition of the peat soils was assessed at Site 4 and Site 5 at depths of 0.5 m and 1 m. The results of the elementary composition are as follows:

a) The organic carbon (C) content of the peat ranged from 23 to 44%, averaging to 33 ± 3% (**Table 31**)
b) The hydrogen (H) and nitrogen (N) contents averaged 4.0 ± 0.7% and 1.8 ± 0.7% respectively. The nitrogen values were generally higher in the upper layers of the peat profile
c) The CHN values were generally elevated in the upper layers of the peat profile. Peat soils were slightly decomposed, especially in the upper layers of the peat profile, which was indicated by an average C/N ratio of 19:1
d) Peat soils were relatively low in sulphur (S) content, averaging to 0.6 ± 0.7%
e) Organic matter (OM) and humic acid (HA) content averaged to 59.2 ± 3%, and 18.5 ± 6% respectively (**Table 31**).

9.3.6 Cations and trace elements

The cation and trace element composition of the peat soils was assessed at Site 4 and Site 5 at depths of 0.5 m and 1 m. The results of the cation and trace element composition analysis are as follows:

a) At all the sites, peat soils were found to be deficient in copper concentration in all layers of the peat profile. Potassium ions were also deficient in all layers of Site 4, as were zinc ions at Site 4 (in the upper layer) and Site 5 (in the bottom layer)
b) Al, Fe and Ca levels were elevated especially in the bottom layers (Table 33) and Cr, B, Mg, Na and K concentrations were low.9.4 Culvert peat chemistry.

9.4.1 Physical composition

The physical composition of the peat in Culvert peatland was assessed at Site 1 at depths of 0.2 m and 0.8 m. The results of the physical composition analysis are as follows:

a) The upper layers of the peat profile contained saturated reddish, partially decomposed, woody material with a high fibre content
b) The bottom layers were composed of saturated peat material containing a large amount of black organic material with high fibre content.

9.4.2 Soil pH

The peat soil pH values were assessed at Site 6 at a depth of 0.5 m. The pH values of the soil were found to be as follows:

a) Peat soils were acidic, characterized by pH values ranging from 5.73 to 5.82 with a mean pH value of 5.78 ± 0. (**Table 29**).

9.4.3 Nutrient composition

The total N and P compositions were assessed in Site 1 at 0.20m and 0.8m and Site 6 at 0.5m depths. The results of analysis for the total N and P concentration are as follows:

a) Peat soils were found to be relatively high in total P concentration, ranging from 1.04 to 1.20%, averaging to 1.12 ± 0.1%. They were higher in the upper layers of the peat profile (**Table 29**)
b) They were generally low in total N concentration, ranging from 0.18 to 0.19%, averaging to 0.19 ± 0.01%. They were higher in the upper layers of the peat profile.

9.4.4 Proximate composition

The proximate composition of the peat soils was assessed at Site 1 at a depth of 0.8 m and at Site 6 at a depth of 0.5 m. The results of the proximate composition analysis are as follows:

a) Peat soils at Site 1 were found to be low in ash, whereas at Site 6 ash content was elevated due to high levels of inorganic material (sediments). The ash content averaged 51 ± 38% (**Table 30**)
b) The inherent moisture, volatiles and fixed carbon contents were lower at high mineral sites. They averaged to 7.0 ± 6%, 30 ± 18% and 12 ± 14% respectively
c) The calorific values ranged from 3.6 to 13 MJ/Kg, averaging 8.4 ± 7 MJ/kg.

9.4.5 Elementary and organic composition

The elementary and organic composition of the peat soils were assessed at Site 1 at 0.20 m and 0.8 m; and at Site 6 at 0.5 m depths. The results of the elementary and organic composition analysis are as follows:

a) The organic carbon (C) content of the peat was relatively low, ranging from 13 to 32%, averaging to 20 ± 10% (**Table 31**)
b) The hydrogen (H) and nitrogen (N) contents averaged 2.4 ± 1% and 1.0 ± 3% respectively

c) The CHN values were generally higher in the lower layers of the peat profile. Peat soils were slightly decomposed especially in the upper layers of the peat profile, indicated by an average C/N ratio of 19:1
d) Peat soils were relatively low in sulphur (S) content, averaging to 0.4 ± 0.3%
e) Organic matter (OM) and humic acid (HA) content averaged 40 ± 24% and 8.8 ± 2% respectively (**Table 31**).

9.4.6 Cations and trace elements

The cation and trace element composition of the peat soils was assessed at Site 1 at a depth of 0.8 m and Site 6 at a depth of 0.5 m. The results of the cation and trace elements analysis are as follows:

a) Peat soils were found to be deficient in copper, potassium and zinc concentrations in all layers of the peat profile. Site 6 was also deficient in sodium concentration
b) They were elevated in Al, Fe, Ca and Mg concentration at Site 1, while Site 6 was slightly elevated in Cr and B concentrations (**Table 32**).

9.5 Qondwane peat chemistry

9.5.1 Physical composition

The physical composition of the peat in Qondwane peatland was assessment at Site AA at depths of 0.2 m and 0.8 m. The results of the peat physical composition analysis are as follows:

a) Peat soils in Qondwane peatland were cultivated. The upper layer of the peat profile was black, saturated and rich in partially decomposed organic matter with a high amount of fibrous material. The bottom layer was also black, saturated, and rich in organic matter with a high amount of fibrous material.

9.5.2 Nutrient composition

The total N and P composition of the peat soils was assessed at Site AA at depths of 0.2 m and 0.8 m. The results of the nutrient composition are as follows:

a) Peat soils in Qondwane peatland were found to be higher in total P concentration than all the peatlands assessed in the Mgobezeleni catchment, especially in the upper layer of the peat profile. The concentration ranged from 1.1 to 7.7%, averaging to 4.4 ± 5% (**Table 29**)

b) They were also more elevated in total N concentration than all the other peatlands assessed in Mgobezeleni catchment, especially in the upper layer of the peat profile. The concentration ranged from 1.18 to 1.2%, averaging to 1.2 ± 0.03%.

9.5.3 Proximate composition

The proximate composition of the peat soils was assessed at Site AA at 0.2 m and 0.8 m; and Site 7 at 0.5 m and 1.0 m depths. The results of the proximate composition are shown in **Table 30**:

a) Peat soils were found to be low in ash content, averaging 29 ± 30%, due to elevated organic material at Site 7 in the upper layer (**Table 30**). The higher ash content of 74% was observed in the lower layer at Site 1, which indicated that the peat was decomposed
b) The inherent moisture, volatiles and fixed carbon contents were lower at the high mineral site, averaging 11 ± 5%, 41 ± 17% and 19 ± 9% respectively
c) The calorific values ranged from 5.7 to 17 MJ/Kg, averaging 13 ± 5 MJ/kg.

9.5.4 Elementary and organic compositions

The elementary and organic composition of the peat soils was assessed at Site AA at 0.2 m and 0.8 m; and at Site 7 at 0.5 m and 1.0 m depths. The results of the elementary and organic composition analyses are shown in **Table 31**:

a) Peat soils were found to be relatively high in carbon (C) content, averaging 49 ± 10% (Table 32)
b) They were also elevated in hydrogen (H) and nitrogen (N) contents. They were, however, lower in the bottom layer at Site 1
c) Sulphur, OM content and humic acid averaged 0.80 ± 0.3%, 49 ± 13 and of 8.8 ± 5% respectively (**Table 31**).

9.5.5 Cations and trace elements

The cation and trace element composition were assessed at similar sites as those indicated above and the results are shown in **Table 33**:

a) Peat soils were found to be deficient in Cu and K concentrations in the bottoms layers of the peat. Site 1 was also found to be deficient in Na and Zn in the bottom layers
b) All sites were found to have elevated levels of Al, Fe, Ca, Mg, Cr and Zn (**Table 33**).

9.6. KwaZikhali peatland

9.6.1 Physical composition

The physical composition of peat in KwaZikhali peatland was assessed in six augured peat holes, as indicated in **Figure 49**. Peat soils were predominantly shallow in depth with low organic content because of high inorganic material and burning of the peat soils.

9.6.2 Proximate composition

The peat proximate composition was assessed in the six augured holes. The results of the peat proximate composition analysis are as follows:

a) Peat soils were found to be high in ash content, ranging from 85 to 96% and averaging to 92 ± 3% (**Table 32**)
b) The inherent moisture, volatiles and fixed carbon of the peat were very low, averaging 2.1 ± 1%, 3.3 ± 2% and 2.4 ± 2% respectively
c) The calorific values of the peat were also very low, averaging 1.8 ± 0.8 MJ/Kg
d) They were also low in sulphur concentration, averaging 0.6 ± 0.5%

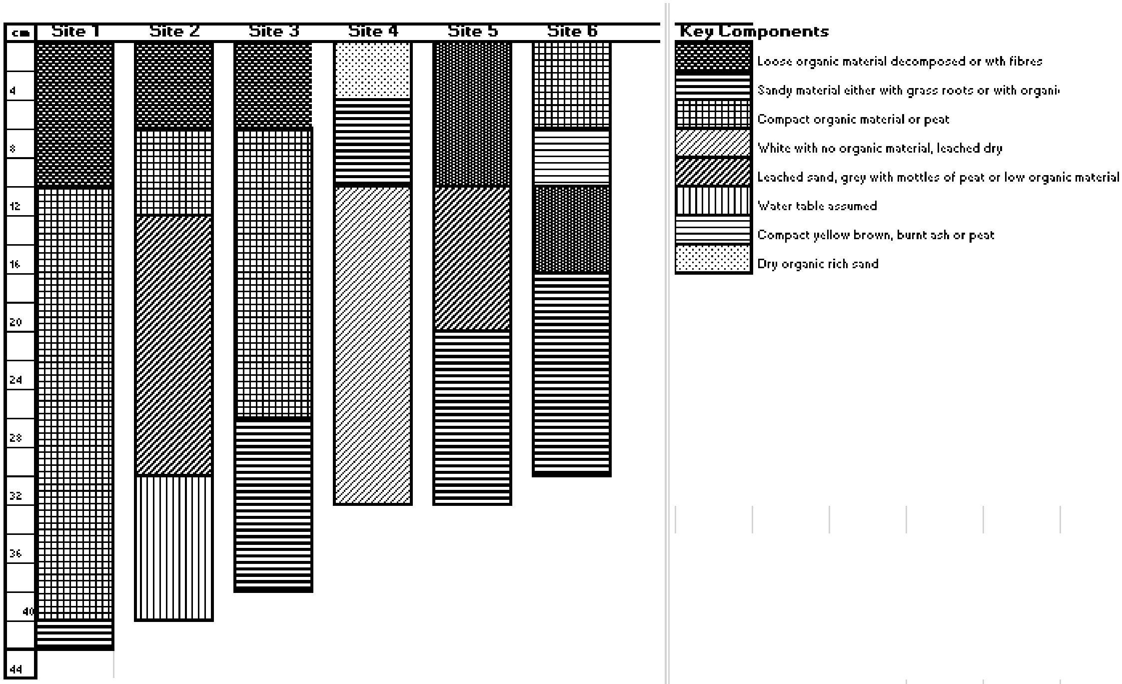

Figure 49: KwaZikhali peat soil profile

9.7 Sangweni Pan

9.7.1 Physical composition

The physical composition of the peat soils in Sangweni Pan was assessed from the five augured peat holes (**Figure 50**). The results are as follows:

a) The upper layers of the peat profile contained loose organic material with no fibre content
b) The middle layers at Site 2 contained compacted low organic material
c) The bottom layers at Site 3 contained sand material which was peaty

9.7.2 Proximate composition

The proximate composition was assessed from the five augured peat holes. The results are as follows:

a) The peat soils were very high in ash content, ranging from 72 to 96% and averaging to 87 ± 7% due to elevated inorganic material especially in the lower layers of the peat profile (**Table 30**)
b) They were low in moisture, volatiles and fixed carbon and sulphur contents, averaging 3.7 ± 2%, 5.1 ± 3%, 4.0 ± 2% and 0.40 ± 0.5% respectively
c) The calorific value of the peat ranged from 1.1 to 5.5-MJ/Kg, averaging 2.8 ± 1 MJ/Kg

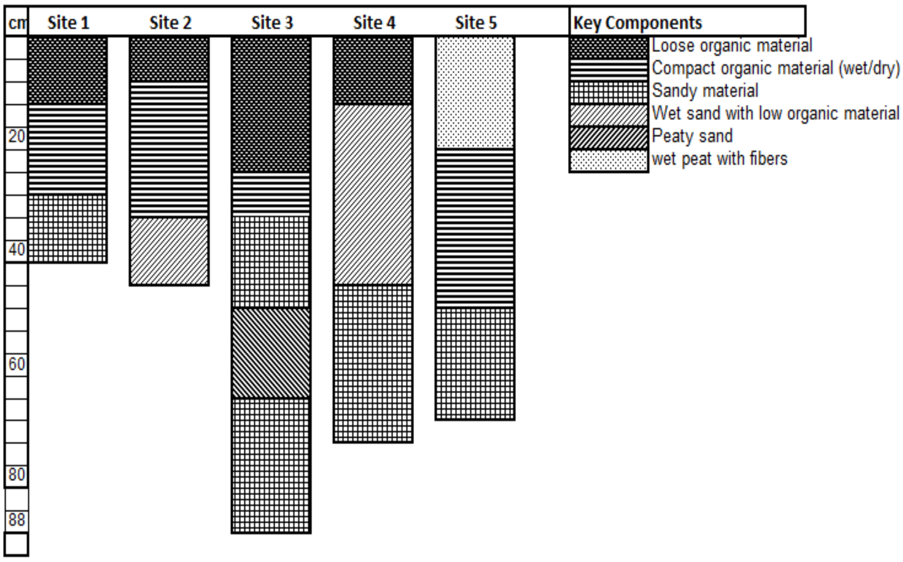

Figure 50: Sangweni Pan peat profile

9.8 Discussion

a) Bhekaphandle peatland

Bhekaphandle peatland peat soils are relatively undecomposed mostly in the upper layers of uncultivated sites but partially decomposed and drained at cultivated sites. The bottom layers of the outermost (on the edge of the wetland) peat sites are found to be higher in inorganic material than the innermost (in the centre of the wetland) peat site. The peat occurs within the stream which appeared to have been affected by flooding.

The P concentration is high due to its general occurrence in the sedimentary cycle. Phosphorous in most wetlands is bound to organic material and peat (Gosselink and Mitch, 2000). Inorganic phosphorus generally sorbs in oxides and hydroxides of Fe^{3+}, Al^{3+} and $CaCO_3$. These oxides and hydroxides are deposited on sediments at the base of the wetland. The total N concentration of the peat soil is low due to the denitrification (reduction of nitrate ions) and nitrate ammonification (reducing nitrate ions) processes which keep nitrogen in solution. Nitrate ammonification conserves the total nitrogen in the soil while denitrification removes nitrogen.

Owing to high levels of partially decomposed organic material in the upper layer (0.5 m depth) of the peat profile, peat soils are elevated in total N and P concentrations. However, the P concentration is higher than the N concentration and the range (0.01 to 0.5%) suggested by the FAO (1988) for peatlands and the N concentration is lower than the range (0.3 to 4%) also suggested by the FAO (1988).

Peat soils are acidic owing to the presence of organic acids from the partially decomposed plant material that forms peat in the wetland. Dissolved CO_2 from the organic material biodegradation process and sulphur compounds also contribute to the acidity of the water in the wetlands. The pH values generally decrease with the peat depth. Soils varied significantly in terms of ash composition. High ash content was observed in the bottom layers of the peat profile and at cultivated sites, owing to high levels of inorganic material (sediments). Inherent moisture, volatiles, and fixed carbon contents appeared to decrease with the peat depth. Based on the peat soils proximate analysis, Bhekaphandle peatland was classified as a medium ash peatland according to the Maputaland peat classification (Grundling and Mazus, 1998).

Bhekaphandle peatland is relatively high in CHN values, especially in the bottom layers of the peat profile. Peat soils are decomposed especially in the upper layers of the peat profile as indicated by the average C/N ratio of 19:1. Less decomposed peat with a C/N ratio of above 23:1 is observed at Site 3. Soils are elevated in S, OM and humic acid contents due to partially decomposed peat vegetation. Peat soils are found to be low in copper concentration from the carboxylic and phenolic functional groups forming organometallic compounds with copper ions. Some of the sites were also deficient in potassium and zinc, but generally elevated in Al, Fe, Cr, Zn and Ca ions due to the formation of organophosphate complexes with phosphorus, which are bound to the peat soils.

b) Thungwini peatland

Cultivated sites at the Thungwini peatland are elevated in inorganic material without any fibre content, which indicated peat organic material decomposition throughout the peat profile. Uncultivated peatlands are elevated in total N and P concentrations, with the P concentration being higher than the nitrogen concentration and the range suggested by the FAO (1988). However, the N concentration is also lower than the range suggested by the FAO (1988).

Peat soils are found to be acidic because of the presence of organic acids and dissolved carbon dioxide from the biodegradation of organic material. The pH generally decreased with the peat depth. Peat ash content varied significantly with the sites assessed. Based on the average peat soils proximate analysis, Thungwini peatland is classified as high ash peatland according to the Maputaland peat classification (Grundling and Mazus, 1998). Inherent moisture in the peat appeared to decrease, whereas volatile and fixed carbon increased with the peat depth.

CHN values in the peat soils are elevated at the bottom of the peat profile, resulting from the organic material decomposition in the upper layers of the peat profile, which is indicated by the average C/N ratio of 19:1. Peat soils are generally elevated in Al, Fe and Ca ions due to the formation of organophosphate complexes with phosphorus, which are bound to the peat soil.

c) Culvert peatland

Peat soils in Culvert peatland at Site 1 are high in organic material with a high fibre content. The upper layers of the peat profile are reddish in colour while the bottom ones are black. They are also found to be high in total P concentration due to phosphate sorption on the oxide and hydroxides of Fe, Al, and Ca. The total N concentration is low due to denitrification and nitrogen ammonification processes. Soils are acidic owing to the generation of organic acids and CO_2 from the biodegradation of organic matter.

Soils are generally high in ash content as a result of high inorganic material. Based on the Maputaland Peat Proximate Analysis Classification by Grundling and Mazus, (1998), Culvert peatland is classified as inorganic ash. CHN values are elevated in the lower layer of the peat profile due to peat decomposition in the upper layers of the profile. The peat is, on average, decomposed which is indicated by the average C/N ratio of 19:1. Peat soils have elevated Al, Fe, Ca and Mg, Cr and B concentrations.

d) Qondwane peatland

Peat soils in the Qondwane peatland at Site AA are saturated and high in fibrous material. They are also high in total N and P concentrations resulting from the partially decomposed organic material. Soils are found to be low in ash content at Site AA but elevated at Site 7, and ash, volatiles and fixed carbon appeared to decrease with the peat depth. Based on the Maputaland peat proximate analysis classification by Grundling and Mazus (1998), the Qondwane peatland is classified as medium-ash. On overage soils are found to be high in calorific value.

Soils are also found to be high in CHN values in the upper layers of the peat profile. CHS values at Site 7 increased, while N decreased with the peat depth. Owing to low organic material in the lower layer at Site 1, CHN values decreased with the peat depth. The peat is on average decomposed, which is indicated by an average C/N ratio of 19:1. Soils have elevated levels of Al, Fe, Ca, Mg, Cr and Zn.

e) KwaZikhali peatland and Sangweni Pan

The peat deposits at KwaZikhali peatland were affected by veld fires, which had resulted in the burning of the peat organic matter. At KwaZikhali peatland, and other sites as well, because of the high ash content peat soils are low in moisture, volatiles, fixed carbon and sulphur content. Based on the Maputaland Peat Proximate Analysis Classification by Grundling and Mazus (1998), KwaZikhali peatland is classified as inorganic ash.

The peat deposits at Sangweni Pan are found to be similar to KwaZikhali peatland in terms of the peat profile and physical composition, especially at the first three sites. The peat is high in ash content because of elevated inorganic material and low in moisture, volatiles and fixed carbon and sulphur content and calorific values. Based on the Maputaland Peat Proximate Analysis Classification by Grundling and Mazus (1998), the peat in Sangweni Pan was classified as inorganic ash.

9.9 Conclusions

Therefore, the peat in peatlands is generally decomposed (humified) releasing organic material to the wetlands and increasing the nutrient composition the water. Organic material is composed of humic substances (humic acid and fulvic acid) that generate blackwater in the water resources. Most of the cations, anions and trace elements are fixed by the peat in wetlands, resulting in low dissolved ions in the water column.

CHAPTER 10

CONCLUSION

10.1 Mgobezeleni catchment demographics

The Mgobezeleni catchment is a semi-rural settlement comprising modern and freestanding structures on large plots. Its population and households have increased by 8.3% p.a and 33.8% p.a respectively since 1999. The most densely populated residential areas are Mbazwana, Hagaza and Qondwane. The dominant inhabitants of the area are Zulus and Thonga-Thembe people.

The Local Municipality supplies water to the residential areas through metered connections sourced from the Lake Sibaya. However, this water supply suffers frequent breakdowns owing to illegal connections. Some of this water recharges the groundwater system as a result of frequent pipelines leaks. The presence of the high-yielding, shallow aquifer of the KwaMbonambi Formation has resulted in some of the residents, businesses and institutions in the area, especially in Qondwane and Thungwini, sourcing water for domestic use from private boreholes to supplement the water supplied by the municipality. The groundwater is generally pre-treated (chlorinated) prior to use in business enterprises and institutions. Complaints were received from Qondwane regarding the turbidity of the groundwater. Some residents also harvest rainwater for domestic use.

The catchment (excluding Sodwana Bay) has no waste water treatment plant. Sewage systems include the use of long drops (LDs), ventilated improved pit latrines (VIPs) and septic tanks. Septic tanks are mainly for business enterprises, institutions and high-income earners. Some of newly established households of low-income earners have no sanitation systems. Most of the nutrients in these systems end up in the groundwater system due to unconsolidated sediments and mean annual high precipitation (MAP). Based on the total population in the Mgobezeleni catchment, the groundwater in the shallow aquifers were estimated to consists of 0.026mg/l and 0.0044mg/l of N and P concentrations respectively

Business enterprises, institutions and high-income earners either dispose their solid waste in the Local Municipal landfill site or Local Municipal landfill collects the waste on weekly basis. The solid waste in catchment is generally managed by individual households through burning. Waste disposal in this manner pose groundwater pollution through leaching of nutrients including toxic organic and inorganic compounds by the high annual rainfall.

The catchment area contains large-scale Mbazwana forestry plantations which are used for black economic empowerment and for providing employment. Because of the low nutrient soils, poor road access to local markets and lack of irrigation schemes, the area has low agricultural potential. Most of the subsistence farming activities in the area generally occur in the wetland soils and in the backyards of homesteads. Forest plantation causes the groundwater table reduction. Fluctuation in the groundwater table and cultivation of wetland soils result in peat decomposition.

10.2 The Mgobezeleni catchment groundwater chemistry characterization

The groundwater in the Mgobezeleni catchment is relatively low in NO_3-N concentration, averaging to 2.8±3mg/l. However, elevated NO_3-N concentration is observed in boreholes in the proximity of LDs and VIPs in high density population residential areas (such as Mbazwana, Qondwane and Thungwini, highest concentration of 12mg/l in Mbazwana) owing to leaching of the organic matter from sewage systems. Some of these Mbazwana boreholes are elevated in bacteria as indicated by a standard plate count (ranging from 0 to >3000count/ml), total coliform (ranging from 0 to >300cfm/100ml) and faecal coliform (ranging from 0->300). The NH_4-N and PO_4-P concentrations are relatively high in most boreholes, averaging to 0.66±2mg/l and 0.23±1mg/l respectively, which are above the TWQG limits. The NH_4-N ions are above SANS 241:2011 limit, however, they are not toxic to humans. Owing to relatively high average N concentration (3.4±3mg/l) in the groundwater, it was classified as eutrophic. Due to low nutrients in the rainwater and tap water qualities, these sources are considered to have no significant impact on the groundwater quality of the catchment in terms of nutrient composition.

Consequently, the slow groundwater movement, confining intermediate layers of the KwaMbonambi Formation, unconsolidated sediments and high MAP in the catchment is causing nutrients to accumulate in the shallow aquifers, especially in high population density residential areas such Mbazwana. Since the groundwater movement is very slow especially in the Mbazwana area and the recharge is only visible after several decades as base flow in the streams and lakes, nutrients persist in the groundwater for up to 10 to 20 years. The actual average N and P concentrations in groundwater are higher than the estimated nutrient values from the population, thus indicating accumulation of nutrients in the groundwater. Owing to the average NH_4-N and PO_4-P concentrations, the groundwater discharge in surface water resources has the potential to cause eutrophication.

The groundwater is generally acidic, pH values averaged to 5.31±0.9, which is below the TWQG limit. The lowest pH value of 4.28 which is below SANS 241 was observed in Qondwane. The disintegration of domestic organic compounds produces organic acids that contribute to acidity of the groundwater with high observed turbidity averaging to 97±3NTU, which is above SANS 241. TDS and EC values average 193±57mg/l and 30±11mS/m respectively. However, high concentration of 394mg/l and 77mS/m respectively, observed in Mbazwana.

The groundwater is low in Ca, Mg, K, SO_4 concentrations, however elevated in Na and Cl concentrations. The average Ca concentration is higher than Mg concentration, Ca: Mg ratio was 3:1 the groundwater is characterized by a sodium-chloride ion signature. It is a common groundwater signature in shallow aquifers in the Maputaland region with low HCO_3^- ions, owing to recent cyclic salt input from the sea (Allan and van Wyk, 1969). Due to acidic groundwater quality, it is elevated in Fe, Al and Mn above the TWQG limits. These ions are toxic to the aquatic life.

10.3Mgobezeleni catchment surface water chemistry characterization

a) Lake Mgobezeleni

Lake Mgobezeleni receives water from the groundwater as base flow and directly from the peat enriched streams, rich in N and P composition. It is relatively low in NO_3-N concentration throughout the water column, averaging to 0.21±0.2mg/l, indicating assimilation of nitrate ions by plants. However, elevated average concentration (0.35±0mg/l in sludge sample) is observed near the base of the Lake, indicating accumulation of nutrients at the base of the Lake. The NH_4-N and PO_4-P concentrations are elevated above the TWQG limits, averaging to 0.18±0.2mg/l and 0.01±0.01mg/l respectively, from the decomposition of plant material. Based on the Lake TN concentrations of 0.41±0.2mg/l (on the water column) and 0.81±0.2mg/l (near base of the Lake), It is classified oligotrophic and mesotrophic respectively. This indicates that organic material is generally accumulating at the base of the Lake increasing the N and P concentrations, thus causing eutrophication.

Considering the steady state annual net groundwater inflow into the Lake and the total Lake water storage volume (the annual groundwater dilution factor estimated at 1:21), the TN concentration is estimated at 0.28 mg/l. Owing to the actual groundwater TN concentration (0.41±0.2mg/l) of the Lake, it is therefore concluded that the groundwater is not the only source of nutrients. Streams water quality together with decomposing plant material from the vegetation surrounding the Lakes and the streams contribute to the nutrients, dissolved OC and OM composition into the Lake water column, especially at the base of the Lake. The dissolved OC and OM averaged to 20±13mg/l and 45±31mg/l respectively. Characterization of the dissolved OM content in lake was achieved using the IR Spectrum and UV-Vis spectrum, which reflected high degree of structure of aromatic compounds indicating the presence of the humic acid components (Chin, *et al.*, 1994). The presence of humic acid contributed to the *blackwater* in the Lake. Due to the presence of high dissolved OM at the bottom of the Lake, it is elevated in microalgal species such as cyanophytes (toxic *Microcystic aeruginosa* dominant) flagellates, diatoms and dinophytes population. The toxic *Microcystic aeruginosa* can the domestic and wildlife and threatens the water supply to Ezemvelo Wildlife residential areas.

The lake is characterized by a mean pH value of 8.04±0.7. The pH values range between 6.20 and 8.38, which tend to decrease towards the bottom of the lake. The water is turbid with high suspended solids, averaging to 7.5±4NTU and 9.6±8mg/l, owing to partially decomposed plant material fragments. It is low in salinity averaging to 0.18±0ppt. It is characterized by a mean DO concentration of 8.45±1mg/l and appears to decrease towards bottom of the lake. The total alkalinity averaged to 52.4±10mg/l, indicating good buffering capacity in the lake.

Similar to the groundwater, the lake was low in Ca, Mg, K, SO_4 concentrations. Humic substances forms complexes with cations, thus resulting in low cations and anions in the lake. The calcium: magnesium ratio was 3:1. It is characterized by a sodium-chloride ion signature. It was low in Al, however, elevated in Fe and Mn concentrations.

b) Lake Shazibe

Similarly, to Lake Mgobezeleni, Lake Shazibe receives water from the groundwater recharge as base flow and from the streams, rich in N and P concentrations. It is relatively low in NO_3-N concentration averaging to 0.27±0.1mg/l, which is slightly elevated in the shallow region of the Lake, indicating assimilation of nitrates ions by submerged macrophytes in the bottom of the Lake. The NH_4-N and PO_4-P concentrations averaged to 0.51±0.7mg/l and 0.49±2mg/l respectively, which are above the TWQG limits. Based on the Lake TN concentration (0.81±0.7mg/l), it is classified as mesotrophic. Due to the number of submerged macrophytes decomposing at the bottom of the Lake, the N and P concentrations are elevated in the bottom part of the Lake causing eutrophication.

Considering the steady state annual net groundwater inflow into the Lake and the total Lake water storage volume (the annual groundwater dilution factor estimated at 1:4), TN concentration was estimated at 1.34mg/l. Owing to the actual TN concentration (0.81±0.7mg/l) in the Lake, it is therefore concluded that nitrogen in the Lake is consumed by submerged macrophytes resulting in eutrophication. The decaying plant material at the bottom of the Lake produces dissolved OC and OM, which averaged to 29±5mg/l and 65±12mg/l respectively. Characterization of dissolved OM reflected a large composition of aliphatic structures and low quantity of condensed aromatic structure indicating the dominance of fulvic acid components. Due to the presence of high OM content, it resulted in the formation of *blackwater* in the Lake. The Lake contains elevated macrophytes species and microalgal species such as cyanophytes, flagellates, diatoms and Dinophytes population, which are lower than in Lake Mgobezeleni.

The Lake is characterized by a mean pH of 7.46±0.6, pH values appear to be relatively higher in the upper region of the Lake. The water is high in turbidity (averaged to 168±50NTU) and suspended solids (averaged to 1432±3464mg/l) due to high amount of partially decomposed plant material. It is low in salinity averaging to 0.19±0.01ppt. It is relatively low DO concentration averaged to 7.38±2mg/l, which is below the TWQG limit. The DO concentration ranged from 3.68mg/l to 9.65mg/l, the lower concentration is observed at the bottom of the Lake, which indicate oxygen consumption by decomposing plant organic material. The high concentration is attributed to photosynthesis. The TDS and EC values averaged to 252±5mg/l and 38.0±3mS/m. The water is well buffered indicated by total alkalinity averaging to 68±10mg/l, which attributed to HCO_3^- ions, including CO_2 gas produced from disintegration of plant organic matter at the bottom of the Lake.

The water in the Lake is characterized by low Ca, Mg, K and SO_4 concentrations, however elevated in Na and Cl concentrations. The calcium is higher than magnesium indicated by a Ca: Mg ratio of 2:1. It is characterized by sodium-chloride ion signature, and was low in Al, concentration however elevated in Fe and Mn concentrations.

Lake Shazibe is elevated in Na, Mg, Cl, HCO_3^- , SO_4 and Mn concentrations above the groundwater quality, and Thungwinin Wetland, therefore there the Lake is likely to be receive saline water intrusion or there is potential treated sewage effluent being discharged into the Lake contributing to the above ions. The same ions were also traced from the Lake outflow, except for the SO_4 ions.

c) Mgobezeleni Estuary

Mgobezeleni Estuary receives water from the groundwater as base flow and directly from the stream recharged by the lakes outflows, rich and N and P concentrations. It is low in NO_3-N concentration averaging to 0.41±0.3mg/l, which was elevated in shallow region of the Estuary. It is relatively higher than in both lakes owing to the small size of the Estuary. The NH_4-N and PO_4-P concentrations averaged to 0.41±0.21 and 0.03±0.01 respectively, which is elevated above the TWQG limits, especially in the bottom part of the Estuary because of partially decomposed plant organic matter. Based on the Estuary average TN concentration (0.83±0.3mg/l), it is classified as mesotrophic.

Owing to elevated partially decomposed organic material at the bottom of the Estuary and suspended organic fragments, it is elevated in dissolved OC and OM averaging to 40±5mg/l and 91±30mg/l respectively, especially when the Estuary's mouth is closed. Characterization of the dissolved OM reflected a large composition of aliphatic structures and low quantity of condensed aromatic structure indicating the dominance of fulvic acid components. Due to the presence of high OM content in the Estuary, it results in the formation of the *blackwater*. It contains usual population of microalgal species but is found to be elevated in macrophyte species. It is low in *microphytobenthos* and cyanophytes species than expected.

The Estuarine water is characterized by a mean pH value of 7.53±0.1, pH values are relatively elevated in deeper region of the Estuary due to generation of organic acids from partially decomposed organic material. It is turbid and high in suspended solids owing to partially decomposed organic material. Due to consumption of oxygen by compositing organic matter, the water is low in DO, averaging to 7.80±1mg/l, especially in bottom layers of Estuary. Owing to sea influx into the Estuary, it is elevated in average TDS (16g/l), EC (2058±1322mS/m and salinity (12 ±9ppt) values. It is also high in alkalinity, averaging to 80±15mg/l. It is characterized by low Ca, Mg, K and SO_4 concentrations, however elevated in Na and Cl concentrations. The Ca: Mg ratio is 1.1. It is characterized by a sodium-chloride ion signature, with low Al, Fe concentrations, however, elevated in Mn concentration.

10.4 Mgobezeleni catchment wetland water chemistry characterization

Bhekaphandle, Thungwini, Culvert and Sangweni Pan are the four interdunal wetlands in the Mgobezeleni catchment assessed for water quality. They are groundwater fed and, in turn, are responsible for lake, estuary and stream water recharge. They are rich in peat deposits which serve as a basis for subsistence crop cultivation by the local community.

a) Bhekaphandle Wetland

Bhekaphandle Wetland water recharges Lake Mgobezeleni and directly receives groundwater recharge as base flow. It is relatively low in NO_3-N concentration, averaging to 0.21±0.2mg/l, which is equivalent to the mean nitrate concentration in Lake Mgobezeleni. The average NH_4-N (0.29±0.1mg/l) and PO_4-P (0.04±0.1mg/l) concentrations are above the TWQG limits, owing to decomposing plant organic matter (including peat). Based on the average TN concentration (0.51± 0.4mg/l), Bhekaphandle Wetland is classified as mesotrophic.

It's elevated in dissolved OC and OM averaging to 47±22mg/l and 112±53mg/l respectively, owing to peat fragments from cultivated peatlands and partially decomposed plant organic matter in the Wetland. Characterization of the dissolved OM reflected a large number of aliphatic compounds indicating the presence of fulvic acid, causing the generation of the *blackwater* in the Wetland.

It is characterized by a mean pH value of 6.08±0.6. Owing to the presence of peat fragments from cultivated peatlands and partially decomposed plant organic material in the Wetland, the water is turbid and elevated in suspended solids, averaging to 9.18±37NTU and 845±17mg/l respectively. The TDS and EC values averaged to 265±120mg/l and 40.9±9mS/m respectively. The water is low in Ca, Mg, K, and SO_4 concentrations, however elevated in Na and Cl concentrations. Calcium ions are more dominant than magnesium ions, indicated by a Ca: Mg ratio of 3:1. It is characterized by a sodium-chloride ion signature. It is elevated in Al, Fe, and Mn concentrations above the TWQG limits.

b) Thungwini Wetland

Thungwini Wetland water recharges Lake Shazibe and directly receives groundwater recharge as base flow. Similarly, to other water resources, it is relatively low in NO_3-N concentration averaging to 0.35±0mg/l. Owing to decomposing plant material and peat fragments in the water it is elevated in average NH_4-N (0.45±0mg/l) and PO_4-P (0.03±0.1mg/l) concentrations respectively, above the TWQG limits. Based on the average TN concentration (0.81± 4mg/l), Thungwini Wetland is classified mesotrophic.

Due to high partially decomposed plant material in the water, it is relatively high in dissolved OC and OM, averaging to 71±61mg/l and 164±141mg/l respectively. The dissolved OM in the Wetland contains a large quantity of condensed aromatic structures, indicating the presence of humic acid components, resulting in the generation of the *blackwater* in the Wetland.

The water is characterized by a mean pH value of 7.03±0.0. It is turbid and contains high suspended solids as result of the decomposing plant material and peat fragments, averaging to 4.53±3NTU and 1.0±1mg/l. The TDS and EC values averaged to 149±5mg/l and 29.9±0.4mS/m. It is low in Ca, Mg, K and SO_4 concentrations, however elevated in Na and Cl concentrations. The Wetland is relatively low has Ca: Mg ratio of 5:1. It is characterized by a sodium-chloride ion signature. It is relatively elevated in Al, Fe and Mn above the TWQG limits.

c) Culvert Wetland

Culvert wetland water recharges the Mgobezeleni Estuary and receives water recharge from groundwater as base flow and from Lake Shazibe outflow. It is relatively low in NO_3-N concentration averaging to 0.12±0.2mg/l. It is elevated in NH_4-N (0.17±0mg/l) and PO_4-P (0.02±0mg/l) concentrations, owing to decomposing plant organic material. Based on the low average TN concentration (0.30± 0.4mg/l), the Culvert Wetland is classified as oligotrophic.

Owing to decomposing plant organic material in the wetland from the surrounding thick forest, it is elevated in dissolved OC and OM contents, averaging to 41±20mg/l and 95±45mg/l respectively. The dissolved OM matter content was characterized using IR and UV-Vis spectra and reflected the presence of large condensed aromatic structures of humic acid components. Humic substance are responsible for the *blackwater* formation in the Wetland.

Wetland is characterized by a mean pH value of 6.32±0.2. Due to relatively high stream current in the Wetland, it is low in turbidity and suspended solids. The TDS and EC values averaged to 240±6mg/l and 36.6±0.3ms/m respectively. It is low in Ca, Mg, K, SO4 concentrations, however elevated in Na and Cl concentrations. It is characterized by a sodium- chloride ion signature. It is elevated Al, Fe and Mn concentrations above the TWQG limits.

d) Sangweni Pan

Sangweni Pan is an endorheic and is located upgradient of Lake Mgobezeleni. It is relatively low in NO_3-N concentration averaging to 0.19±0.2mg/l. Owing to animal droppings as well as the low water level in the Pan, the average NH_4-N (9.35±2mg/l) and PO_4-P (0.02±0.01mg/l) concentrations are elevated above the TWQG limits. Based on the average TN concentration (9.55± 2mg/l), Sangweni Pan is classified hypertonic (highly productive system).

It is characterized by a mean pH value of 4.13±0.6, which is below the TWQG limit. It is high in turbidity and suspended solids values averaging to 807±105NTU and 154±20mg/l respectively. It is low in Ca concentration, however elevated in Mg (46.7±10mg/l), Na (186±16mg/l), K (13.2±0.3mg/l), Cl (309±19mg/l), and SO_4 (218±105mg/l) concentrations. Mg ions are higher than Ca ions, the Ca: Mg ratio is 1:3. It is characterized by a sodium-chloride-sulphate ions signature. It is elevated in Al, Fe and Mn above the TWQG limits.

10.5 The Mgobezeleni catchment peat chemistry characterization

Selected peatlands in the Mgobezeleni catchment included Bhekaphandle Wetland, Thungwini Wetland, Culvert Wetland, Qondwane Wetland, KwaZikhali Wetland and Sangweni Pan. The Mgobezeleni catchment peat thickness ranges between 0.40m and 2.9m. The peat is generally saturated, fibrous, containing brownish to black organic material especially in the O-horizon of uncultivated sites. However, the peat in Sangweni Pan and KwaZikhali Wetland is shallow and decomposed in all layer of the peat profile. Cultivated sites in the Mgobezeleni catchment are generally decomposed in the O-horizon, resulting in 1ow fibre content (about 10%). The slightly or moderately decomposed peat is found to have a high to low fibre content in various levels of the peat profile. The bottom layers are generally found to be high in inorganic (sand) material, especially in Thungwini Wetland, KwaZikhali Wetland and Sangweni Pan, with no fibre content. Some of the peat deposits in KwaZikhali peatland are affected by veld fires, which had caused intense decomposition of organic peat material.

The total N and P concentrations are relatively higher in the upper layers of the peat profile due to partially decomposed organic material, ranging from 0.12% to 1.2%; and 0.78% and 7.7% respectively. Peat soil are higher in total P concentration; however, it only becomes readily available for plant assimilation upon mineralisation. P in wetlands, is generally adsorbed (fixed) on surfaces of mineral ions such as Al, and Fe complexes and is removed in solution by precipitation on sediments. Draining or cultivation of the peat enhances the fixation power of P due to relatively high accumulations of Al and Fe compounds in the peat soils (FAO, 1988). The highest concentration is observed in the Qondwane peatland. The total N concentration of peat soils is within the low range of FAO (1988). Nitrogen is mineralised to NH_4^+ and NO_3^-, which are assimilated by plants. The decomposable nitrogenous components of the peat are mineralised first such as NH_4^+ and become very soluble in water which is indicated by the high levels in the water resources as NH_4-N concentration. The total N concentration is directly affected by the temperature, moisture content, aeration and acidity of the soils; and varies widely with the nature of the peat and its decomposition status (FAO, 1988).

Peat soils are acidic due to the presence of organic acids and probably exchangeable H^+, $Al^{3+,}$ FeS_2 and other oxidizable S compounds. The pH values are found to range from 4.89 to 5.99, indicating acid peat soils. The upper layers are more acid due to the presence of partially decomposed plant material generating organic acids. Ombrogeneous and oligotrophic peat are commonly acidic or extremely acidic in the uppermost layers owing to poor cations which cause extreme acidity. Decomposing vegetation generates acidic conditions in the upper layers of the peat profile. Under acidic conditions, P forms insoluble Fe and Al phosphate complexes.

The ash content of the peat ranges from 12% to 96%. It is relatively high in the bottom layers of the peat profile due to elevated inorganic material (sand). Cultivated sites are slightly elevated in ash content owing to peat decomposition. Inherent moisture, volatiles, and fixed carbon contents are also relatively higher in the upper layers of the peat profile. Based on the Maputaland peat proximate classification by Grundling and Mazus (1998), the Mgobezeleni peatlands are classified as medium to inorganic ash.

The organic matter (OM) content ranges from 23% to 62%. It is elevated in the upper layers of the peat profile owing to partially decomposed organic plant material. The CHN, S and HA values are elevated in the bottom layers. Based on the average C/N ratio (ranging between 16:1 and 23:1), the peat in the Mgobezeleni peatlands is decomposed, especially in the upper part of the peat profile. Peat soils are elevated Mg, Ca, Na, Al, Fe, Cr and B concentrations resulting from coagulation with humic substances which form insoluble complexes. However, Ca, Cr, K and Zn concentrations are deficient in other sites. Potassium, sodium and magnesium generally undergo cation exchange with hydrogen on the active site of the peat.

10.6 The cause of the blackwater in the Mgobezeleni catchment

The *blackwater* was assessed in Lake Mgobezeleni, Lake Shazibe, Mgobezeleni Estuary and all selected Wetlands excluding the Sangweni Pan using the infrared (IR) Spectrum and Ultra-violet- visible region (UV-Vis spectrum). The water in all the systems contains high levels of dissolved OM which is characterized by humic substances, which reflected a high degree of aromatic and aliphatic compounds indicating the presence of the humic acid and fulvic acid components respectively (Chin, *et al.*, 1994). The presence of humic substances contributed to the *blackwater* in the water resources.

RECOMMENDATIONS

a) Owing to the growing human population and the associated environmental effects on the groundwater quality in the shallow aquifer in the Mgobezeleni catchment regarding the leaching of nutrients from sanitation systems, there is a need to identify suitable land for future development and to establish proper sanitation systems to prevent groundwater contamination.

b) An expanded groundwater and surface monitoring network is required for the ongoing monitoring of the impact of population growth.

c) All relevant stakeholders, including the local communities, should participate in a programme to protect the natural resources of the catchment area.

d) The Ezemvelo KZN Wildlife together with the Department Agriculture, Forestry and Fisheries (DAFF) and the Department of Water and Sanitation (DWS) in KZN, should create a forum to educate all relevant stakeholders, including the public, on the protection of both the important biodiversity and the water resources on the Maputaland coastal plain.

e) The ecotourism facilities in the Maputaland region should implement suitable sanitation systems that will reduce groundwater contamination.

f) The groundwater and surface monitoring network along the Maputaland coastal plain should be increased to monitor the impact of population growth on these systems.

g) A further study is required to investigate the toxicity levels of trace elements such as Pb, Ag, Zn, Cu, Ni in the groundwater, lakes, estuary and wetlands arising from sewage disposal.

h) A surface water study required to assess the sources of elevated Na, Cl and SO_4 concentrations in Lake Shazibe, whether it is treated sewage effluent disposal or saline intrusion into the Lake.

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