

**THE IMPACT OF FLOODING CHARACTERISTICS OF
THE NYANDO RIVER ON COTTON CULTIVATION IN
LOWER KANO PLAINS IN NYANDO DISTRICT,
WESTERN KENYA**

PETER OMONDI OCHOLLA

**DEPARTMENT OF HYDROLOGY
UNIVERSITY OF ZULULAND**

**DISSERTATION SUBMITTED
TO THE FACULTY OF SCIENCE AND AGRICULTURE**

**FOR THE DEGREE OF MASTER OF SCIENCE IN
HYDROLOGY**

2010

APPROVAL

Supervisors:

Professor Bruce Kelbe:.....Date:.....

Department of Hydrology

University of Zululand, South Africa

Mr. Brian Rawlins :.....Date:.....

HOD-Department of Hydrology

University of Zululand, South Africa

DECLARATION

I declare that this study “The Impact of Flooding Characteristics on Cotton Cultivation in Lower Kano Plain in Nyando District, Western Kenya”, is my work both in the conception and execution, except where specifically indicated to the contrary in the text. All the information that was used has been acknowledged in the text and in the references.

Signed:.....

Peter Omondi Ocholla

ACKNOWLEDGEMENTS

The final product of this work is a culmination, of many contributions, moral and material, academic and professional; from institutions and people, a few of whom only will be mentioned here.

First and foremost, I wish to mention my supervisors, Prof. Bruce Kelbe and Mr. Brian Rawlins both of Department of Hydrology, for painstakingly reading this work, from the initial stage of its proposal, the manuscript form, and finally to the current stage. I am greatly indebted to their tireless efforts, advice and financial support that have made it possible to produce this work in its final current form.

University of Zululand is acknowledged for granting me the opportunity to pursue a Master of Science degree in hydrology. All that was possible because of the financial assistance and goodwill from Prof. Dennis N. Ocholla, of the Department of Library and Information Science and his family, who practically gave support both of material and financial, during my fieldwork and stay at the University. Their support is greatly appreciated.

Special mention must be reserved for the Provincial Administration, Nyanza Province, Lake Basin Development Authority (LBDA), the Ahero Irrigation Rice Scheme, the National Environmental Management Authority (NEMA), the Kenya Agricultural Research Institute (KARI), and the National Centres for Environmental Prediction (NCEP), for providing data used in this thesis.

A word of thanks also goes to my colleagues in the Department of Hydrology: Messrs. Jean Simonis and Gelmer Mulder, for their inspiration and technical assistance. To Mr. George Aike (ICRAF-Kenya); for offering his valuable time during ArcGIS map preparation. To my wife Eunice Muzungu, for patiently withstanding my absence from home, God bless you. I extend my sincere thanks to Mr. Lombard in the Department of Mathematics and Mrs. Kibirige of Physics and Engineering for sharing with me critical aspects of the analysis of Fourier series. Finally, the author bears all responsibility for errors and /or omissions in this thesis.

TABLE OF CONTENTS

APPROVAL	I
DECLARATION	II
ACKNOWLEDGEMENTS	III
ABSTRACT.....	X
CHAPTER 1: INTRODUCTION AND PROBLEM SETTING	1
1.0 INTRODUCTION AND CONCEPTUAL FRAMEWORK.....	1
1.1 CONTEXTUAL SETTING	5
1.2 STATEMENT OF THE PROBLEM.....	16
1.3 AIM AND OBJECTIVES OF THE STUDY	17
1.4 RESEARCH QUESTIONS	17
1.5 ORGANISATION OF THE DISSERTATION.....	18
1.6 OPERATIONAL DEFINITIONS	20
1.7 SUMMARY	21
CHAPTER 2: BACKGROUND OF THE STUDY AREA IN NYANDO BASIN	22
2.1 INTRODUCTION	22
2.2 LOCATION AND SIZE OF THE STUDY AREA	22
2.3 THE PHYSIOGRAPHY OF THE KANO PLAIN AND NYANDO BASIN	25
2.4 CLIMATIC CHARACTERISTICS AND AGRO-ECOLOGICAL ZONES OF KANO PLAINS	27
2.5 SOIL CHARACTERISTICS, FLOODING AND LAND USE IN THE KANO PLAINS	36
2.6 SETTLEMENT IN THE NYANDO BASIN AND FLOOD PRONE STUDY AREA.....	39
2.7 THE CULTIVATION OF COTTON AND FLOOD PROBLEMS IN THE KANO PLAIN	42
2.8 SUMMARY.....	47
CHAPTER 3: LITERATURE REVIEW.....	48
3.0 INTRODUCTION	48
3.1 FLOODING AND FLOOD DRIVING MECHANISMS.....	49
3.2 DRAINAGE BASIN CHARACTERISTICS AND FLOODING	50
3.3 LINKS BETWEEN LAND COVER (LAND USE) AND FLOW GENERATION.....	53
3.4 THE CAUSE OF FLOODING AND INUNDATION ON CROP CULTIVATION	62
3.5 COTTON GROWING ON THE KANO PLAINS IN KENYA	63
3.6 SUMMARY OF LITERATURE REVIEW	65

CHAPTER 4: DATA AND METHODOLOGY	66
4.0 INTRODUCTION.....	66
4.1 A PILOT ANECDOTAL SURVEY	66
4.2 RESEARCH QUESTIONS	66
4.3 RESEARCH METHODS.....	67
4.4 POPULATION AND SAMPLE FRAME	68
4.5 DATA TYPE AND SOURCE FOR PHYSICAL (HYDROLOGIC) ANALYSIS.....	73
4.6 PHYSICAL METHODS.....	79
4.7 LIMITATION OF THE FIELD RESEARCH.....	91
4.8 SUMMARY	92
CHAPTER 5: ANALYSIS, INTERPRETATION AND PRESENTATION	93
5.0 INTRODUCTION.....	93
5.1 THE PHYSICAL AND RAINFALL CHARACTERISTICS OF THE NYANDO BASIN	93
5.2 THE IMPACT OF RAINFALL AND FLOW REGIMEN IN THE KANO PLAINS	108
5.3 IMPACT OF FLOODING CHARACTERISTICS ON COTTON CULTIVATION IN THE KANO PLAINS ..	150
5.4 SUMMARY.....	166
CHAPTER SIX: SUMMARY AND DISCUSSION	168
6.0 INTRODUCTION.....	168
6.1 CHARACTERISTICS OF THE DRAINAGE BASIN OF THE NYANDO RIVER.....	170
6.2 THE TEMPORAL AND SPATIAL VARIABILITY OF RAINFALL AND FLOW	173
6.3 SUMMARY.....	194
CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS	196
7.0 INTRODUCTION.....	196
7.1 CONCLUSIONS	198
7.2 RECOMMENDATION	203
REFERENCES.....	207
APPENDIX 1: INDIVIDUAL QUESTIONNAIRE	219
APPENDIX 2A: 31 YEARS TIME SERIES SATELLITE DATA OF RAINFALL FOR THE NYANDO RIVER EXTRACTED AT 34⁰E AND 35⁰04 E AND 0' NORTHING.....	226
APPENDIX 2B: MONTHLY ACTUAL RAINFALL FOR KANO PLAINS IN NYANDO RIVER BASIN IN KENYA	227
APPENDIX 3: 31 YEARS TIME SERIES DATA FOR FLOW OF THE NYANDO RIVER AT GAUGE STATION IGD03	228

APPENDIX 4: 21 YEARS TIME SERIES DATA FOR FLOW OF THE NYANDO RIVER AT GAUGE STATION IGB03	230
--	------------

LIST OF FIGURES

FIGURE 1.1: THE NYANDO RIVER BASIN IN KENYA AND LOWER KANO PLAINS.	7
FIGURE 2.1: THE STUDY AREA IN NYANDO AND THE BORDERING DISTRICTS.	24
FIGURE 2.2: A DIGITAL ELEVATION MODEL (DEM) OF THE NYANDO BASIN	25
FIGURE 2.3: THE DEM SHOWING THE KANO PLAINS.	26
FIGURE 2.4: MEAN ANNUAL RAINFALL DISTRIBUTION IN KENYA.	28
FIGURE 2.5: MEAN ANNUAL RAINFALL DISTRIBUTION IN THE NYANDO BASIN	30
FIGURE 2.6: THE BOX AND WHISKER PLOT OF VARIABILITY OF RAINFALL	31
FIGURE 2.7A: THE CIRCULATION OF THE RAINFALL PATTERN (LAND BREEZE).....	34
FIGURE 2.7B: THE CIRCULATION OF THE RAINFALL PATTERN (LAKE BREEZE).	35
FIGURE 2.8: KANO PLAINS SHOWING THE POORLY DRAINED VERTISOLS	38
FIGURE 2.9: DEM WITH THE SETTLEMENT OVERLAID IN THE NYANDO BASIN AND FLOOD PRONE LOWER KANO PLAINS.	41
FIGURE 3: AVERAGE ANNUAL FLOOD DAMAGE IN THE KANO PLAINS.....	61
FIGURE 4.2: THE VILLAGES SURVEYED IN LOWER KANO PLAINS (STUDY AREA).	72
FIGURE 4.3: DOUBLE MASS CURVE FOR KANO (1GD03) STATION	77
FIGURE 4.4: DOUBLE MASS CURVE OF ANNUAL FLOW AT STATION 1GD03.....	78
FIGURE 5.1: THE DEM OF THE NYANDO BASIN, SHOWING STREAM DENSITY.....	94
FIGURE 5.2A: TURBIDITY OF FOUR RIVERS DRAINING INTO LAKE VICTORIA	96
FIGURE 5.2B: SEDIMENT YIELD BY THE NYANDO RIVER INTO LAKE VICTORIA.....	96
FIGURE 5.3: THE SUB-CATCHMENTS OF THE NYANDO BASIN	97
FIGURE 5.4A: DISTRIBUTION OF 11 RAIN GAUGE STATIONS IN NYANDO BASIN	98
FIGURE 5.4B: SAMPLED RAIN GAUGE STATIONS FOR ANALYSIS.....	98
FIGURE 5.5: TOPOGRAPHIC INFLUENCE ON ANNUAL RAINFALL.....	100
FIGURE 5.6: THE HYDROGRAPHIC BASIN AND THIESSEN POLYGONS DISTRIBUTION.	103
FIGURE 5.7: RUNOFF COEFFICIENT OF FLOW.....	107
FIGURE 5.8A: MEAN MONTHLY DEVIATIONS OF RAINFALL FOR 31 YEAR PERIOD. ...	108
FIGURE 5.8B: MONTHLY MEAN CYCLE OF RAINFALL AND FLOW IN THE LOWER KANO PLAIN BETWEEN 1970 AND 2000.....	109
FIGURE 5.9: ANNUAL MEAN VARIABILITY OF RAINFALL AND FLOW	111

FIGURE 5.10A: THE VARIABILITY OF RAINFALL AND FLOW IN 1976.	112
FIGURE 5.10B: THE VARIABILITY OF FLOW AND RAINFALL FOR 1984.....	112
FIGURE 5.10C: THE VARIABILITY OF RAINFALL AND FLOW FOR 1986.....	113
FIGURE 5.10D: THE VARIABILITY OF RAINFALL AND FLOW FOR 1997.....	113
FIGURE 5.11A: 5-YEAR RUNNING MEAN OF RAINFALL SHOWING WET & DRY PERIODS	115
FIGURE 5.11B: 5-YEAR MEAN SHOWING THE WET AND DROUGHT DISCHARGE BY THE NYANDO RIVER.	115
FIGURE 5.12A: MONTHLY PRECIPITATION FOR KANO PLAINS (JAN,1970 TO DEC 2000	125
FIGURE 5.12B: CORRELOGRAM FOR MONTHLY RAINFALL FOR STATION IGD04.	126
FIGURE 5.12C: SPECTRAL DENSITY FUNCTION FOR RAINFALL AT 1GD04.....	127
FIGURE 5.13A: THE MONTHLY FLOW FOR THE NYANDO RIVER AT WEIR IDG04.....	128
FIGURE 5.13B: CORRELATION OF FLOW.	129
FIGURE 5.13C: SPECTRAL DENSITY FUNCTION FOR THE MONTHLY FLOW (1GD04). 130	
FIGURE 5.14A: SPECTRAL DENSITY FUNCTION OF FLOW.....	131
FIGURE 5.14B: SPECTRAL DENSITY OF RAINFALL FROM 1970 TO 1984.....	132
FIGURE 5.14C: THE SPECTRAL DENSITY OF FLOW FROM 1970 TO 1984.....	133
FIGURE 5.14D: THE SPECTRAL DENSITY OF RAINFALL FROM 1985 TO 2000.	133
FIGURE 5.14E: THE SPECTRAL DENSITY OF FLOW FROM 1985 TO 2000.....	134
FIGURE 5.15A: THE WAVELET POWER SPECTRUM OF RAINFALL.....	137
FIGURE 5.15B: THE WAVELET POWER SPECTRUM OF FLOW.....	138
FIGURE 5.15C: THE WAVELET POWER OF 5-MONTH MEAN SATELLITE RAINFALL....	139
FIGURE 5.15D: THE WAVELET ANALYSIS OF 5-MONTH FILTERED FLOW.	140
FIGURE 5.16A: THE FREQUENCY HISTOGRAM OF FLOW.....	145
FIGURE 5.16B: THE FREQUENCY HISTOGRAM OF THE MEAN AND STANDARD DEVIATION OF DISCHARGE OF THE NYANDO RIVER	145
FIGURE 5.17: RECURRENCE FREQUENCY OF PEAK FLOW.....	146
FIGURE 5.18: PERCEPTIONS ON THE IMPACT OF FLOODS ON COTTON CULTIVATION.157	
FIGURE 5.19: THE PORTION OF THE COTTON FIELDS AFFECTED BY FLOODS.	159
FIGURE 5.20: TREND OF COTTON PRODUCTION IN NYANDO DISTRICT.....	160
FIGURE 5.21A: AREAS UNDER COTTON PER PROVINCE IN KENYA	161
FIGURE 5.21B: PRODUCTION OF SEED COTTON BY PROVINCE IN KENYA	162
FIGURE 5.22: PERCEPTIONS ON THE DECLINE IN COTTON OUTPUT (1995-2000).....	164

LIST OF TABLES

TABLE 1: YIELD AND LAND UNDER COTTON BY PROVINCE	15
TABLE 2.1: COTTON CULTIVATION CALENDAR IN KENYA AND THE KANO PLAIN	44
TABLE 2.2: LABOUR REQUIREMENT FOR COTTON PRODUCTION IN THE KANO PLAIN.....	46
TABLE 4.1: STATISTICAL PARAMETERS OF ANNUAL RAINFALL IN NYANDO RIVER BASIN..	76
TABLE 5.1: STATISTICS OF ANNUAL RAINFALL FOR 5 STATIONS IN THE NYANDO BASIN ...	99
TABLE 5.2: THE ATTRIBUTES OF AREA FROM THIESSEN POLYGON	102
TABLE 5.3A: RIVER BASIN RUNOFF COEFFICIENT	104
TABLE 5.3B: RUNOFF COEFFICIENT OF ANNUAL FLOW	106
TABLE 5.4A: F-STATISTICS (ANOVA) FOR RAINFALL AND FLOW	117
TABLE 5.4B: F-STATISTICS (ANOVA) FOR RAINFALL AND FLOW BETWEEN AND WITHIN MONTHS IN 31 YEARS PERIOD.....	118
TABLE 5.4C: MULTIPLE COMPARISONS OF MEANS OF RAINFALL	120
TABLE 5.4D: MULTIPLE COMPARISONS OF THE MEAN OF FLOW USING DUNCAN'S MUTIPLE RANGE TEST (DMRT).....	121
TABLE 5.4E: MULTIPLE COMPARISON OF MONTHLY MEANS OF RAINFALL USING DMRT...	122
TABLE 5.5: MULTIPLE COMPARISON OF MONTHLY MEANS OF FLOW USING DUNCAN'S MRT	122
TABLE 5.6: REGRESSION ANALYSIS OF RAINFALL AND FLOW USING (ANOVA).....	141
TABLE 5.7: CORRELATION COEFFICIENT OF ANNUAL MONTHLY RAINFALL AND FLOW	142
TABLE 5.8: FLOOD FREQUENCY AND MAGNITUDE USING THE WEIBULL PROBABILITY MODEL	144
TABLE 5.9 FLOOD FREQUENCY IN THE LOWER KANO PLAINS	147
TABLE 5.10: PERCEPTIONS ON THE CAUSES OF FLOODING OF THE NYANDO RIVER	151
TABLE 5.11: MAJOR FLOODING EVENTS CITED BY RESPONDENTS.....	152
TABLE 5.12: THE PERCEIVED GENERAL DAMAGE CAUSED BY THE 1964 FLOODS	153
TABLE 5.13: THE DAMAGE CAUSED BY FLOODING OF 1977.....	154
TABLE 5.14: THE DAMAGE CAUSED BY FLOODING OF 1988	154

TABLE 5.15: THE IMPACTS OF EL-NINO FLOODS BETWEEN 1996 AND 1998	154
TABLE 5.16: THE AVERAGE FLOOD DEPTHS CITED IN THE STUDY AREA	155
TABLE 5.17: THE DAMAGE CITED AS A RESULT OF HIGH FLOOD DEPTH	155
TABLE 5.18: THE DURATION OF FLOODING AS RECALLED BY RESPONDENTS.....	156
TABLE 5.19: THE AVERAGE CULTIVATED LAND (HA) OWNED BY HOUSEHOLDS	158
TABLE 5.20: THE PERCEIVED TREND IN COTTON OUTPUT IN THE LOWER KANO PLAIN	163
TABLE 5.21: PERCEPTIONS ON THE IMPACT OF FLOODING ON THE COTTON CYCLE.....	165

LIST OF PLATES

PLATE 1A: DEFORESTATION AND WOOD FUEL COLLECTION BY THE RIPARIAN HOUSEHOLDS IN KANO PLAINS.....	9
PLATE 1B: FLOOD EROSION INTO CULTIVABLE LAND DOWNSTREAM OF THE NYANDO RIVER.....	9
PLATE 1C: TEMPORARY SWAMP	PLATE 1D: THE AFFECTED HOUSEHOLDS10
PLATE 2.1A: DEPOSITED FLOOD REMNANTS	PLATE 2.1B: FLOOD IMPACT ON LAND USE39
PLATE 2.2A: COTTON AFTER FLOOD RECEDE	PLATE 2.2B: COTTON NOT AFFECTED BY FLOODING....43

ABSTRACT

Flooding continues to be a common environmental hazard in both developed and developing countries. Kenya has not been spared by the destruction that is usually associated with floods. Crops, settlement and infrastructure are usually impaired wherever flooding occur. The severity of damage as a result of floods has been documented to have had a relationship with the flood magnitude, flood frequency and occupation of the flood prone floodplains of large rivers. In the Lower Kano Plains of Western Kenya, damage to crops by floods is exacerbated by occupation of the lower reaches of the Nyando River.

This study sets out to assess the impact of flooding characteristics of the Nyando River on cotton cultivation in the Lower Kano Plains. In particular, the study examined the characteristics of the Nyando River Basin with the aim of describing how the river morphometry could have influenced flooding in the Lower Kano Plains. Also investigated, is the change in the flood magnitude and frequency with time and space, and finally, what anecdotal data (perception of cotton farmers) are available to support the assessment of flooding on cotton cultivation.

The study deployed both quantitative and qualitative research methods in examining the variability of rainfall and flow and the consequent impacts of flooding on cotton cultivation. Households living downstream in Lower Kano Plains were the target social unit of analysis. Multi-stage sampling technique was used to sample the respondents whom were interviewed through the use of a self administered questionnaire schedule. Descriptive and inferential statistical techniques were used in data analysis. Relevant probability models were used to analyze the flood magnitude

and flood frequency. Generally, the findings related to the research question have shown that flooding in the Lower Kano Plains has inhibited cotton cultivation and lower crop acreage. Furthermore, output has significantly declined for the period when spate has either denied farmers the ability for early planting or destroyed cotton already in the fields.

The inter-seasonal and intra-seasonal variability of rainfall and flow show their first peaks are dominant in April and May, while October and November present the second cycle. There is however, a shift in the cycles towards August and September, making the annual flow cycle highly variable in terms of decisions for crop growing. These peaks interfere with the cotton growing calendar, and results in delays in planting or destruction of cotton already planted.

The results from the spectral analysis revealed a strong annual and biannual cycle of both rainfall and flow, and an oscillating 4 months cycle that exhibited climate instability. A strong seasonal signal was evidenced between 6 and 12 month period that correspond with the flooding peaks. Similarly, wavelet results demonstrated a strong 12 month spectrum of both rainfall and floods with a large frequency of oscillation in the later period of the 31-year time series. The high power band of 2 to 5 years for both the raw and filtered rainfall and flow time series revealed a Quasi Biennial Oscillation (QBO) and a shift in the rainfall and flow cycle. The findings of the correlation also revealed that ($r^2 = 0.278$) rainfall in catchment explains 27.8% of high flow. The rest (72.2%) is attributed to other factors such as anthropogenic or hydro geologic characteristics of the study area. The study area was revealed to be prone to between 3 and 7 years flood return frequency with an average magnitude of 400 m³/sec. Further results showed that out of the 31 years of continuous time series

flow the Nyando River recorded 18 years of bankful flow (200 to 387.6 m³/sec). The high frequency of bankful flow illustrates that Nyando River has limited channel capacity and is therefore vulnerable to flooding downstream.

The 1 year return frequency characterizes the Lower Kano Plains to crop damage by annual spates, and thus, demands a shift in the cropping pattern and or change of crop variety to those ones that withstand poor drainage. Other factors that have exacerbated the decline in cotton production include poor price of lint, competition from synthetic fibres and rising cost of cotton production. Because of poor remuneration from cotton production, farmers are shifting to the growing of other crops such as rice and sugarcane that are less affected by flooding conditions. The two latter crops are said to be highly viable, cost effective and reliable. The problem of cotton cultivation in the study area is therefore due to variability of hydrologic conditions and economic factors. There is a need for a sound flood mitigation policy as well as the adoption of appropriate agronomic practices that would enhance cotton cultivation and improve output in the flood prone areas for it to be profitable in the present economic climate.

CHAPTER 1: INTRODUCTION AND PROBLEM SETTING

1.0 Introduction and Conceptual Framework

Water is a key element in the economic, social and cultural development of any society. Throughout history, people have settled next to waterways and in flood plains because of the advantages that they offer. In spite of these benefits, water can also cause destruction and damage. Flood devastation results in loss of lives, widespread crop destruction, water borne diseases and associated economic disasters (Ahmed, 1998; Dollar, 2001; International Centre for Research and Agro-forestry, 2002; Republic of Kenya, 2004).

Chapman (1994) describes flooding as the occurrence of “water where it is not wanted” and explains that flooding occurs most commonly from rainfall when natural watercourses do not have the capacity to convey the excess water. This description is supported by the United States Geological Survey (2006), which attributes flooding to weather phenomena and events that deliver more precipitation to a drainage basin than can be readily stored within the river. Floods, according to Chapman (1994), Penning-Rowse (1996) and USGS (2006), are an overflow or inundation that comes from a river or other body of water and causes or threatens damage. In other words, any relatively high streamflow overtopping the natural or artificial banks in any reach of a stream (USGS, 2006).

The early 1960s’ already witnessed a growing interest in the quantitative study of floods, floodplains and flood-prone areas (Leopold *et al.*, 1964). This prompted the definitions of flooding to shift from mere qualitative descriptions to a more rigorous

statistical definition (Penning-Rowsell 1996). Since then, flooding has usually been described in terms of a recurring event for a river, where the flow equals or exceeds a specific level of flow (Leopold *et al.*, 1964).

The geomorphic characteristics of the floodplains have also been used by some authors to describe the nature of flooding (Myers and White, 1993). According to Myers and White (1993), when heavy or continuous rainfall exceeds the absorptive capacity of soil, and the flow capacity of rivers, streams, and coastal areas, flooding may occur. This causes a watercourse to overflow its banks onto adjacent lands (Myers and White 1993). Floodplains are, in general, those lands most subject to recurring floods and are situated adjacent to rivers and streams. Floodplains are by their nature therefore “flood-prone” and are hazardous to development activities if the vulnerability of those activities exceeds a specified level (Penning-Rowsell, 1996).

Flooding and its impacts continue to threaten (damage) most parts of the developed and developing world, and is viewed as the most frequent and catastrophic disaster that affects human settlements, infrastructures and farming in the flood prone areas (Nelson, 2004).

The flooding by the Hindus and Brahmaputra Rivers are reported to impair human activities in the valleys in Shimla and New Delhi in India (Nelson, 2004). The Parana-Uruguay-Paraguay River system that drains both the northern part of Argentina and large areas of other South American countries is reported to subject the extensive floodplains to several months of inundation (Penning-Rowsell 1996). For instance, it is reported that the Parana River Basin in Brazil, Paraguay and Argentina

experiences serious flooding in the watershed that occasionally results in loss of life, millions of dollars' worth of damage, and disruption of life in the major cities of Argentina (Anderson *et al.*, 1993; Penning-Rowse, 1996).

In recent years many river systems in the world have generated several major floods (Penning-Rowse, 1996). Citing the flood destruction caused by the Parana River in Argentina and Brazil, Leeden, *et al.*, (1990) trace the major floods that have occurred throughout the historical record, and note that the 1983 and 1992 floods in that region, each with a return period of greater than one hundred years, are the fifth ranked flood events among all-time world records. In Japan the maxim of “develop now, clean up later” is noted to have degraded the major river systems and exacerbated extreme flood events (Nakamura *et al.*, 2006). In their study of the Tone River system in Japan, Nakamura *et al.*, (2006) remark that rapid urbanization has enlarged the area of impermeable landscapes, thereby increasing flood risks.

The Organisation of American States hereafter referred to as the OAS notes that some streams and their floodplains experience inundation at intervals of 10 years or more, that is attributed to differences in climate and land use. In some climates, several years of intense flood activity are followed by many years in which few floods occur (Penning-Rowse, 1996; Peckham, 2003; OAS 2006). Penning-Rowse (1996) and Peckham (2003) observe that during such periods of low flood activity, floodplains may be developed and occupied, which subjects the developments to increased risk of flooding as the cycle of flooding returns.

Like Peckham (2003) and OAS (2006), Anderson *et al.*, (1993) and Mazvimavi *et al.*, (2005) cite deforestation and intense crop production as being responsible for drastically changing runoff conditions, thereby increasing streamflow during normal rainfall cycles and thus increasing the risk of flooding. Halcrow and Partners (1994) also argue that deforestation and the changing land use in the catchments of the Brazilian forests have increased streamflow during the rainy season.

The duration of inundation has sometimes been associated with the size of the catchment stream, the channel slope, and climatic characteristics. For instance, Mazvimari *et al.*, (2005) as well as OAS (2006) note that floods induced by rainfall usually last from only a few hours to a few days in small streams, but in the case of large rivers flood runoff may exceed channel capacity for a month or more.

Montgomery (1992), Rosgen (1996) and Mazvimavi *et al.*, (2005) all acknowledge the importance of geomorphic characteristics of a river system in determining the river's response to flooding events. Rosgen (1996) and Mazvimavi *et al.*, (2005) argued that:

- 1) Streams with limited channel capacity, which are unable to contain excess flows, are more prone to flooding, and
- 2) Catchments characterized by high rainfall amounts, uncontrolled flows and entrenched streams tend to be highly susceptible to floods.

The hydrological response of the rivers in Kenya to either geomorphic characteristics or the hydrological input within the river basin is varied (National Environmental Management Authority, 2004). There is a reported increase in the frequency and severity of major floods in the Nzoia, Tana, Athi and the Nyando Rivers (NEMA,

2004). The variability of rainfall and floods in Kenya is not clear; neither is the flood driving mechanism and its impact on land use, particularly with regard to crop cultivation. The occupation of the flood prone Lower Kano Plains and farming practice in the area have led to increased damage to crops that have had a large impact on the social, cultural and economic life of the region (NEMA, 2004).

1.1 Contextual Setting

In the recent past, exceptionally heavy rains associated with varying flooding characteristics, particularly prolonged and frequent spates, have been experienced in Eastern Africa (Soya, 1998), with severe damage to crops, both in the field and in stores, as well as loss of large numbers of livestock. In some countries such as Somalia and Kenya, loss of human life has been significant, and this has attracted the attention of both local and international communities (Soya, 1998). Severe damage has also been inflicted on the sub-region's infrastructure (roads, bridges, railway lines), seriously disrupting the movement of goods within and between countries (Soya, 1998).

In Kenya, the government often has to cope with various forms of disasters. The most common and re-current problem has been persistent meteorological droughts, which have negative impacts on the sources of livelihood of a significant proportion of the country's population (Mutua, 2000; NEMA, 2004). Floods, however, have been rated second after droughts in terms of frequency and severity of impacts on land use, as they continue to cause physical damage to crops grown in the floodplains of major rivers (Republic of Kenya, 2001a).

Flooding in the Kano Plain (Figure 1.1) is usually experienced in the long rainy season starting in March, and continues intermittently until after May (NEMA, 2004). During this period rains can assume deluge proportions within certain areas, such as the delta of the Nyando River, where the equivalent of two months' rainfall can be experienced within a 24-hour period (Lake Basin Development Authority, 1992; Kriner, 2002). The area damaged as a result of flooding is estimated at about 2000 hectares, which are covered whenever flooding occurs, while more than 500 head of livestock are injured, hundreds of people left homeless, and damages estimated to be in excess of US\$ 100 000 are incurred (World Meteorological Organisation, 2001).

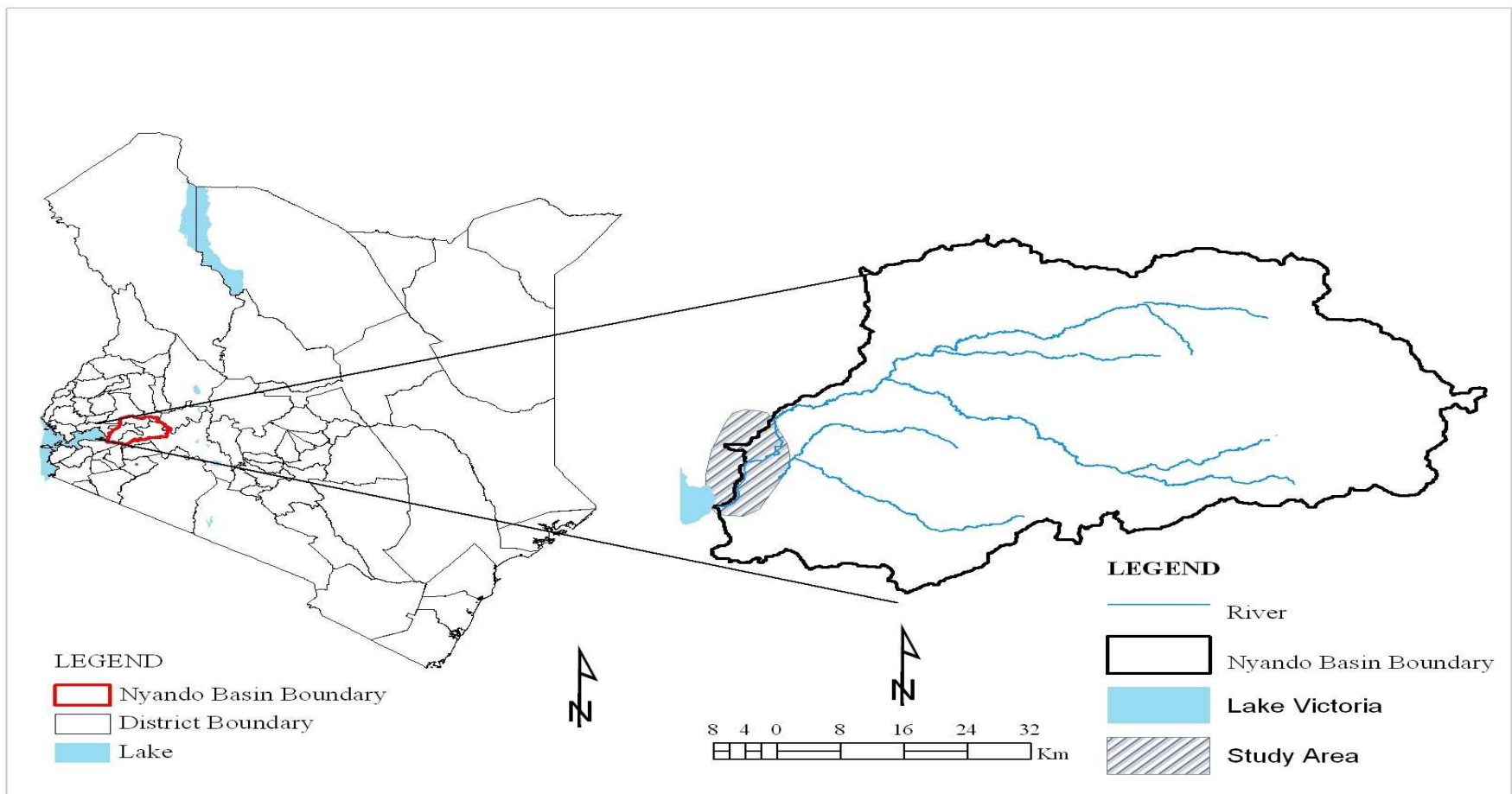


Figure 1.1: The Nyando River Basin in Kenya and Lower Kano Plains

In recent years, 3 major flood events were experienced in the Lake Victoria Basin. The 1996 and 1998 floods were the consequence of long and intensive rainfall when wetter than normal conditions were observed in Kenya (NEMA, 2004) and have been related to El Nino. Almost the entire Kano Plain was inundated and agricultural crops were completely destroyed (Republic of Kenya, 2004). In the year 2002, a total of 175,000 people and thousands of hectares of cultivated lands were reportedly affected by flooding that inundated seven provinces in Kenya (Food and Agricultural Organisation and World Food Programme, 2002). The flooding impact stretched from the shores of Lake Victoria in Nyanza Province in the west of Kenya, to the Coastal Province in the east.

Deforestation of the headwaters have been singled out as one of the poor land use practices (Plate 1a) that have increased runoff, erosion and the cycles of flooding of the Kano Plains by the Nyando River (ICRAF and Ministry of Water and Livestock Development, 2000). Furthermore, the increasing runoff into the floodplains has not only induced erosion (Plate 1b) as reported by ICRAF (2001), but has also made the Lower Kano Plain more vulnerable to the cycle of large flow events that have resulted in devastating destruction of farmlands.



Plate 1a: Deforestation and wood fuel collection by the riparian households in Kano Plains



Plate 1b: Flood erosion into cultivable land downstream of the Nyando River

In the Kano Plain, about 60 percent of the households are temporarily denied access to cultivable lands when it is flooded (Njogu, 2000). The poor drainage of the floodplains make large portions of the farmlands inaccessible (Plates 1c and 1d), while some portions of the arable land are under prolonged inundation that reduces the number of hectares under cropping (Obara, 1983; LBDA, 1992; Rowan, 2002 and Republic of Kenya, 2002).



Plate 1c: Temporary swamp

Plate 1d: The affected households

In addition, when floods occur, subsistence households living along the river banks are displaced by the high water levels, and then have to seek refuge on the raised grounds or in neighbouring trading centres. Most of these households have to live in temporary shelters until flooding recedes and they can return to their former homesteads and farmlands.

While the flooding causes damage to the major food and cash crops grown on the River's floodplains, the growing of crops, such as cotton, has not been stopped in the flood-prone valley bottom of the Kano Plain (Republic of Kenya, 2001a). In the Kano Plains, flood damage with regard to maize, sorghum, rice, sugarcane and cotton, has raised numerous concerns (LBDA, 1992), mainly in connection with the continued occupation of the flood prone areas and the need to switch to crops that are resistant to water stress as a result of prolonged inundation (ICRAF, 2001).

The impact of flooding on farming is a continued concern since agriculture is the basis for economic growth, employment creation and foreign exchange earnings in Kenya (Kenya Export Processing Zone, 2004). The farming sector accounts for about 24% of Kenya's GDP; it contributes more than 50% of the country's export earnings and employs about 75% of the population (KEPZ, 2004).

Cotton production offers the greatest potential for increased employment, poverty reduction, rural development and generation of increased incomes in the arid and semi-arid areas of the country (KEPZ, 2004). This sub-sector has been identified as one that could help bring economic development to the country and has been classified as a core industry by the Kenyan government (KEPZ, 2004).

The debate on farming practices in the flood prone Kano Plains took a new twist in 1983 when Obara (1983) conducted a study on the agronomic and environmental conditions with regard to cotton cultivation on the Kano Plains. It is evident from his results that although cotton farming is a source of income and employs many families, the majority of these families are unable to utilise the modern farming techniques in order to improve yields. In general, Obara (1983) showed that poor crop husbandry and low remuneration are the reasons for the declining agricultural production in Kenya (Obara, 1983), a view that has strongly been supported by Ikiara and Ndirangu (2001). The findings of Obara (1983) and Ikiara and Ndirangu (2003) alerted the Kenyan government to problems in this regard and who then applied the necessary strategies to re-examine challenges facing the textile industry.

Kenya has since 2003 continued to participate in the cotton textile trade, including cotton, lint and yarn production and the manufacturing of apparel (Kenya Institute for Public Policy Research and Analysis, 2003). Despite the introduction of cotton in the 1900's by the colonial administration, it was only in the early 1960's that cotton farming began to spread to many parts of the country (KIPPRA, 2003). Mainly small-scale farmers on holdings of less than one hectare each now grow cotton in Nyanza and in the Western, Coastal, Central, Eastern, and Rift Valley Provinces where rainfall conditions are favourable.

In order to promote cotton growing, the Kenyan government established the East African Cotton Research Corporation (CRC) as well as the Kenya Cotton Lint and Seed Marketing Board (CLSMB), bodies, which support cotton production, processing and marketing activities (KIPPRA, 2003). The formation of co-operatives and unions was allowed under the Cotton Act of 1955 and they were given the mandate of managing primary cotton activities, such as the supply of farm input products (i.e., pesticides and fertilizers), payment for cotton, and cotton processing.

In the early 80's the textile industry was the leading manufacturing activity in Kenya, both in terms of size and employment. The industry employed over 200 000 farming households at the time, which was about 30% of the labour force in the national manufacturing sector. However, this sub-sector started declining from the mid-1980 up to the 1990's (KEPZ, 2004). This decline was largely due to the dumping of used clothing originally intended for the troubled Great Lakes region, but which somehow ended up retailing in the local market at very low prices, leading to the collapse of the

local textile industry in the early 1990's (KEPZ, 2004). Since the liberalization of the economy in 1990, the influx of textile goods into Kenya became a major problem that reduced the average capacity utilization in the textile mills by about 50%. The textile sector, which was once the fifth largest foreign exchange earner in Kenya, dropped to the status of a very small contributor to the Gross Domestic Product (GDP) from the mid and late 90's. However, data available for the last 5 years indicates that the sector may be on its way to recovery, largely due to the African Growth and Opportunity Act [AGOA] and increased government support (KEPZ, 2004).

Between 1963 and the end of 1990, control regulations were introduced into the cotton sector through the CLSMB after a long period of monopoly by private ginneries. The government helped co-operative societies to purchase ginneries from private companies, controlling marketing margins, fixing producer prices and investing heavily in the textile mills. The main objective of the government was to promote cotton production, and by 1991 the Cotton Board of Kenya dominated primary purchase of seed cotton, directly or through cooperative unions and private sector agents (McCormick *et al.*, 2001).

The goodwill of the government towards the cotton sector saw production expanding to such an extent that, from 1965 to 1985, annual lint production gradually increased from 20,000 to 70,000 bales per year. This increase (1965-1985) in production was followed by a further increase (between 1986 and 1994) that was attributed to the lack of competition in the global market, as well as increased assistance from the government and donor agencies in terms of subsidy for farm inputs and the setting up of a price regulation framework. Government's protection of cotton against

competition lasted only up to 1995/96, by which time most of the government's regulatory mechanisms had become politically compromised and therefore ineffective. This failure became evident when lint production dropped to about 20,000 bales per year, a level that has faltered the recovery propositions that were predicted earlier (Ikiara and Ndirangu, 2003).

Both ADEC (1998), as well as Ikiara and Ndirangu (2003) have shown that by 2003 the average yield of seed cotton had dropped from 572 kg/ha to 350 kg/ha of lint across the provinces. Nyanza Province, which had the highest output and hectareage in the 1950's and 1960's, recorded the lowest in 2003 (350 kg/ha), although it had the largest land size (93,000 ha) under cotton, compared to the rest of the cotton growing provinces in Kenya.

This yield has not only dropped from the estimates made a few years ago (350 kg/ha) of lint reported by ADEC (1998), but is also low compared to those of West and Central Africa (1000-1200 kg/ha), Pakistan (500 kg/ha), Mexico (1,000 kg/ha), Israel (1, 400 kg/ha), and the world average (589 kg/ha in 2000/01). In Kenya cotton farming is small-scale enterprise, with average land size under the crop slightly less than a hectare (Table 1).

Table 1: Yield and land under cotton by province

Province	Yield, Kg/ha	Land under cotton in (thousands ha)	Percentage of land under cotton
Western	625.0	0.40	0.13
Nyanza	350.0	0.93	0.40
Rift Valley	800.0	0.78	0.27
Central	372.5	0.68	0.23
Eastern	403.5	1.20	0.38
Coast	657.7	1.10	0.35
Overall	572.5	0.95	0.35

Source: Ikiara and Ndirangu, 2003.

The low productivity of cotton in Kenya is attributed to numerous factors. Some of these are:

- low lint prices (Ikiara and Ndirangu, 2003);
- high cost of purchased inputs, and therefore low input usage (Gereffi 1994; McCormick *et al.* 2001);
- poor seed quality (McCormick *et al.*, 2001);
- erratic weather (McCormick *et al.*, 2001, Ikiara and Ndirangu, 2003);
- lack of credit (McCormick *et al.*, 2001), and
- Inter-cropping (Ikiara and Ndirangu, 2003).

The above factors documented by Gereffi (1994), McCormick *et.al.*, (2001), and Ikiara and Ndirangu (2003) generally agree with earlier findings by Obara (1983), who also cited poor crop husbandry, incidence of pests and diseases, poor market prices and low usage of farm inputs (i.e. fertilizers and pesticides), as the main

problems that affect cotton production and yield on the Kano Plains. Ikiara and Ndirangu (2003) furthermore point out that late planting of cotton in the Nyanza Province, particularly in the Nyando District in Kenya, exposed cotton to the onset of the long dry spell. Since cotton is mostly intercropped with either maize or beans, mainly after the weeding period (March), there is generally a delay in the planting of cotton. These studies did not, however, examine:

- how the delay in planting subjects cotton to a change in flooding regimes, partially exposing it to physical damage during the rain seasons, and
- how the onset of the long rains and subsequent flows, may hinder accessibility to farmlands, which delay cotton sowing that may lead to crop failure.

1.2 Statement of the Problem

Numerous researchers have examined the impact of exceptionally heavy rains and flooding on crops and infrastructure (Soya, 1998; Mutua, 2000; NEMA, 2004). Mutua (2000) and NEMA (2004) attest that although the damage of crops by floods in East Africa has increased in the past 20 years, floods are rated second after drought in terms of their frequency and damage. The temporal and spatial variability of the impact of flooding characteristics on cotton cultivation, at individual household level, has not received adequate attention.

The average area planted under cotton in the Kano Plain has declined from 1,600 hectares in the 2003/2004 production year to 500 hectares in 1994/95 (Republic of Kenya, 2001a). Notwithstanding the contribution of other factors cited by previous authors as responsible for the decline, none of these studies has examined the extent to which flooding has caused a reduction of the area under cotton. Neither has any

study specifically assessed how the variability of rainfall causes the variation in flood regime and the consequent damage to cotton growing in the Kano Plains of the Nyando Basin in Western Kenya (Figure 1.1).

1.3 Aim and Objectives of the study

This study examines the impact of flooding characteristics of the Nyando River on cotton cultivation in the Lower Kano Plains in the Nyando District of Western Kenya. Specifically the study seeks to:

1. determine if the flooding characteristics have changed over time or whether they are variable in space,
2. describe the natural flooding regime that probably existed before large anthropogenic influence, and compute its frequency and magnitude in the Lower Kano Plains, and
3. describe anecdotal data to support the impact assessment of flooding characteristics on cotton cultivation in the study area.

1.4 Research Questions

Based on the aims mentioned above, four research questions were formulated, namely;

1. Has there been any quantifiable change in flood magnitude and frequency over time and space?
2. What were the flooding regimes, frequency and magnitude in the recent past before the increasing anthropogenic impacts that have characterized the study area?

3. What anecdotal data (perceptions of cotton farmers) is there to support the assessment of flooding on cotton cultivation?

1.5 Organisation of the dissertation

Chapter One provides the introduction and problem statement. This chapter also contains the conceptual setting; the contextual framework and the statement of the problem; the motivation, scope and delimitation of the study; the research questions and objectives of the study, as well as an outline of its significance.

Chapter Two, consists of a description of the study area. It describes the geographical size and administrative location; the physiographic and hydrological conditions, and lastly the agro-climatological characteristics and land use patterns.

Chapter Three consists of a literature review and conceptual framework for the study. The description of the drainage basin and its influence on flooding characteristics is discussed. Flooding characteristics, particularly the nature of rainfall and flow cycles are reviewed. An overview of land use with specific reference to cotton cultivation, and how floods impact on cotton growing, is also discussed. Finally, the relationship between human environment and flooding hazard as an open hydrologic system is presented.

Chapter Four discusses the research methodology and data type. Chapter Four also contains descriptions of the research method; descriptions of the area of study; the target population; the sampling frame and sample selection; the data type and data

acquisition procedure; data processing, analyses and presentation procedure. This is followed by problems encountered during research.

Chapter Five contains the data presentation, analysis and interpretation. Analysis of the Nyando Basin focuses on flooding in the drainage area and on stream density. This is followed by an analysis of flooding characteristics over time and in space. The following aspects are analyzed: seasonal cycles of rainfall and flow, inter-seasonal cycles and intra-seasonal cycles. The trend of rainfall and flows is analyzed using a 3-year moving average. Finally, rainfall and flow frequency is computed using a probability model. Description and interpretation of anecdotal data to support the impact of assessment of flooding characteristics on cotton cultivation is presented.

Chapter Six discusses the findings of the study under several sub-headings that include drainage basin characteristics, influence of drainage basin characteristics on flooding, temporal and area characteristics of flooding, a description of the flooding regime, and the impact of flooding characteristics on cotton cultivation. Chapter Six also explores the variability of rainfall and flooding.

Chapter Seven provides the conclusion reached in the study as well as its recommendations. Recommendations cover policy issues and suggestions for further research. Finally, references and appendices are provided at the end of the dissertation.

1.6 Operational Definitions

Technical terms are liable to different interpretations depending on the subject area, the theory in question, and the background of those who read them. In this particular study the following definitions should guide the reader in understanding the context in which the various terminologies were used:

Flooding: Flooding according to this study refers to the process whereby the flow from the Nyando River exceeds 387.9 m³/s and overtops its banks and flows in the floodplains, thereby covering the farmlands in the Kano Plains (NEMA, 2004).

Floodplain: The “floodplain” refers to the surface where water spreads over the dry land and generally impairs agricultural activities.

Flood Duration: This refers to the time that the river (Nyando River) remains at flood stage.

Flood Extent: This term is used to refer to the expanse of dry and arable lands within Lower Kano Plains that are inundated.

Arable land: Refers to the total land within the study area that has a potential for crop cultivation.

Flood frequency: In this study the term refers to a flood level that has a specific percentage chance of being equaled or exceeded in any given year. For example, a 100-year flood event occurs on average once every 100 years and thus has a 1-percent chance of being equaled or exceeded in any given year.

Discharge: Refers to rate of flow commonly expressed in cubic meters per second (m³/sec).

Drainage basin: Refers to a part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water.

1.7 Summary

In concluding this chapter, it has emerged that although there is continued occupation and cultivation of the flood prone areas, cotton production is faced with a number of environmental, agronomic, economic and institutional problems. Most of the riparian communities living along the river banks have been cited to suffer flood damage with regard to crops, settlements and infrastructures. The study area is documented to be prone to inundation that impacts on cultivable lands, thereby affecting crop production.

Some of the noted impacts are manifested in changing cropping practice, a decline in crop husbandry, unstable financial markets and frequent government intervention in cotton production. The change in cropping practice has shifted the cropping cycle which has changed its interaction with the climate and hydrological regime.

CHAPTER 2: BACKGROUND OF THE STUDY AREA IN NYANDO BASIN

2.1 Introduction

This chapter examines, in general, the physical, hydrological, agricultural and socio-economic background of the Lower Kano Plain of the Nyando River Basin. Chapter Two also highlights the challenges facing cotton production in the flood prone areas in Kano Plain. Various aspects in this regard are discussed in the sections that follow.

2.2 Location and Size of the Study Area

The Lower Kano Plain is located in the Nyando District of Nyanza Province in Western Kenya (Figure 2.1). Nyando is one of the 12 districts in Nyanza Province that were carved out of Kisumu District in 1998. It borders the districts of Kisumu to the west, Nandi to the north, Kericho to the east and Rachuonyo to the south (National Environmental Management Authority, 2004).

The Lower Kano Plain lies between longitudes 0°50'S and 0°10'S and between latitudes 33°05'E and 34°25'E (National Environmental Management Authority, 2004). The plain is surrounded, geographically, by the Nandi Hills and the Nyabondo Escarpment (LBDA, 1992; Republic of Kenya, 2001a).

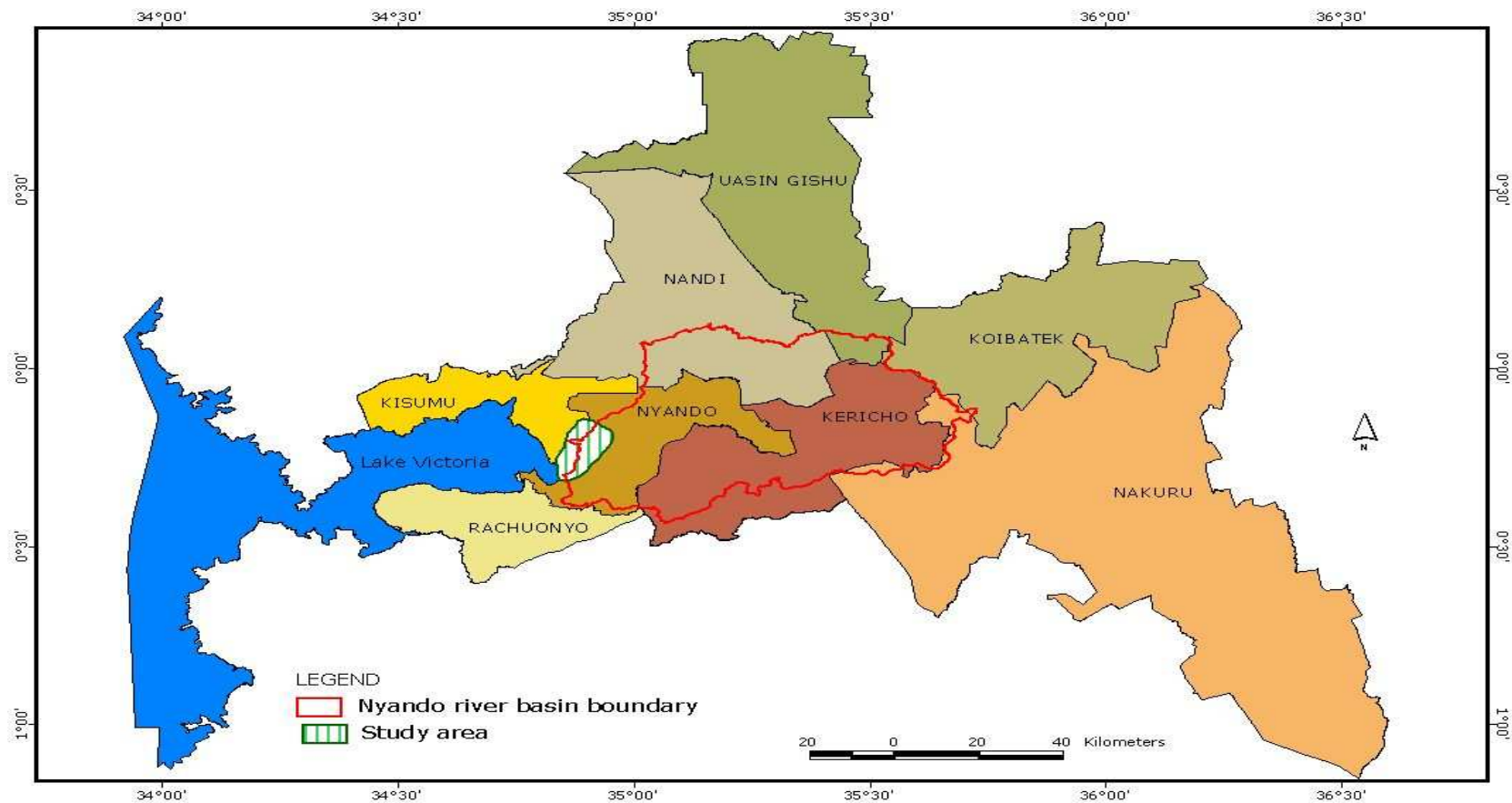


Figure 2.1: The study area in Nyando District, and the bordering districts

2.3 The Physiography of the Kano Plain and Nyando basin

The Kano Plain lies in a depression which is part of a large lowland area that forms the floodplain of the Nyando River. It borders the Winam Gulf, a protruding part of Lake Victoria, at the end of which is Kisumu Town. The plain is, however, characterized by broken low ridges and river valleys [Figure 2.2].

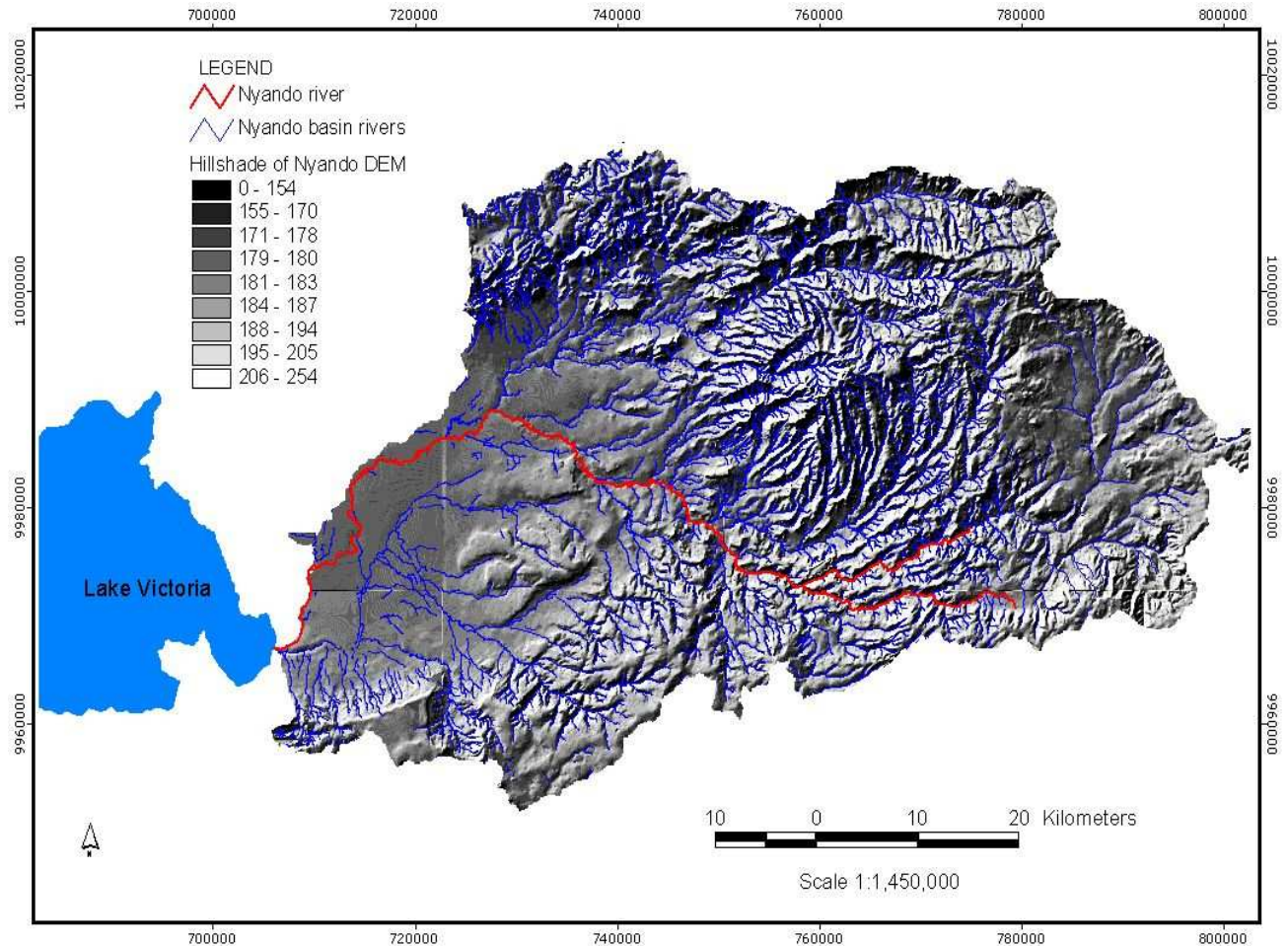


Figure 2.2: A digital elevation model (DEM) of the Nyando Basin

The processes associated with the formation of the Rift Valley, are believed to have influenced the formation of the vast Kano Plains in general, and downstream of the river, in particular (Jaetzold and Schmidt, 1982). The Plain is located between the steep Sondu Escarpment that forms the border to the north (Njogu, 2000) and the foothills of the Nandi Highlands to the north. The Kericho Highlands are located to the south (Figure 2.3).

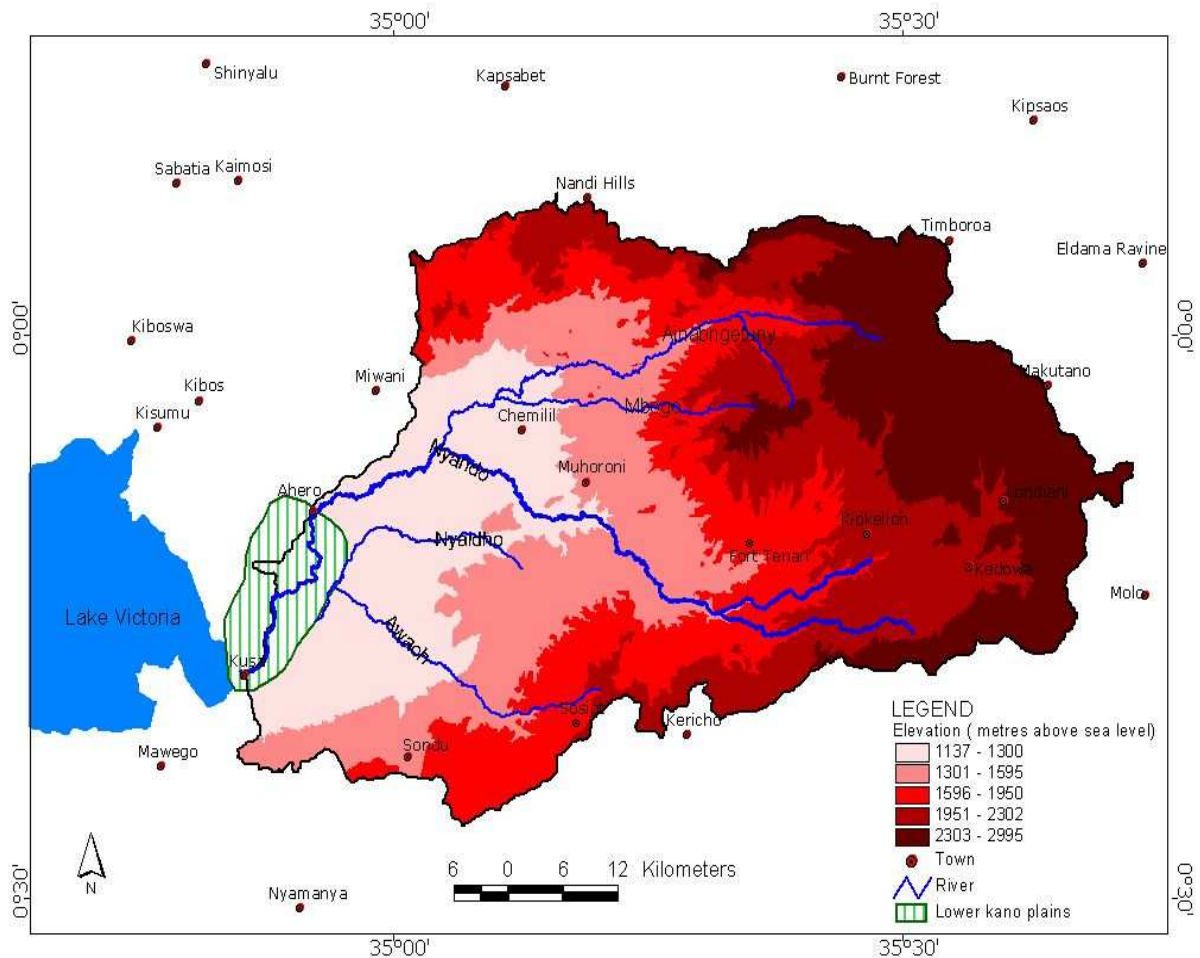


Figure 2.3: The DEM showing the Kano Plains

The Nyando River has its origin in the highlands of the Nandi Hills with an altitude of over 1700m above sea level. From the highlands the river flows down *V*-shaped valleys in the mountainous areas with an estimated bed width of 20 m and a gradient of 1: 45 (National Environmental Management Authority, 2004). In the middle reaches the Nyando River meanders through a narrow valley floor with a bed width of about 40 m and gradient of 1: 160. The lower reaches of the Nyando River are characterized by pronounced meandering over a wide flood plain, the bed width is estimated to increase to about 50m and the gradient flattens further to 1: 170 (National Environmental Management Authority, 2004).

2. 4 Climatic characteristics and Agro-ecological zones of Kano Plains

Kenya is located in the tropical savanna zone, but exhibits considerable climatic variation from humid and hot coast lands, to the wet and cool highlands (LBDA, 1992). About four fifths of the land is semi-arid and only 18% of the total land area constitutes moderate and favourable climate for agricultural production (NEMA, 2004) (Figure 2.4).

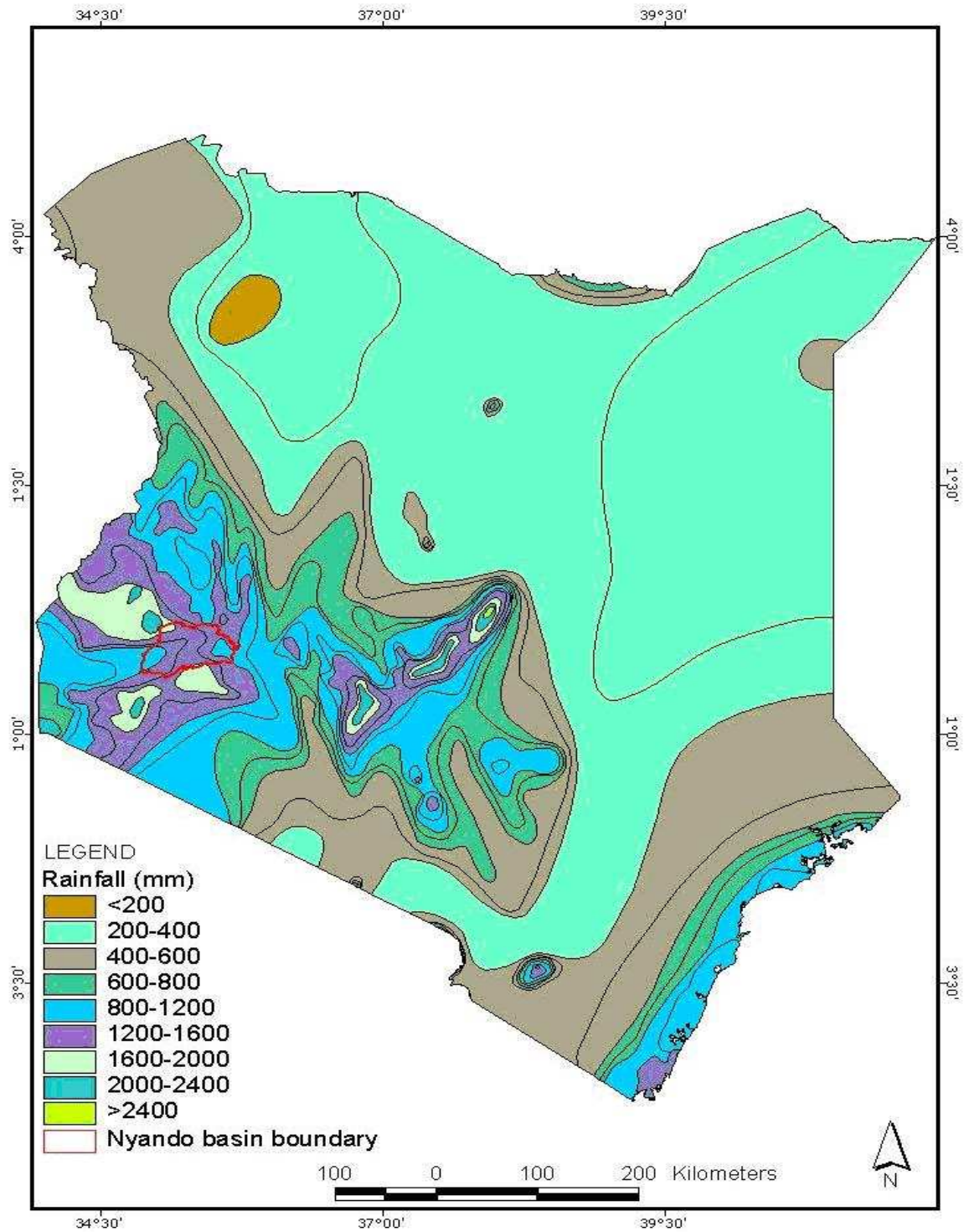


Figure 2.4: Mean annual rainfall distribution in Kenya

The Kano Plains are situated in a sub-humid zone. The mean annual maximum temperature ranges from about 27⁰C to about 32⁰C, and the mean annual maximum temperature is recorded in June through July. The annual minimum temperature ranges from 14⁰C to 18⁰C, with the peak minimum temperature recorded in August through September (LBDA, 1992; Republic of Kenya, 1985a). The temperatures show variation with rainy and dry seasons, where maximum temperatures occur in the long dry spell and minimum temperatures in the rainy seasons. The basin experiences distinctive seasonal climatic variation throughout the year, with two maximum rainy seasons observed between April and May and between November and October.

The lowland area lies in a region of low rainfall, receiving a mean of between 800 mm to 1200 mm annually while sections of the basin in the north and south experience > 1600 mm (Figure 2.5). The highest rainfall occurs in the Nandi Hills towards the north region, which gradually reduces in the southeastern direction (WMO and UNEP, 2004).

In the Kano Plains there are generally four distinct seasons, i.e. two rainy seasons and two dry seasons. The rainy seasons are further sub-divided into the long rainy season and the short rainy season (Republic of Kenya, 2002). Likewise, the dry season is also sub-divided into a long dry season, and a short dry season. The long rainy season usually begins in March through to May, with nearly 40% of the total rainfall. This is normally followed by a long dry spell, which starts in June and ends in August. The short rainy season starts in October and lasts for two months until November, followed by the long dry spell which starts in December through to February (National Environmental Management Authority, 2004). The mean annual rainfall distribution in the Lower Kano

Plain is shown in Figure 2.5, while the seasonal variability of rainfall is illustrated in Figure 2.6.

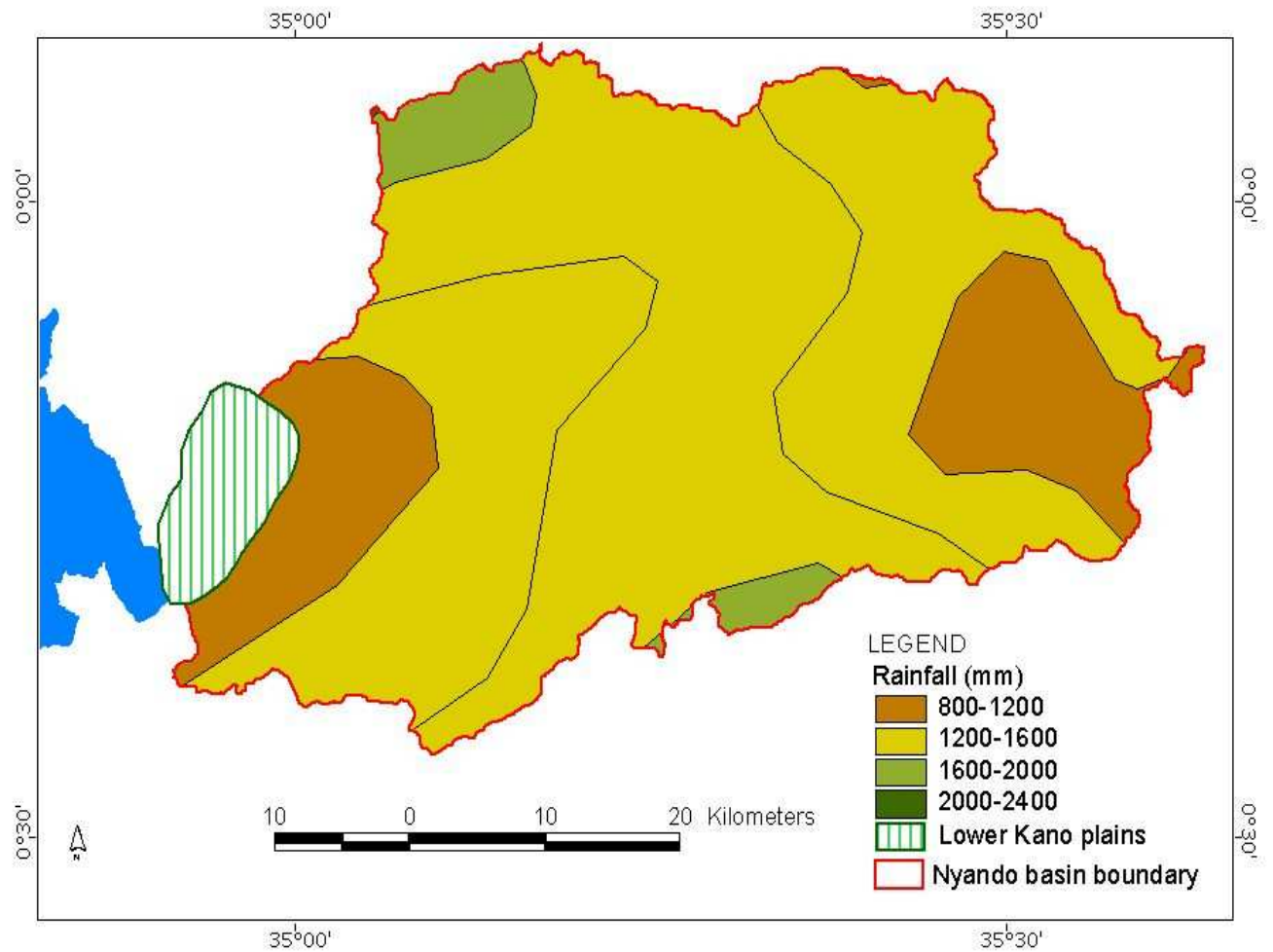


Figure 2.5: Mean annual rainfall distribution in the Nyando Basin

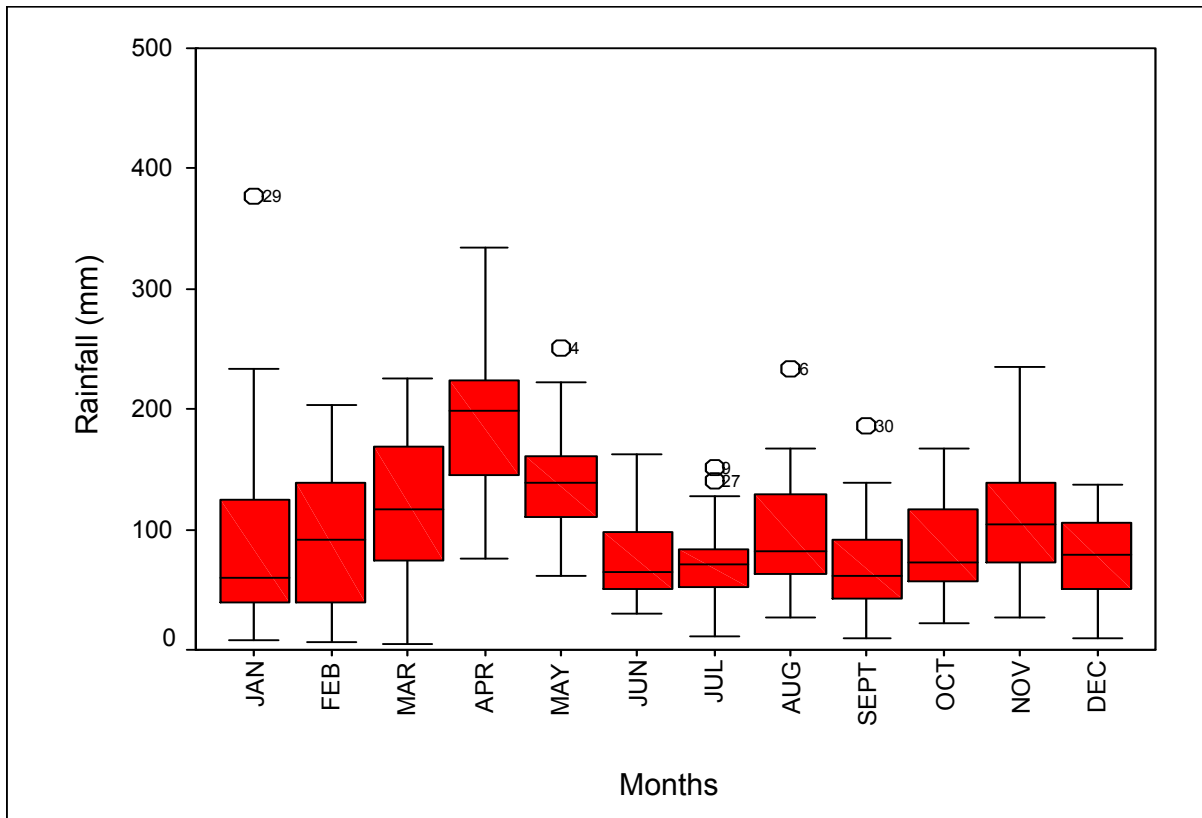


Figure 2.6: The Box and Whisker plot of variability of rainfall

The Box and Whisker plots presented in Figure 2.6 shows the monthly distribution of rainfall for the 31 year period (1970-2000) in the Lower Kano Plain. The observed structure of the box plot illustrates the range; the quartiles and the median, with a significantly high variance in both the median and the range. The long and short rainfall periods are exhibited with each of the statistic (median, UQ, LQ) for the long rains (March, April, May) higher than the short rainfall season (October- November). The wet periods have the median and Upper Quartile of the box plot clustered, which reveal high rainfall concentration.

Further analysis of the box plot reveal an overlap in the monthly rainfall range where 373.3 mm spread (377.40 mm - 4.10 mm) is computed. The median show a significant departure with the long rain period (March, April and May) revealing both a higher overlap and high median (117.3 mm, 198 mm and 139 mm) respectively compared to the dry season, which exhibits a low overlap and a significantly lower median (61.6 mm and 72.7 mm) as demonstrated between June and September, and a farther 60.1 mm and 91.8 mm variance in the median for the period between December and February.

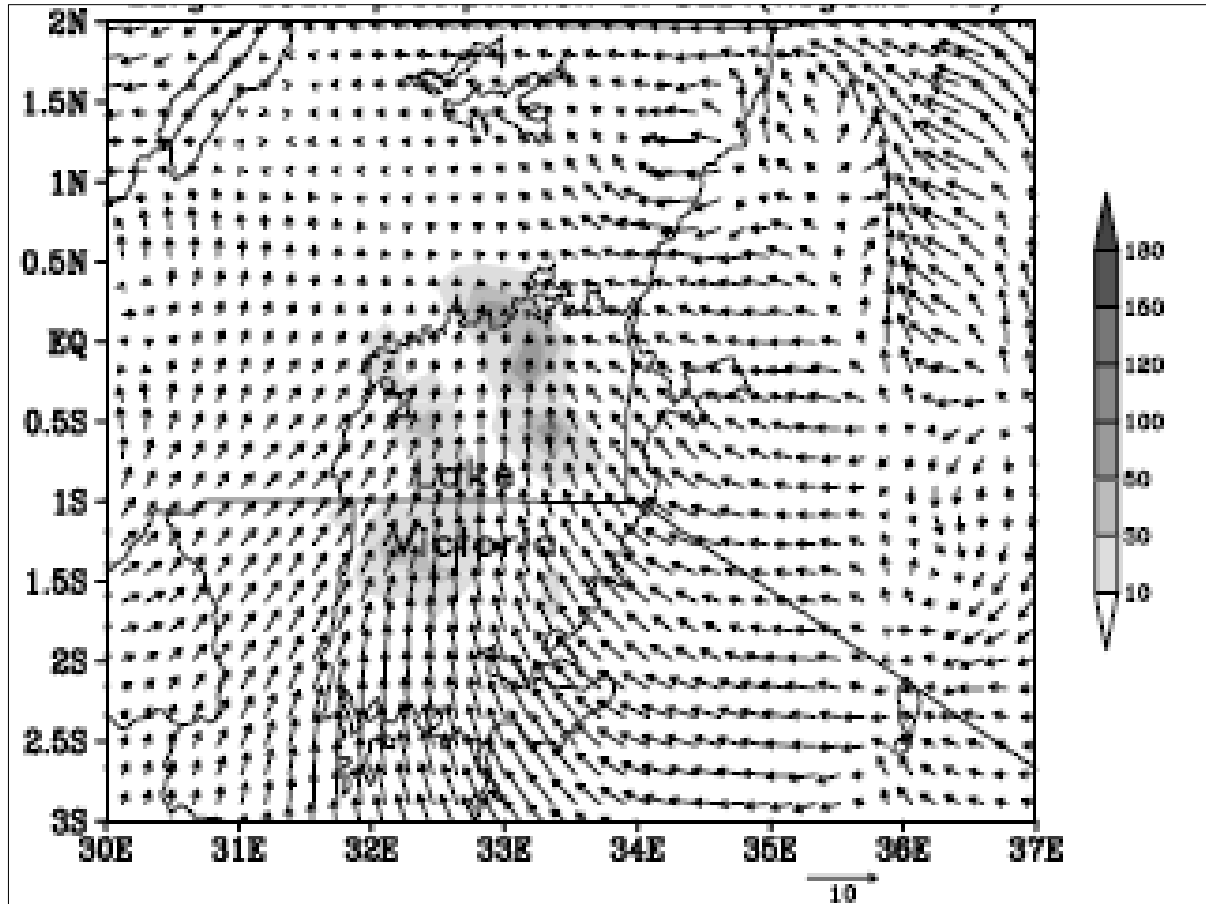
Overall, rainfall distribution in the Lower Kano Plain is bimodal and highly clustered above the median during the long rain season. Also revealed is a significantly high range of between 188.4 mm and 220.7 mm during the rain season and a low range (between 128.2 mm and 196.7 mm) recorded in the dry season.

A myriad of local and large-scale circulation systems are said to combine in the modulation of the regional climate that borders Lake Victoria (Song *et al.*, 2003). The factors noted to stimulate the climate variability of the lands bordering Lake Victoria Basin (including the Kano Plains) include topographic and land-induced circulations, widespread variations in land cover/land use characteristics, monsoonal circulations associated with the thermal contrast between land and the nearby oceans (in particular the Indian Ocean), and the influence of the Congo air-mass emanating from the tropical (Congo) rainforest (Song *et al.*, 2003).

The rainfall pattern in the Kano Plains is also considered to respond to the influence of the Inter Tropical Convergence Zone (ITCZ). Both Matitu (1999) and Lukiya (2003) have argued that the ITCZ is responsible for the modulation of tropical African climate. The seasonal climate of the Lake Victoria generally (Song *et al.*, 2003) and Kano Plain in particular (Matitu, 1999; Nicholson, 1996) is primarily governed by the passage of the ITCZ. The ITCZ crosses East Africa twice every year, once during March-April-May (long rains) and again during October-November-December (short rains) (Nicholson, 1996).

It is recognized that the study area has sufficient rainfall for dry land agricultural production (LBDA, 1992) because rainfall is more or less evenly spread over the year. The rising air mass of the ITCZ is a global circulation system that interacts with the regional/local plain-valley circulation system to produce heavy tropical showers. These mainly occur during the late afternoons, starting in the hills and moving westerly over the plain. This is usually free convective rainfall that is initiated by surface heating under anabatic (down slope) or katabatic (upslope) circulation as opposed to forced convective or relief rain, normally received in the northern and southern parts of the plains, where the relief is higher (Kelbe, pers comm.).

The diurnal pattern of circulation and precipitation over Lake Victoria described by Anyah *et al.*, (2003) is associated with peak hours of land breeze and lake breeze, as represented in Figures 2.7a and 2.7b respectively (Anyah *et al* 2003). The effect of the convergence flow over Lake Victoria and the adjoining land is illustrated in Figure 2.7.



Source: Anyah *et al.*, (2003)

Figure 2.7a: The circulation of the rainfall pattern (land breeze)

The nocturnal circulation (land breeze) is normally experienced between midnight and early morning hours when the lake surface is much warmer than the surrounding land areas. The simulated experiment in Figure 2.7a reveal a weaker land breeze front that is confined within the western rim of the lake surface (Anyah *et al.*, 2003)

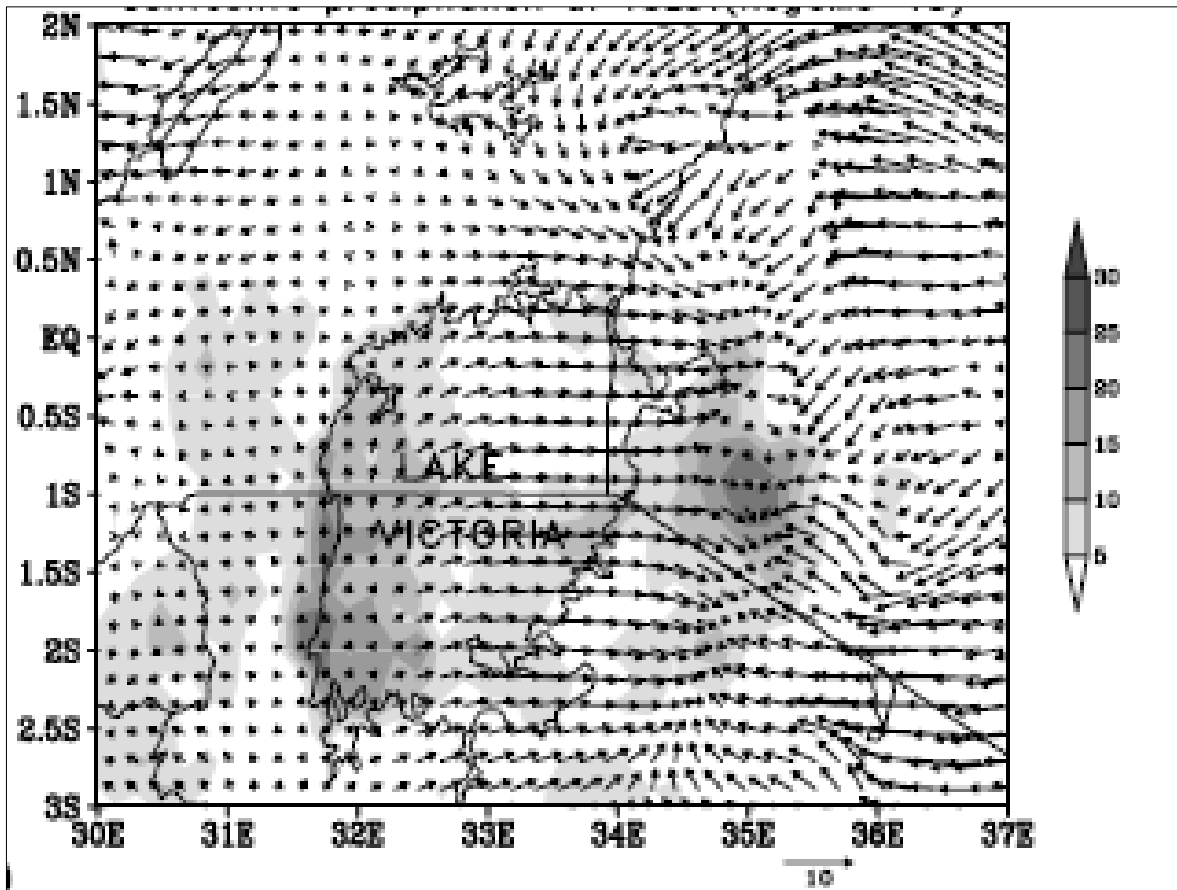


Figure 2.7b: The circulation of the rainfall pattern (lake breezes)

Peak lake breeze circulation is observed to occur between late afternoon and early evening, when the adjoining land surface is much warmer than the lake surface. The circulation pattern over the Lake Basin is highly associated by flow convergence over the western sector of the lake with the lake breeze front located 2° (200km) to the east of the lake (Anyah *et al.*, 2003). The lake breeze also shows clearly that thermal contrast between the lake and land is more pronounced to the east, compared to the west of the lake. This is evidenced by a weaker simulated land breeze circulation, which tends to be confined within the western rim of the lake surface (Figure 2.7a).

2.5 Soil characteristics, flooding and land use in the Kano Plains

While soils are important in the physiological and chemical growth of crops (ICRAF, 2001), they also control the rate of infiltration. The soil types in the Kano Plain derive much of their characteristics from several hydro-geomorphic zones within the Nyando Basin. These classifications are derived from the exploratory soil map of Kenya [1:1.000.000] (ICRAF, 2001), where the map uses a physiographic approach to distinguish zones based on geomorphology (ICRAF, 2001).

Through the use of hydro-geomorphic zoning methodology, different processes have been described as responsible for the differences in soil structure, soil texture, slope and vegetation cover (Daas, 2002), which classifies the soil types within the catchment into three major hydro-geomorphic zones: 1) upland 2) hills and minor scarps and 3) piedmont plains (Figure 2.2) (Daas, 2002).

Daas (2002) describes the upland zone as forming the highest part of the catchments with the parent material in this zone composed of basic igneous rocks. The upland zone is comprised dominantly, of friable clay texture soils, which are extremely deep (3 to 6 m) and are classified as a humic nitosol. The hills and minor scarps are, however, divided into two sub-zones (Daas, 2002). The scarps are characterised by very shallow soil depths (± 5 cm), while the soil is also very rocky. Most soils have been washed away by the runoff processes. The texture in this zone is gravelly clayish, and the soil type is classified as a humic cambisol (Daas, 2002).

The hills however, have less steep slopes than the scarp and therefore have a somewhat deeper soil depth. The soils consist of firm stony or boulder clay with humic topsoil and are classified as verto-luvic phaeozems (Daas, 2002).

The Piedmont plains are predominantly of alluvium origin, which is sediment that has been transported from the upper parts of the catchments by alluvial processes and has been deposited at the foot of the hills through flooding processes. The soil matrix in the piedmont consists of firm to very firm clay. The soil type in this zone is a planosol (Daas, 2002), which in some places have developed a sodic subsoil layer that is dominant in the lower reaches of the river basin. This group of sodic subsoils is also referred to as vertisol. The spatial distribution of the soils is shown in Figure 2.8.

In the Kano Plains, vertisols (Figure 2.8) are the dominant soil types, and have been used for sugarcane, rice and cotton production. Despite the suitability of the soils to cotton growth, earlier studies have reported the risk of pounding of the soil that could inhibit the vegetative development of crops; specifically on cotton that the reports cited to have recorded a steady decline in terms of both production per hectare and total output of cotton (WMO and UNEP, 2004). There is scanty evidence from the reports that one of the causes of the declining production of cotton in the lower sections of the Nyando River is frequent flooding and the declining area of land to grow non-subsistence crops like cotton since most households living downstream of the Nyando River have portions of the available arable land under prolonged inundation after the rainy season.

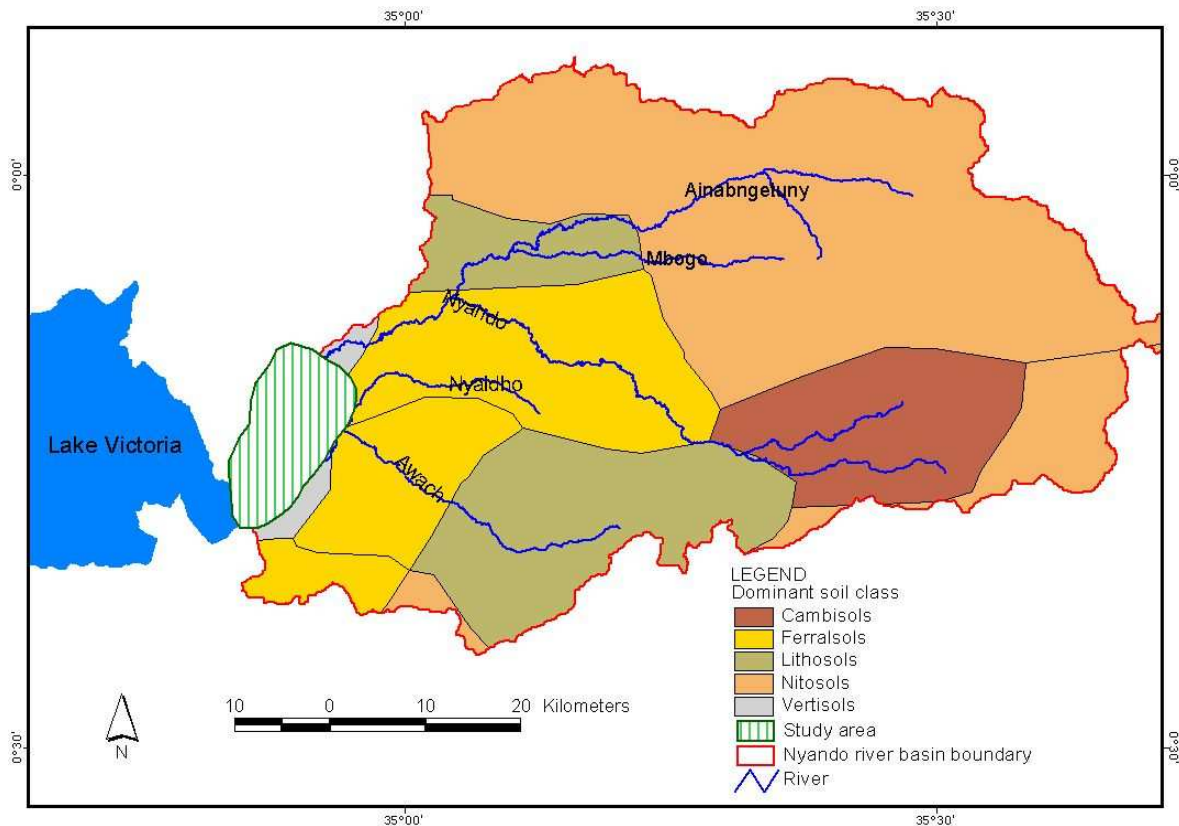


Figure 2.8: Kano Plains showing the poorly drained vertisols

The vertisols (black cotton soils) are characterized by high to moderate fertility, although subject to water logging and inundation during the long rainy season that prohibits the physiological development of the crops grown in the flood prone plain (NEMA, 2004). The poor drainage characteristics of the vertisols are more obvious on the western part of the Nyando Floodplains where much of the soils are associated with swamps, and are more prone to inundation (Jaetzold and Schmidt, 1982; ICRAF, 2001).

The floodplains have a silt content of 20% and a clay content of over 50% (Republic of Kenya, 1984) and are the former lake sediments, which are the remnant deposits, after the lake receded during the Kavirondian Era some 20 million years ago (ICRAF, 2001).

Although the vertisols are predominant in the study area and are considered suitable for cotton cultivation, frequent flooding, water logging conditions and impeded drainage, continue to cause physical damage and also limit the area under crop. The poor drainage of the vertisols and the impact of flooding on land use in the study area are further illustrated in the plates below.



Plate 2.1a: Deposited flood remnants



Plate 2.1b: Flooding impact on land use

Plate 2.1a In the foreground logs uprooted by the concentrated rains and flows upstream are deposited downstream where the Nyando River has limited channel capacity. Plate 2.1b illustrates overbank flows into the floodplain. In the background the grassland and scattered woodland can be seen. The disruption of the settlement as a result of flood waters from the Nyando River can be seen at the background.

2.6 Settlement in the Nyando basin and flood prone study area

The settlement pattern in the Lower Kano Plain is patriarchal – a system in which land is owned by the larger family unit (clan) and is sub-divided among the next-of-kin (relatives), who form the sub-family units referred to as the households (Muhia *et al.*, 2001).

The patriarchal land ownership system ensures that every male member of the community has access to land and is able to utilize the agro-hydrological potential of the said land legitimately, either for crop cultivation or cattle grazing, whichever form of basic land use practices are prevalent within the study area (Muhia *et al.* , 2001).

The land use pattern shows that there is a clustering of settlements (Figure 2.9) around areas that do not flood under normal circumstances (ICRAF, 2001). While the majority of indigenous land ownership is determined traditionally (patriarchal), the geophysical factors such as relief, water bodies, vegetation and swamps have influenced the pattern of settlement as well as crop cultivation in the Lower Kano Plain (NEMA, 2004). The majority (over 75%) of the households have settled on comparatively higher grounds within the plain, where they practice agriculture under rain-fed conditions, while the rest (25%) still occupy the low lying flood prone areas due to population pressure. The settlement density in the Nyando Basin and the Lower Kano Plain is illustrated in Figure 2.9.

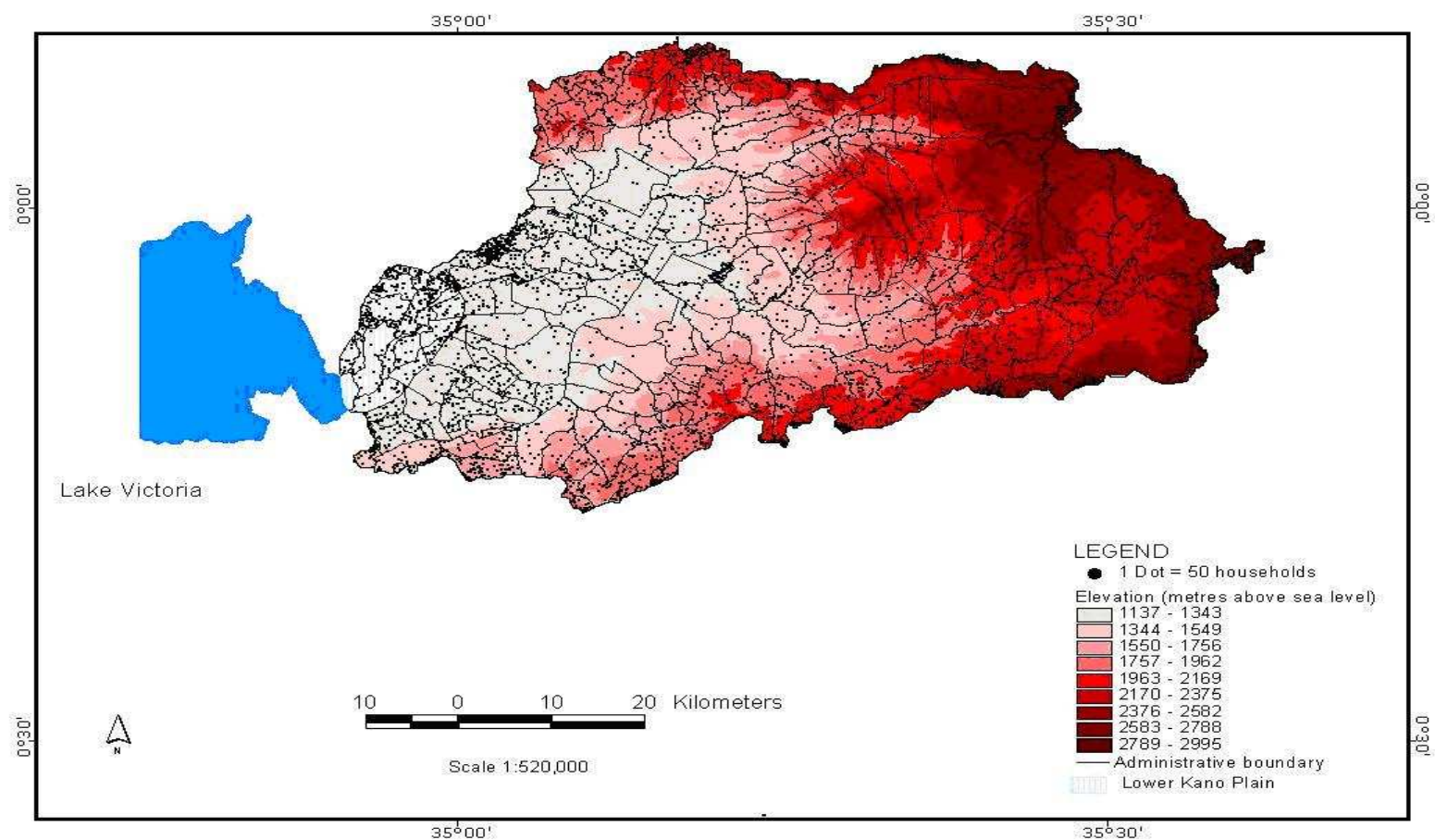


Figure 2.9: DEM with the settlement overlaid in the Nyando Basin and flood prone Lower Kano Plains

2.7 The cultivation of cotton and flood problems in the Kano Plain

The crop growing pattern in the Kano Plain is influenced by the distribution of rainfall and soils. The main crops cultivated are cereal crops that include maize, sorghum and rice, followed by pulses (beans, green grams, cowpeas and groundnut), cotton and tuber crops (cassava and sweet potato). Sugarcane is cultivated mainly in the northern upstream areas of the Kano Plain, which are closer to the sugarcane refineries. The most common cropping pattern is the cultivation of upland crops under rain-fed conditions, where maize and sorghum are generally intercropped with several kinds of pulses, cotton plants and cassava.

Rice is grown in the floodprone areas where irrigation facilities have been developed. The root crops, such as sweet potato and cassava, are cultivated in almost all of the area as a reserve food crop, which provides food in the case of a shortage of the main food crops due to damage as a result of either flooding or prolonged drought that are common hydrological hazards during the crop growing cycle in the study area.

In the Kano Plain, like in most regions in Kenya, cotton is grown at different timing of agricultural activities (Table 2.1). Cotton is an annual crop with a single harvesting period – except in some regions in Kenya, where it is sown at the beginning of the short rains, and can then be harvested for the first time after four to five months (this is known as the “bottom crop”). If the cotton plants are left in the field, the vegetative growth will revive during the long rains, and a second harvest is possible (known as the “top” crop).

The main cotton varieties that are grown in the Kano Plain are UKA (59) 240 and BPA 75, both medium to long staples. BPA is of a slightly longer staple, and therefore more successful for the export market than UKA, which is much closer related to American varieties. UKA has a relatively longer growing period, which makes pest control more difficult, while BPA is less resistant to drought. UKA is grown under rainfall conditions found in the Kano Plain, while BPA is grown under irrigation.

The cropping pattern and growth period of cotton is largely affected by seasonal distribution of rainfall and flooding (LBDA, 1992). The planting and harvesting times have a wide range and fluctuate year by year. This is due to the fact that the crop is usually planted at the onset of the rainy season or at the end of a flooding period. The typical growth of cotton in the Lower Kano Plain is shown in Plates 2.2a and 2.2b, and in Table 2.1.



Plate 2.2a Cotton affected by floods



Plate 2.2b Cotton not affected by flooding

Plates 2.2a-b illustrates the differences in cotton production impact in 2 farming fields that respond differently to the effects of flooding. Fields that are on raised grounds (b) respond positively to precipitation in the study area as opposed to flood prone fields (a).

Table 2.1: The Cotton Cultivation Calendar in Kenya and the Kano Plain

Province	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Western Province			Early sowing			Late sowing				Harvesting		
Nyanza Province			Sowing							Harvesting		
Kano Plain												
Central/ Eastern Provinces	Harvest bottom		Renewed vegetative growth				harvest -top		Sowing			
Coastal Province			Sowing					Harvesting				
Rift Valley Province		Sowing							Harvesting			
Hola/Bura irrigation		Sowing						Harvesting				

Source: Generated from LBDA, 1992

Cotton is mainly intercropped or relay cropped with maize or sorghum and is planted two to three months after the sowing of maize or sorghum, and is harvested during October to January. The application of fertilisers, herbicides, pesticides and fungicides is recommended because productive lint output is only achieved by a limited number of farmers who are prepared to invest more in the farm inputs. Less successful farmers tend to apply pesticides only two to three times during a season. One of the reasons for such very low farming input is the fact that cotton plants in this region are more likely to suffer due to meteorological stress in the form of floods and drought, than from insects. As is evident from Table 2.2, cotton is highly labour intensive – and its cultivation should be remunerating to farmers despite the impacts of floods and drought.

The major constraints of farming practices and the cropping patterns that have been noted to affect the Kano Plain include limitation of access to farms and instability of yield of crops, which is attributed to a year-to-year variation in the rainfall pattern, water stress and flood damage (LBDA, 1992). Furthermore, the majority of farmers are not willing to use high inputs and have no incentive to improve cultural practices under these anomalous climatic conditions, which tend to lower the crop yield to a relatively low level.

Table 2.2: Labour requirement for cotton production in the Kano Plain

Labour (in man days	Maize	Sorghum	Rice	Cotton	Sugarcane
Soil preparation	20	20	50	20	20
Seedling	15	15	5	15	50
Transplanting		-	30	-	-
Weeding	45	45	10	50	10
Harvesting	20	15	40	20	50
Post Harvest	15	15	20	10	-
TOTAL	115	110	155	115	130

Source: Generated LBDA, 1992

2.8 Summary

This chapter outlines the general characteristics of the Nyando River Basin and the Lower Kano Plain. It discusses the physiological, hydro-climatic and land use characteristics of the floodplain in relation to flooding and land use. It is evident that the increasing demand for land has exacerbated settlement in the flood prone areas, whereas deforestation in the upper catchment increases erosion of the floodplain downstream.

The increase in erosion affects the arable land and may impact on crop cultivation along the river-banks as well as in the flood prone depressions that form part of a large lowland in the deltas of the Nyando River. Most households have no alternative but to hope that, the last floods they have experienced along with the damage sustained will live on only in their memories, rather than return as a recurrent threat. The increasing occupation of the flood prone Kano Plain and the concomitant vulnerability of farming communities threatened by the devastation of floods are the focal points of this study.

CHAPTER 3: LITERATURE REVIEW

3.0 Introduction

The purpose of this chapter is to present the literature on the impact assessment of flooding characteristics on cotton cultivation in the Kano Plain and to discuss the theoretical concepts for the description of the impacts of flooding on cotton cultivation in the study area. The characteristics of the drainage basin and the impacts of climate variability on river flow and flooding is presented in the literature and explored in this chapter.

Numerous researchers have documented the relevance of literature in demonstrating familiarity with a body of knowledge and in establishing the credibility of theories in scientific investigations (Neuman, 2003; Hardy, 2005). Hardy (2005) demonstrated that studies on fluvial systems tend to be processed-based and henceforth require an exhaustive review of literature based on integrated methodologies, which form a strong foundation in answering broad based problems in water resources. Muhia *et al.*, (2001) has emphasized the need for inclusion of sociological theories and survey methodologies in investigations of the problems posed in river basins. Perhaps, this combination of physical and social theories in investigating catchment characterization and flooding is what Peters (1996) has described as a stimulant to new ideas and scientific thoughts in both the physical and social sciences, while Penning-Rowsell (1996) has perceived the relevance of the two theoretical approaches as a model towards peoples' response to hazards. This chapter therefore examines the available literature that is related to the characteristics of flooding, the flood driving

mechanisms, theoretical approaches in the study of floods and the associated impacts of flooding and inundation on cotton cultivation in Kano Plains.

3.1 Flooding and flood driving mechanisms

Growing interest in the quantitative study of floods, floodplains and flood-prone areas dates back to 1960 (Leopold *et al.*, 1964), which saw the description of flooding change into quantitative analysis. This change prompted the definitions of flooding to shift from mere qualitative descriptions to a more rigorous statistical definition (Penning-Rowse, 1996). Since then, flooding has been described in terms of recurring events for a river where the flow equals or exceeds a specified value (Leopold *et al.*, 1964).

The flood driving mechanisms have, however, broadly been constituted and examined within the physical parameters. This is evident in Myers and White's (1993) usage of the geomorphic characteristics of the floodplains. Myers and White have reiterated that when heavy or continuous rainfall exceeds the absorptive capacity of soil and the flow capacity of rivers, streams, and coastal areas, flooding will occur. This causes a watercourse to overflow its banks onto adjacent lands (Myers and White, 1993). Floodplains are, in general situated adjacent to rivers and streams. Floodplains are therefore "flood-prone" and are hazardous to development activities if the vulnerability of those activities exceeds an acceptable level of sustainable water resource use within the catchment (Penning-Rowse, 1996).

3.2 Drainage basin characteristics and flooding

The significance of the river basin as a hydrological unit of study in water resource management has been singled out as an important hydro-geomorphic and climatic unit of analyses by many researchers in different disciplines and in different geographic areas in the world (Gregory and Walling, 1973; ICRAF, 2001; Clark *et al.*, 2003 and Dollar and Rowntree, 2003). Gregory and Walling (1973) define a drainage basin as an area that contributes water to a particular channel or sets of channels. The same authors furthermore recognise the distinctive characteristics of the basin, and assert that, it is the “source” area of precipitation, eventually providing water to the stream channels by various paths. The paths referred to are hill slopes, rills, gulleys and streams that serve the main river during storms.

Gregory and Walling (1973), Dollar (2001) and Peckham (2003) describe a river basin as a physical, ecological, biological and climatic entity, where a hydrological balance can be struck when one considers inflow and outflow of moisture and energy. In other words, it provides an essential geomorphic unit for analyzing hydrological input and output. A more recent description of river basins by Vogt *et al.*, (2002) analyses the characteristics of drainage basins in Italy. The authors re-affirm that as a hydrological entity, a river basin has complex functions that are the primary drivers of human pressure on water resources. They cite population growth, intensified agriculture, industrialisation and recreational activities as being particularly important drivers towards occupation of the basins.

According to Ferguson *et al.*, (2004), there is an increasingly significant change in the hydrology (i.e. channel profile and average annual flow) and climate (i.e. the distribution, characteristics and amount of rainfall) of many river basins. This change is responsible for the seasonal floods and droughts that affect the population living within the river basins (Ferguson *et al.*, 2004).

Hydrological changes, mainly increasing runoff and flooding in the river basins, have recently been responsible for increased investigation of the geometric characteristics of the drainage basin as a unit of landscape analysis (Hardy, 2005). The most examined geometric characteristics are the topology of the stream networks, and the quantitative descriptions of the drainage texture, pattern, shape, and relief (Baker *et al.*, 1988).

Quantitative analyses and descriptions of river basin morphometry have been extended to include interrelationships between river characteristics and flow (Vogt and Somma, 2000). Apart from this development, there have also been efforts to show the correlation between flow and sediment yield within the network geometry of small streams draining diverse lithologies (Benda *et al.*, 2004).

Benda *et.al.*, (2004) studied streams in both humid and semi-arid environments in the Western United States and Canada and observed that confluence related landforms are dominated by depositional features downstream. They ascribe this pattern as being driven by the frequency and magnitude of floods within a watershed.

Jain and Sinha (2004) studied the Baghmata River system in the north Bihar Plains in Eastern India, and report that the dissecting streams are characterised by a low width-depth ratio, gentle gradient, variable discharge, frequent flooding and high sediment load. The anabranching stream in the midstream reach is a response of the channel system to its inability to transport high sediment load due to gentle channel slope and the dominance of the aggradation process.

Lang *et al.*, (2003) studied the anthropogenic changes within the Rhine River system and reiterate that although these changes date back 200 years, the impacts of land use change have been felt since 500 years ago. They, however, acknowledge that there is growing change in the fluvial systems, which are yielding different runoffs, and these are varied in time and dependent upon the magnitude of rainfall.

Dollar and Rowntree (2003) cite five important hydrological factors necessary to consider when evaluating a drainage basin, namely: (1) morphometry of the drainage network; (2) soil characteristics, particularly those related to infiltration; (3) geology as it is related to structure and terrain erodibility; (4) vegetation as it affects erosion, infiltration and surface detention; and (5) meteorological-climatic conditions that control the nature of the rainfall input

The quantification of the drainage basin composition has largely been viewed in order to analyse drainage network evolution through conceptual models based on the physical processes of overland flow (Gregory and Walling, 1973). It also spawned a generation of studies concerned with the recognition and interdependence of drainage network elements as well as attempts to correlate these new parameters to hydrologic

phenomena (Vogt and Somma, 2000). In examining climate as a dominant hydrologic variable within the river basin, Vogt and Somma (2000) have cited climatic extremes, such as droughts, as having potential to alter or interfere with the energy flow within a river basin. Dollar (2001) and Jury (2003) have argued that some of the extreme climatic changes are global and the response has been the cycles of desertification and flooding, which is common in the catchments and the floodplains of Southern Africa.

Nelson (2004) points out that the accumulation of flows from the primary streams into the main rivers are responsible for the continued flooding and inundation witnessed in the large river basins in the world. This, he asserts, has made floods to be the most common and costly type of natural disaster. In other words, streams with heavy flows and with limited channel capacity downstream, are highly susceptible to over bank flows, flooding of dry lands leading to disaster if occupied by humans. However, such lands were often flooded before humans occupied them (Calder, 1996; Nelson, 2004).

3.3 Links between land cover and river flow

Land cover, specifically tropical forests are assumed to be important for preventing flooding, protecting dry-season water supply and maintaining rainfall patterns (Calder and Aylward, 2006; Sakeyo, 2008). However, the benefits of forest preservation in hydrological terms is highly location-specific and scale-dependent (Sakeyo, 2008). Several studies have demonstrated that a large reduction in forest cover increases annual stream flow and storm flow volumes both in temperate, humid and dry tropical areas, though the extent of the increase varies (Zang *et al.*, 2000; Cui *et al.*, 2007). Majority of these studies have, however, mainly been based on data from plots and small catchments without taking into account a mosaic of different land uses and

practices, heterogeneous geology, topography and soils that are common in large river basins. Sakeyo (2008) reporting on the impact of deforestation on stream flow in Chalimbana River in Zambia has noted that the spatial variability, in combination with spatial and temporal differences in precipitation patterns, will moderate the integrated river basin hydrological response. It is therefore not certain that conclusions drawn from small scale studies are directly applicable to large watershed even when there is evidence that limited research on the hydrological response on land cover in large river basins has been carried out (Sakeyo, 2008).

The Ganges River Basin, which begins flowing from the Central Himalayas, has had a devastating impact on land use in the Ganges-Brahmaputra Deltaic Plain. Being the most populous river basin in the world (400 million people), it has therefore recorded the worst damage as a result of flooding (Nelson, 2004). But, the devastating characteristics of the Ganges floods are attributed to the poor land use, especially deforestation of the mountainsides that has significantly reduced the Himalayas' capacity to absorb the monsoon rains. Furthermore, settlements in flood prone areas increase the damage that is associated with floods (Nelson, 2004).

The linkage between deforestation and its associated impact on flooding has led to a growing debate among researchers, some of whom have questioned the evidence that alludes that loss of forest cover exacerbates runoff causing flooding (Calder and Aylward, 2006; Cui *et al.*, 2007). Some of the leading critics in the debate of forests and floods (Calder, 1996 and Aylward, 2006) have argued that although floods are either natural or human induced, they generally have an impact on people and the economy. The perceptions of the impacts of floods are reiterated to be influenced by

first hand experience; conventional wisdom; scientific observations and the expected gains and losses (Calder and Aylward, 2006).

Citing the annual floods in Bangladesh, Calder and Aylward (2006) recognized the existing disparity in terms of the impact of flood among the lowland farmers and upland community. The authors have argued that while the lowland farmers and fishermen welcome the annual flood to bring down sediments rich in nutrients and water that is sufficient to support their livelihood, the upland community has in their part the least to complain of floods even when the devastation is bad or when the gains are good.

Considering these popular perceptions of the two communities it is emerging that the community that have encroached onto the floodplain and are not reliant on floodplain waters for their livelihood, often view flood as a plague to be blamed on any external cause. Studies on the impact of deforestation on flooding have been presented with many researchers going with the public notion that reduction in forest land cover exposes the catchment to heavy storms and increased runoff due to the decline in percolation of the rain waters. For instance, Bolton *et al.*, (2007) wrote that extreme deforestation in the Himalayas, in Nepal, undoubtedly contributes to the sedimentation problems of the rivers draining the region. She noted that the same amount of water floods more than before and points the accusing finger at the loss of forest cover.

Zang *et al.*, (2000) reported that deforestation in the upper reaches of the Yangtze Basin in China led to the decline of forest cover from 22% of the total area in 1957 to

10% in 1986. This resulted in soil erosion from the upper reaches and sediment redistribution in the lower reaches intensifying the cumulative effect of the most severe flood in China in 1998 affecting 223 million people.

Cui *et al.*, (2007) in their study of the hydrological impacts of deforestation on the southeast Tibetan Plateau have demonstrated that the deforestation in the plateau has decreased transpiration and increased summer precipitation in the deforested area causing a wetter and warmer climate that would likely have produced more runoff into the rivers and worsen flooding disasters downstream.

Bolton *et al.*, (2007) in support of the role of forests in improving water retention and land holding capacity against erosion agents has given summary of the role deforestation plays in flooding equation and argues that; since trees prevent sediment runoff and forests hold and use more water than farms or grasslands, the rainwater that stays on leaves may evaporate directly to the air. Leaves according to Bolton *et al.*, (2007) reduce raindrops, reduce erosion and prevent sediment significance in flooding equation.

Quin (1983) cited in Sakeyo (2008) could not detect a change in stream flow after a 30% loss of tall forest on a large (727 km²) catchment in China. Similar results emerged from a catchment of 14500 km² in Pasak River Basin in Northern Thailand after a removal of 40 to 50% of the forest (Sakeyo, 2008). Furthermore, no evidence was ever observed that stream flow or sediment regimes had changed significantly in mountainous watershed in Northern Thailand since the 1950s, while Brandt (1992) did not reveal any clear trends of changes in evapotranspiration or runoff in studies of

catchments in Sweden with areas between 1400 and 25000 km², in spite of considerable increases of the biomass. In Sri Lanka a statistically significant increase in the annual runoff was reported between 1944 and 1981 from the 1108 km² Mahawelli Basin even when a weak trend towards a decreasing rainfall was reported (Elkaduwa and Sakthivadivel, 1999). The latter researcher, however, revealed that a 35% reduction in forest cover showed stream flow to have remained at similar levels as before the removal, despite the decrease in rainfall when a longer time period is analysed (1940 to 1997) for the nearby Nilwa Basin (380 km²), which was alluded to the expansion in the tea holding (Elkaduwa and Sakthivadivel, 1999).

Ziegler and Giambelluca, 1997) studied the hydrological significance of base flow during the dry season and reported that if infiltration capacity can be maintained to allow water gained by decreased transpiration to penetrate the soil and not to be lost to surface runoff after forest clearance, an increase in base flow will result. Similarly, a simulated rainfall in excess of infiltration rates in Northern Thailand occurred frequently on road surfaces and margins, while rarely on agricultural, secondary vegetation and forested lands (Ziegler and Giambelluca, 1997). Others studies have attributed climate change to the demise in the tropical forests (Henderson-Sellers *et al.*, 1996) with replacement by degraded grassland showed a decrease in precipitation in different studies in the Amazon Basin (5,000,000 km²) (between 186 and 580 mm year⁻¹) and in Southeast Asia where a smaller decline (7%) in precipitation which is attributed to the monsoon-dominated climate that should be smaller than the Amazon Basin where 21% decrease in precipitation was revealed after removal of forest cover (Henderson-Sellers *et al.*, 1996). Some researchers (McGuffie *et al.*, 1995) have argued that the large decline in precipitation in Amazon Basin is too large to be

entirely attributed to land-use changes and is more likely to be as a result of monsoonal air circulation patterns or global climate. This conclusion is similar to Calder's proposition that although trees do increase the orographic effect slightly, the excess rainfall over the forests is nearly always more than compensated by higher evapotranspiration, and should only be looked at on a very limited scale (Calder, 1998).

Timberlake and Wijkman (1984), in their famous book on hazards, "Acts of God or Man," acknowledge that both physical and anthropogenic processes are to blame for the rising impacts of natural disasters. In their study of the variability of the flood problem along the Ganges River, they note the pattern of increasing flood damage from West to East (downstream) and from South to North (towards the hills) (Timberlake and Wijkman, 1984). This view is supported by Penning-Rowsell (1996), who advises that sustainable flood coping mechanisms must integrate and examine the processes upstream as well as the impacts downstream.

Damage to crops by floods and inundation has been reported in several river valleys in Kenya since the 1970s. According to Njogu (2000), the four-month flooding of the Nzoia River in Kenya, between 1975 and 1976, disturbed not only the harvesting process but also crop yield in the catchment area. NEMA (2004) described the damage of crops caused downstream by the Nzoia River to have had periodic pattern and have continued in 1977, 1978, 1988, 1996 and 1998.

LBDA (1992) and Shepherd *et al.*, (2000) have documented extensive damage of farmlands and crops caused by floods in the Kano Plain of Western Kenya. Damage

of this kind continues to occur due to the fact that the floodplains attract intensive agricultural practices. While Obara (1983) and LBDA (1992) argue that poor crop husbandry is to blame for poor crop output, Shepherd *et al.*, (2000) cites deforestation at the head waters as a cause for exacerbated flooding and erosion of the Kano Floodplains. LBDA (1992) highlights the economic and agricultural potentials of the floodplains in terms of being a source of fertile alluvial deposits that are suitable for crop cultivation. The benefits of soil fertility are seen as a major motivating force for cultivation in the flood prone river valleys despite the known dangers of floods.

Dollar (2001) describes floods as both three-dimensional and binary, in the sense that they are influenced by two or three factors. LBDA (1992), Shepherd *et al.*, (2000), ICRAF (2001) and Ochola and Kerkides (2003), in studies of the flooding characteristics in Kano Plains, describe the Nyando Floods as binary in that they are mostly influenced by two sets of factors, namely climatic and physiographic. While Shepherd *et al.* (2000), ICRAF (2001) and Ochola and Kerkides (2003) have attempted to identify the relationships between the physiographic factors and flood characteristics, this study mostly involved multiple regression techniques designed to isolate the contribution of the different physiographic parameters towards peak flows.

The three-dimensional nature of floods described by Dollar (2001) is derived from three significant characteristics: magnitude, frequency and timing. Ochola and Kerkides (2003), for instance have used a Markov Chain Simulation Model of rainfall (MCSM) to determine the seasonal duration of the wet and dry spells in Kenya by means of the bimodal rainfall pattern in Kano Plains. Their study reveals:

- duration of the dry spells to be 14 days in the long rainy season and 12 days in the short rainy season;
- wet spells in the Kano Plains to be 12 and 8 days, for the long and short rains respectively.

While Ochola and Kerkides (2003) attempted to determine the seasonal climatic conditions they did not examine:

- the variability of the wet and dry spell to the stream flow;
- extent to which the stream flow variation causes flooding downstream and the impacts of flood damage on land use generally and on crop cultivation in particular.
- Shepherd *et.al.*, (2000) or ICRAF (2001) did not deal with the assessment of the variability of floods. These two reports rather concentrated on the impact of land cover change on erosion, which they attribute to severe anthropogenic factors, mostly due to deforestation in the catchments.

In the past, the local communities under the supervision of the Administrative Chiefs have carried out flood protection works in the Kano Area. This involved the building of low dykes of about 1m high along the riverbanks (NEMA, 2004). The problem was that the dykes were often located too close to the river and were, therefore, prone to damage during floods. Even efforts by the Ministry of Agriculture in building check dams and diversion channels in 1984 to protect agricultural fields or to enforce soil conservation measures as part of on-farm practices have failed to stop flood damage in the Kano Plain.

It is argued that some of the engineering efforts to exercise control over the floods in the Kano Plains are also to blame for the significant rise in the sediment load into the Nyando River (Ongwenyi, 1985) and for the rising turbidity in the River mouth (NEMA, 2004). These two hydrological factors are process-based and have contributed to the declining capacity of the Nyando River channel to discharge the heavy load downstream (Mwaka, 1994).

Mwaka (1994), in turn, has pointed out that the shallow riverbed is vulnerable to flows exceeding $(87\text{m}^3/\text{s})$. This type of channel capacity ($87\text{m}^3/\text{sec}$) is unable to contain excess flows during the long rainy seasons, and this explains why the frequency of floods has increased in the recent past. In the Kenya National Water Master Plan (1992), it is reported that the average annual damage in flood prone areas (at 2003 prices) tends to increase with a decrease in probability of flood shown in Figure 3.

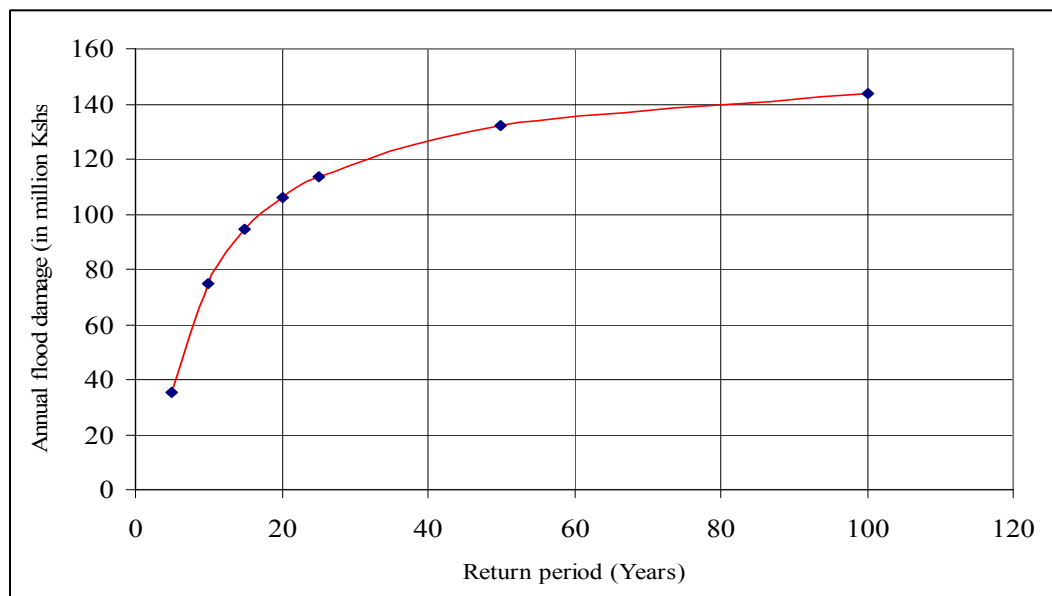


Figure 3: Average Annual Flood Damage in the Kano Plains

Source: Basic data computed from the Kenya National Water Master Plan (1992)

3.4 The cause of flooding and inundation on crop cultivation

Flooding and its impact on land use has been a subject of intense investigation all over the world, including Africa. Numerous authors (Shepherd *et al.*, 2000; ICRAF, 2001, and Nelson, 2004) perceive flooding as a natural consequence of stream flow in a continually changing environment. Streams receive most of their water input from precipitation, and the amount of precipitation falling in any given drainage basin varies from year-to-year (Nelson, 2004).

FAO and WFP (1998) observe that Zambia suffered one of its worst crop losses as a result of El Nino-related weather anomalies. They indicate that there was a sharp decline in crop production in 1997/98, when maize recorded a 43% decline in output. The northern part of the country experienced abnormally high and incessant rainfall, with extensive flooding throughout the season, while the southern part experienced near-drought conditions. There was a significant crop loss and a decline in yield, especially with regard to cotton, which is grown in the low-lying areas (FAO and WFP, 1998).

Similarly, the low-lying, clay dominant areas of Shinyanga, parts of Mara, Arusha, Kilimanjaro, and Iringa and along the coast north of Lindwere in Tanzania were affected adversely by heavy floods (FAO and WFP, 1998). The cotton crop, which is normally grown on these soils in Shinyanga, Mara and Mwanza, was significantly damaged. In 1998 and 2002, FAO and WFP (2002) reported that the Nile Delta is a problematic area when non-flood tolerant crops are grown – particularly cotton, which has for decades been grown to supplement rice and maize (Hefny and Shata, 1995; Ahmed, 1998).

3.5 Cotton growing on the Kano Plains in Kenya

In the Kano Plains, cotton is regarded as an important cash crop, second only to sugarcane. Cotton does well in the Lower Midland agro-ecological zones. By 1992, cotton was the main cash crop in all the locations of north-west Kano, south-west Kano, and the Kolwa and Kajule areas of the Kano Plains (Lotti and Associates, 1985; Republic of Kenya, 1996).

In terms of yield, ICRAF (2001) observes that the volume of soil water that gives yields of up to 90 percent of lint cotton per hectare on medium textured soils is only capable of giving 50 percent of potential yield on fine textured soil. However, LBDA (1992) notes that an average rainfall of 450 mm over the first four months of cotton growth is optimal for clayey soils and that a much higher early rainfall would cause water logging, thereby inhibiting growth.

Cotton has been described as less resistant than rice and sugarcane to severe floods and water logging conditions by Jaetzold and Schmidt (1982). Other factors included as causing decline in cotton cultivation are poor prices, high cost of both labour and farm in-puts and competition from synthetic fibres (McCormick *et.al*, 2001; KIPPRA, 2003).

The above mentioned studies all suggest that the agricultural potential of the Kano Plains may be limited by the variability of rainfall and hydrological response and economic factors. Other researchers, such as Japan International Cooperation Agency (1985), LBDA (1992) and ICRAF (2002), have examined the climate variability and the relationship between the amount of rainfall and drainage, and have concurred that

too much rainfall on clay soils has severe consequences in terms of water logging that alters the normal aeration and nutrient uptake of crops.

In two related studies, Republic of Kenya (1985b) and Njogu (2000) observed that water logging resulting from flooding is capable of limiting cotton yields, especially in the vertisols that are predominant in the flood plains. Mitchell (1989), cited in Penning-Rowsell (1996), observed the continued impact of floods on agricultural production in developing nations and proposed that relevant studies should be undertaken as an agricultural response to hydrological hazards.

The author suggested this because the damages from flooding are often immediate and visible, especially where people persist in occupying areas that are prone to flood hazard because of economic opportunities, lack of alternative opportunities, short-term horizons and high ratios of reserves to potential loss (Penning-Rowsell, 1996).

3.6 Summary of literature review

The above review and criticism on the role of land cover in generating flow and precipitation is not any unique in both small and large scale catchments in Kenya and Nyando River Basin in particular, which to-date suffer from spontaneous indiscriminate land uses and the removal of forests cover.

The replacement of forest cover with degraded grassland has compromised the role of the catchment as a hydrological buffer for both precipitation and flow generation. Change in forest cover (upstream) and the increasing level of construction works as well as urbanization (downstream) has increased the rate of raindrop caused by the decline in interception rates and increased runoff causing erosion.

A significant increase in sediment yield and transport downstream causing flooding and inundation will be observed if forest cover continues to be replaced with degraded vegetation or the physical structures during constructions in the Nyando Basin.

It is apparent from the review of literature that very little work has been done to explicitly show the relationship between rainfall and flow regime and how these explains the flooding characteristics and cotton growing on the Kano Plains in Kenya. So far, the literature reviewed has pointed out that:

- a) the total area under cotton cultivation has generally declined ;
- b) flooding conditions show an increase in damage, which Shepherd *et.al.*, (2000) and ICRAF (2001) attributed to poor land use, which has increased sediment yields in the Nyando River thereby lowering its channel carrying capacity (Mwaka, 1994).

CHAPTER 4: DATA AND METHODOLOGY

4.0 Introduction

This chapter examines the research methods and the data used in the analyses. The quality and consistency of the data acquired is analysed. Also examined are the target population, the sampling techniques and sample frame as well as the procedure of the field survey.

4.1 Anecdotal pilot survey

The researcher, in order to familiarise himself with the area of study and the local conditions, undertook a site visit of the study area. During the reconnaissance, the researcher gained personal experience of hydrological floods, the farming systems concerned and crops grown. The researcher also familiarised himself with the general geomorphology of the flood plain and the Nyando River, the qualitative descriptions of the flood history and the flood impact as narrated by the households.

The pilot survey was aimed at creating an understanding of the problem under investigation, the population it was to cover, and the possible reaction(s) from the respondents with regard to the pilot-survey questions. After the pilot survey, adjustments were made to the questionnaire in order to incorporate the anecdotal perceptions that were clearly omitted during the survey design.

4.2 Research questions

Research questions are viewed by numerous researchers as being instrumental in providing a theme to be followed throughout the entire research process, without being compromised by many interruptions that may occur during such a process

(Neuman, 2003; King'oriah, 2004). The aim of the research questions in this study was to assist the researcher to concentrate on the problem under investigation as well as to the objectives of the study.

4.3 Research Methods

Quantitative as well as qualitative research procedures were used during data acquisition and data analysis. King'oriah (2004) implies that both the approaches (quantitative and qualitative) allow a comprehensive assessment of the research problem, before any logical conclusion is drawn. Peters (1996) similarly describes the use of both quantitative and qualitative methodologies as useful in not only widening the domain of scientific investigation, but for establishing a representative view of the broader picture of the problem under investigation – a process that Neuman (2003) describes as a top-down approach, as distinguished from the narrow scope, which he termed a 'bottom-up approach'.

In order to execute the impact assessment of the flooding characteristics of the Nyando River on cotton cultivation, the two research methodologies were applied to bridge the gap between the physical analysis of the variability of flow and flooding as well as to understand the anecdotal assessment of the impact of flooding in the study area.

4.3.1 Quantitative and Qualitative Methods

The quantitative approach that was used in this study involved the use of both structured and unstructured questionnaires (for sociological analysis), which were drafted according to the research questions. The structured and un-structured

questions were standardised through a pre-test during the pilot survey for the sake of precision. The unstructured questions were, however used to allow respondents freedom of expression and interpretation. The coding of the unstructured responses rendered the questionnaire more suitable for statistical analysis. This was complimented with qualitative approach where the observation and recording of the flood prone areas, the location of households, the damage by floods with regard to crops and infrastructures, and the general observation of the flow of the Nyando River downstream was carried out and described. Most of these variables were mapped and quantified.

Some of the perceptions about flooding characteristics that were not covered by the questionnaire interview schedule were captured through informal interviews and observations. The approach focused on the daily operations of the household in regard to rainfall, flooding, river flow and crop cultivation. A large amount of qualitative information was gathered on issues relating to the settlement in the flood prone areas, the history of flooding, the frequency of floods, the problems of cotton cultivation and government involvement in flood control on the Lower Kano Plain.

4.4 Population and sample frame

Peters (1996) defines a population as that part of the universe relevant to a specific problem. It is a finite or infinite collection of individual objects and consists of a number of units of enquiry (King'oriah, 2004). A geographical population is therefore a collection of objects with some geographical characteristics in common.

4.4.1 Target population

The target population in this study was drawn from two components of the unit of analysis, namely the geophysical (Nyando Basin) and the social (households).

- a) *Nyando Drainage Basin and Lower Kano Plains*: The river basin has become increasingly accepted as a unit for water resource management (Biswas, 1990; Hardy, 2005). The rationale stems from the concept of a river as an organic system, where interference with or modification of any part of it will be felt elsewhere in the system. The Lower Kano Plain in Nyando Basin, therefore, is used for the acquisition of economic data, climate and hydrological data (i.e. rainfall and flow). Also examined are the descriptors of the river morphology and the characterization of river flow within the basin, which Arnaud *et al.*, (2002); Hardy (2005) and Andreo *et. al.*, (2006) have recommended as important for an understanding of the river basin as an open system of geophysical and social interactions.
- b) *The households*: The households formed the main unit of sociological analysis for the acquisition of anecdotal information. Households within the sampled administrative sub-locations were interviewed in order to derive anecdotal information (perceptions of flooding from cotton growers' point of view). The responses (anecdotal data) from the household with regard to the physical and social characteristics of flooding were supplemented with the results from the physical (hydrologic) analyses.

4.4.2 Sampling and sampling techniques

The importance of sampling and the selection of the sample population in research design are emphasized by Tashakori and Teddlie (1998) and King'oriah (2004). These authors have noted that the whole structure of a sampling survey is, to a considerable extent, determined by the sample where the target population is drawn (households in Lower Kano Plains). Tashakori and Teddlie (1998) also pointed out that there is a need to carefully design a probability sample, where results are representative of the entire population under investigation. In this study the sample populations is represented the households living in the Lower Kano Plain in the lower reaches of the Nyando River. These households have their farms and homesteads located either on the eastern or western banks along the river. These households were treated as a representative sample of the households living in the Kano Plain.

In order to avoid or, at least minimise, the element of bias in the selection procedure, and also to achieve the required precision given the resources available, random sampling were conducted. As noted by the World Agroforestry Centre (2006), increased settlement and crop cultivation takes place in the floodplain and along the banks of the Nyando River. Their report attributes this to an increase in the demand for more land for crop cultivation and food provision. Only the households which are defined by the study area (Figure 4.1) inland of the Nyando River mouth in the Lower Kano Plain were included in the study. Through purposive sampling (non-probability) the interview schedule was mainly focused on the heads of the households (either male or female).

4.4.3 Sampling frame and sample selection

The selection of the households that were to be included in the study began by a delineation of the sub-locations that fell within an area of 48 Km² inland of the Nyando River mouth (Figure 4.1). The 8 villages identified (within the sub-locations) became the entry points in the selection of households for the acquisition of anecdotal data. Village names were mostly used as boundaries, both on the eastern and western sides of the riverbanks. It was within these blocks that ten administrative sub-locations were chosen and the respective villages were selected for the questionnaire interview schedule.

4.4.4 Sampling size for sociological analysis

Peters (1996) and Neuman (2003) point out that the sample size of the study population must be representative in order to yield reliable results. King'oriah (2004) similarly demonstrates that the choice of sample size depends on the homogeneity or heterogeneity of the population under study with a large sample being preferred for a heterogeneous than homogenous population (King'oriah, 2004). While Peters (1996) and Neuman (2003) propose a sample ratio of 30 % (300 respondents per population of 1000), King'oriah (2004) proposes a sample ratio of 10 % (100 respondents) for a homogenous population.

A more recent study on the impact of land use and land carrying capacity on erosion in Kano Plain was carried out by ICRAF (2001), who estimated between 1000 and 1200 homesteads exist in Lower Kano Plains. The households falling within the sampled sub-locations live in homogenous climatic conditions; share similar socio-economic backgrounds; use similar infrastructures and generally share experiences

with regard to the impact of flood damage on agriculture. Hence, a 10 % sample ratio is considered appropriate for the study. A sample size of 100 respondents, that is 10 % of the population, was considered as adequate under these homogenous conditions. A total of 100 households responded to the questionnaire interview. Figure 4.2 shows the administrative sub-locations where the interview schedule and the acquisition of anecdotal (perceptions) data were performed.

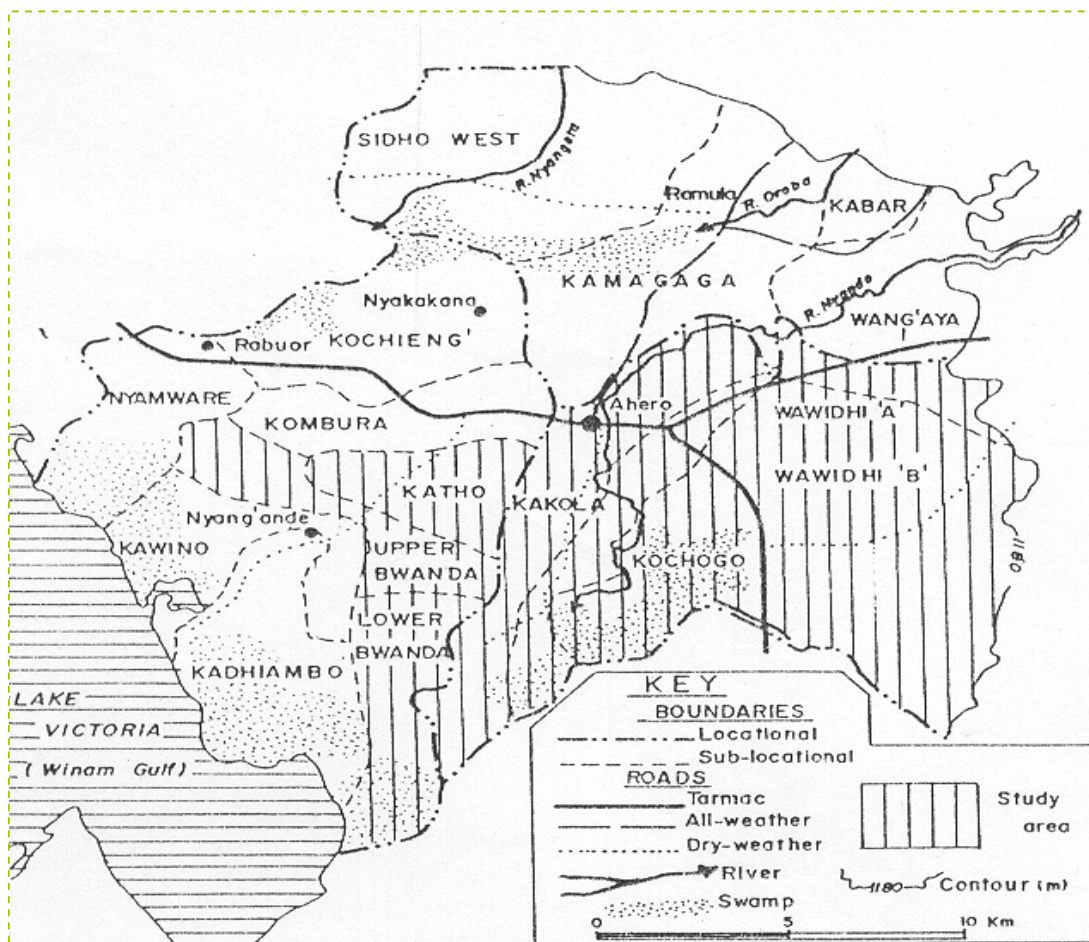


Figure 4.2: The Villages surveyed in Lower Kano Plains (study area)

4.5 Data type and source for physical (hydrologic) analysis

The following data were acquired for the purpose of this study. Most of this data is based on hydrographic records and published in scientific reports. The data types include:

1. Hydrology and physiographic data of the Nyando River Basin ;
2. Monthly rainfall data from five rain gauge stations (Kipkure, Coreng, Kibwari, Kaisugu and Kano) in the Nyando Basin for the period between 1970 and 2000;
3. The 1999 Kenya Population census was acquired to compute the settlement density in and also to generate maps for the administrative boundaries,
4. FAO soil classification shape files (2003) were used to generate the soil map for Kano Plain.

4.5.1 Sources of hydrologic data

The data used in this study is acquired and extracted from a variety of sources. The monthly series climate data provided by the NOAA-CIRES Climate Diagnostics Center, the National Center for Environmental Prediction (NCEP), the Climate Prediction Center (CPC) through the courtesy of University of East Anglia (UEA-CMAP) was acquired from their website

(<http://iridl.ldeo.uea.edu/SOURCES/.NOAA/.NCEP/.CPC/.GMSM/.w/dataselection.html?>).

4.5.1.2 Climate Prediction Centre (CPC) Merged Analysis of Precipitation (CMAP)

The CPC Merged Analysis of Precipitation (CMAP) is a technique which produces pentad and monthly analysis of global precipitation in which observations from rain gauges are merged with precipitation estimates from several satellite-based algorithms (Lukiya, 2003). The CMAP analyses are on a $2.5^0 \times 2.5^0$ latitude/longitude grid, and extend back to 1950s where the monthly rainfall data (Appendix 2a) was extracted from longitude $33^075'E$ and $35^004'E$ and latitude $0^000'S$ and $2^005'S$. The CMAP data was then compared with the actual monthly average rainfall for Kano Plains, where the latter data set was recorded at Ahero Gauge Station (1GD03), and acquired from ICRAF (Appendix 2b). Through CMAP analyses technique monthly rainfall was extracted from January 1960 to August 2006, and was used to supplement the actual data (1970 to 2000) in the analyses of trend, seasonality and periodicity of precipitation in the Kano Plain.

4.5.1.2 Flow data for the Nyando River

The flow data for the Nyando River was acquired from five sources; gauge station 1GD03 (located at Ogilo Bridge near Ahero Township), gauge station 1GB04 (located upstream of the Nyando River); the Ministry of Water and Irrigation; International Centre for Agro Forestry Research (ICRAF-Nairobi) and National Environmental Management Authority. The flow data from station 1GD03 was compared with the flow data set from the Ministry of Water and Irrigation, the National Environmental Management Authority and ICRAF with the aim of checking for good data quality as well as consistency (Elshorbagy *et al.*, 2000; Republic of Kenya, 2002).

In this study, use was made of actual rainfall data from Rain Gauge Station 1GD03, as it is representative of the hydrologic conditions of the Nyando Basin. A 31-year length time series of rainfall data from 1970 up to 2000 was used, together with continuous 37-year annual discharge data from 1963 to 2000. The monthly rainfall data was used to analyze the cycles and periodic variability of rainfall and flow in the Plain.

4.5.1.3 Gauge rainfall data and spatio-temporal variability of rainfall and runoff

The spatio-temporal rainfall and runoff variability in the Kano Plain downstream of the Nyando Basin was analysed. Rainfall data for the five rain gauge stations (Kano, Kibwari, Kaisugu, Coreng and Kipkure) acquired from ICRAF (processed from station 1GD03) are used in the analysis. Heavily used in this study are rainfall data acquired from rain gauge and flow station 1GD03 that is located at Ogilo Bridge downstream of the Nyando River (what is referred to here as Kano Station). Rainfall recording started in different years, with each station having at least 29 years of precipitation record. The rainfall stations are fairly well distributed within the catchment (Figure 5.6) as will be illustrated in sections of Chapter 5.

The average annual rainfall for Kano, Kibwari, Kaisugu, Coreng and Kipkure are 98.6, 123.2, 143.7, 101.2 and 98.5 mm per annum with standard deviation of 14.98, 21.23, 24.08, 22.03 and 23.52 as shown in Table 4.1. Similarly, the running means of annual rainfall for the five stations show each station displays broadly similar characteristics except the magnitude for most of the period (Figure 4.3).

Table 4.1: Statistical parameters of annual rainfall in Nyando River Basin

Station	Period of Record	Mean rainfall (mm)	Std. dev	Max (mm)	Min (mm)
Kano (IGD03)	1970-1998	98.6	14.9	134.7	71.2
Kibwari	1970-1998	123.2	21.2	377.8	69.7
Kaisugu	1970-1998	143.7	24.1	179.8	92.9
Coreng	1970-1998	101.2	22.0	154.5	47.9
Kipkure	1970-1998	98.5	23.5	153.8	41.9

From Table 4.1, the magnitude of rainfall in Kano differed significantly from the other stations during the period 1970 to 1998 as it displayed a relatively low rainfall amount while Kaisugu had the highest rainfall for most of the record period. This is because Kano (IGD03) station is located in the low lying plain of the Nyando River Basin where the precipitation is convective in character. The characteristics and consistency of the rainfall record is further confirmed by plotting the Total Accumulative Mean Rainfall (MTCMAT) of four stations record against Kano (1GD03) located downstream. Although there are differences in rainfall magnitude noted, the stations display similar characteristics. The plots presented by the double mass curve (Figure 4.3) show a linear shape, which confirms the high quality and consistency of the rainfall record and data from station 1GD03 that is heavily used in this study.

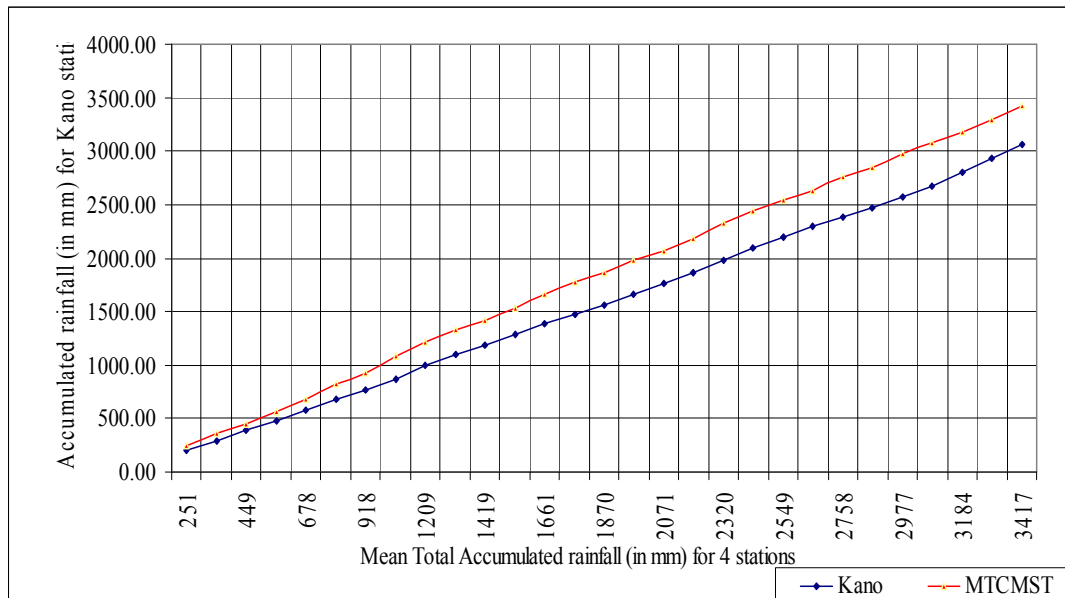


Figure 4.3: Double mass curve for Kano (1GD03) station

Similarly, the accumulated annual discharge at station 1GD03 (downstream) compared to 1GB04 (upstream) also yielded consistency in the flow record as illustrated by the linear trend of the curve (Figure 4.4) a part from the hydrologic period 1977 when there was a sharp drop in discharge followed by a significant rise in 1978 and 1979. The sharp drop of the accumulated annual discharge in 1977 is artificial, and is attributed to efforts to contain floods by regional flood control strategy (Ahero National Irrigation Scheme), which could have altered the river flow regime. One of the methods that have heavily been used to contain the excess flow is through diversion of the flood water into the paddy farms, as well as raising the heights of the dykes to contain flood water from spreading into the dryland, This was followed by uncontrolled flow in the periods 1978 and 1979 when the accumulated flow scoured the Nyando River downstream.

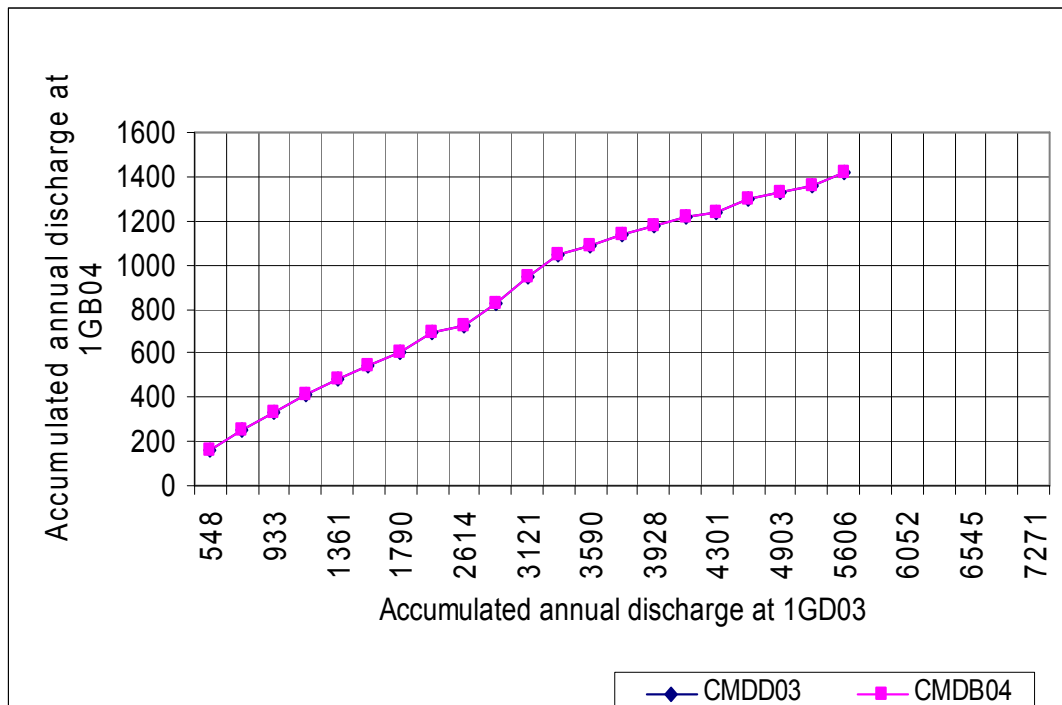


Figure 4.4: Double mass curve of annual flow at station 1GD03

The record of annual flow for the two stations (1GD03 and 1GB04) presented in Figure 4.4, largely demonstrates that the flow downstream is homogenous. The variability in the magnitude is attributed to the location of the gauge station within the Nyando River as well as artificial factors that could be determining the sharp drop and rise in the regime of flow as evidenced between 1977 and 1979. The consistency of the flow records for the stations observed are based on the following fundamental hydrological assumptions;

- a. no change in the measurement and observation procedure;
- b. the flood regime has not changed, and
- c. no change has occurred in the river channel, and catchments' storage

4.5.2 Secondary data

Published and unpublished data existing in libraries, journals and websites was used in order to obtain relevant information on the hydrologic and climate characteristics of the Nyando Basin. EBSCO and Science Direct research databases were used to acquire published research findings on climate change, changes in river hydrology, river basin characteristics, the impacts of flooding on land use and the environmental problems related to cotton cultivation. Other organisations that assisted with the acquisition of relevant data included the Lake Basin Development Authority (LBDA) and the International Center for Research in Agro forestry (ICRAF), where relevant literature related to the Nyando Basin was reviewed. Most of the information on cotton growing in the Kano Plains was acquired from Kibos Cotton Research Station, and from the Ahero Rice Scheme, which also supplied the daily rainfall data. These information is supplemented with data acquired from the District Annual Reports, the Kenya Human Development Report, the Kenya National Development Reports and the NCEP/CDC (for rainfall satellite data for 1970-2000).

Relevant information was also collected from photographs, topographical maps of Kisumu East, and from land use maps and soil survey maps of the Kano Plains. Most of these were obtained from Kenya's Survey Department and from the National Environmental Management Authority (NEMA).

4. 6 Physical methods

The approaches adopted in data analysis are consistent with the study's purpose and the objectives for which it is intended to achieve. The approaches are presented in subsequent sections, below.

4. 6.1 Analysis of the drainage basin characteristics

The first objective of this study is to describe the characteristics of the Nyando Drainage Basin. In order to describe the geomorphic and hydrologic characteristics of the Nyando Basin the basins' physiography showing the stream segments, the topography and elevation are mapped. The Nyando River Basin was delineated into grids before the basic physiographic parameters such as the tributary streams, the basin boundary, and the sub-catchments were processed by means of the ArcGIS data analysis tool. A thematic map of the basin showing stream segments and stream order was produced and the basin hydrography captured into ArcGIS maps presented in the relevant sections of Chapter 5.

The rainfall characteristic within the Nyando Basin is illustrated with sampling emphasis focusing on the estimation of rainfall over drainage area of the basin. Like Kumar (1993); Shaw (2004) pointed out that although there is increasing need to estimate the total quantity of water falling on the catchment (the areal rainfall), the method or model adopted should be carefully used in the catchment that have their boundary well known, and carefully defined. Most studies however have deployed unique models in deriving the areal precipitation over a catchment from rain gauge measurements. The Arithmetic Mean Method is the first, of such models, which involves the simultaneous measurement for a selected duration at all gauges, summed up and the total divided by the number of gauges (Linsley *et al.*, 1982; Kumar, 1993; Shaw, 2004) as illustrated in the following model;

$$P = \frac{P_1 + P_2 + P_3 + \dots + P_n}{n}$$

where, P is the mean precipitation on the basin, and $P_1, P_2, P_3, \dots, P_n$ are respective precipitations at stations 1, 2, 3, n; and, n is the total number of stations. In this study

the Arithmetic Mean Method was not used in computing the areal rainfall in the Nyando Basin because of the topographic differences that are predominantly the floodplain and the surrounding hills.

The limitation of the Arithmetic Mean Method (AMM) in this regard was substituted with Thiessen's Mean Method, which Kumar (1993) and Shaw (2004), have described as highly desirable since the model recognizes the topographic uniqueness of the location of the hydrological stations. While using Thiessen Model, rainfall gauge stations that are situated beyond the boundary of the drainage basin are also evaluated, and the mean rainfall on the basin determined. It is, however noted that the influence of stations beyond the boundary reduces as their distance from the boundary increases (Kumar, 1993).

The presentation of rainfall stations as well as their distribution through the use of Thiessen Polygon shows the configuration of rain gauge stations that are plotted on the catchment map (Figure 5.6). Thiessen Polygon represents the polygon area A_1 , corresponding to the rain gauge stations denoted by P_1 . The measured areal rainfall, P is represented by the following equation;

$$P = \frac{A_1 P_1 + A_2 P_2 + A_3 P_3 + \dots + A_n P_n}{A}$$

Where $P_1, P_2, P_3, \dots, P_n$ represent rainfall at the respective stations, whose surrounding polygons have the areas $A_1, A_2, A_3, \dots, A_n$, respectively. The advantage of Thiessen Polygons is the ability in estimating areas within the Nyando Basin that is experiencing trends recorded by the gauges. Besides, Thiessen Polygons are useful in identifying small areas with significant rainfall trends (see Table 5.2 and Figure 5.6) through grouping areas closer to a gauge into one polygon. For instance

while Corengoni and Kaisugu Stations (see Figure 5.6) are outside the catchment boundary of the Nyando Basin they are nearer to the areas (A_3 and A_5) than to the neighboring gauges 1, 2 and 4 and are therefore better represented by the measurements at gauges 3 and 5. The area fraction a_i/A are the Thiessen Coefficients.

In this study Geographic Information System (GIS) program Arc/Info and Arc View version 9.0 is used to compute the mean rainfall over the Nyando Basin. The point coverage, the rainfall values and the catchment boundary text files were created to aid in the computation. The second file (prec.dat) that includes the gauge sequence and the corresponding values of rainfall recorded was captured, and finally the polygon coverage (border.dat) file that shows the boundary of the area was created. After creating the three text files (point coverage, precipitation values and boundary), the text data files are transformed into an internal GIS data coverage referred to as gauges of the point locations. Finally, the measurement data (rainfall) is attached to the point coverage, and the gauge is then used to join the data table (prec.data) to the point coverage of the gauge location (Figure 5.18 and Table 5.6).

4.6.2 Analysis of hydrological and climate data

Both the second and third objective of this study has comprehensively been examined through the use of multiple statistical approaches. In the second objective of this study aimed at determining whether the flooding characteristics of the Nyando River have changed with time. In order to achieve this objective, the analysis of time series of rainfall and flow were used to determine intra-seasonal and inter-seasonal changes in flow and rainfall patterns. The analyses used 31 years (1970 to 2000) of rainfall and flow data to investigate these variations. Inter-annual time series analysis is used to

show the variability of rainfall and flow within a 31-year continuous record of stream flow and rainfall.

The third objective of this study; however is to describe the natural flooding regime that probably existed before anthropogenic influences. The flood cycle and regimes were determined through inter-seasonal analysis (section 5.2.4); while a 5-year moving mean was used to determine the trend and pattern in the long-term time series data, and also to remove noise from data so that a smooth trend is exhibited in order to assess the seasonality of both rainfall and flow. This was also done to determine whether the moving means for both rainfall and flow explained either the drought period or the wet season. The moving average was obtained in order to further assist in assessing to what extent rainfall explains the changes in stream flow, and thus flooding by the Nyando River. The moving mean assumes a set of observations of a hydrologic variable: $X_1, X_2, X_3, \dots, X_N$. The model represents the moving mean by

a sequence: $\frac{X_1 + X_2 + \dots + X_N}{N}, \frac{X_2 + X_3 + \dots + X_{N+1}}{N}, \frac{X_3 + X_4 + \dots + X_{N+2}}{N}$, where these

are referred to as moving sums of order $[N]$ (Schulz, 1976). Weighting can be applied to the values in each mean to filter out selected cycles.

4.6.3 Regression analysis using the F-statistics

Moore and McCabe (1998) describe linear regression as a tool for exploring the relationships between a response variable (y) and a single explanatory variable (x). The explanatory variable can be non-random, for instance a measure of time and in such cases the analysis of the relationship between the explanatory and response

variable becomes an analysis of temporal trends. A simple linear regression model is described by the equation below:

$$Y = a + bX$$

Where; a , is the Intercept X , is the independent variable, b is the rate of change of Y with each change in variable X , while b , defines the magnitude by which the independent variable must be amplified each time to obtain the value of the dependent variable Y .

The F-statistic is used to determine whether the relationship between the dependent (flow) and independent (rainfall) variable occurs by chance. The hypothesis being tested is that there is no relationship between the response (flow) and predictor (rainfall) variable. The significance of a relationship is tested against the F-statistic at a predefined alpha value ($\alpha = 0.01$) for a measure of (371) degrees of freedom for 31 years rainfall and flow data. The alpha value is used to indicate the probability of erroneously concluding that there is a relationship. The number of x-variables defines the degrees of freedom in which case (for a simple linear regression) the degrees of freedom of the numerator equal 1. The degrees of freedom of the denominator (mean square error) are defined by differences between sample size and the number of x-variables plus one. The F-statistics is computed using the model;

$$F = \frac{\sigma_T^2}{\sigma^2}$$

where, σ_T^2 is the variance due to treatment, and σ^2 , is the crude variance of all the observations in the experiment, and σ is the variance. The decision rule is determined by comparing F_c (calculated) with a F_e (expected) at $\alpha = 0.01$. If F_c (calculated) is

significantly greater than F_c (expected) at ($\alpha = 0.01$) significance level in order to confirm or reject that there is homogeneity between means of precipitation and flow. Since the mode of distribution is at 1.0, when $\sigma_F^2 = \sigma^2$, which indicates that treatments are merely due to chance, and that all the samples from that same population have the same sample mean, which equals the population mean that results, shows the distribution to gravitate around 1.0 - which indicates a positive skew of the distribution.

The closer the ratio of F_c is to 1.0, the greater the chance that the random variable F_c is in the β region below the critical level. The F-statistic for the monthly rainfall and monthly flow for the 31-years of continuous data (1970 to 2000) was analyzed in a statistical package for social sciences (SPSS), before the $F = \frac{\sigma_F^2}{\sigma^2}$ for the two periods of rainfall and flow was calculated. A conclusion that there is a relationship among the variables being investigated is valid when the F-statistic calculated is greater than F-value. The results are presented in Table 5.4.

4.6.4 Time series analysis of 31-years continuous data of rainfall and flow

A time series has been defined as a collection of quantitative observations that are evenly spaced in time and measured successively (Senter, 2004). Monthly rainfall and monthly flow data provide some of the climate and hydrologic parameters that are quantitatively observed, seasonally monitored and periodically forecasted. This is done with an aim of understanding their trend (linear or quadratic) and seasonality (a trend that repeats itself systematically over time). In this study it is assumed that a 31-

year time series of rainfall and flow is sufficient to determine both the trend and seasonal pattern.

The time (stochastic observations) and frequency (for periodic and cyclical observations) domains are used in analysing the 31-years of monthly rainfall and flow. The time domain is analysed using the ARIMA (Auto-Regressive, Integrated, Moving Average) model. The ARIMA technique deploys the running mean and detrending methods to detect and remove autocorrelation in the observations. Spectral analysis and periodogram analysis are used in examining the periodicity and cyclicity (frequency domain) of rainfall and flow.

This analysis made use of Excel and the Statistical Package for Social Science (SPSS) computer software programmes. Monthly rainfall and flow for 31-years (1970 to 2000) is plotted against time (372 data point) in Figure 5.13a and 5.14a. Both the rainfall and flow data sets were inspected for either linear or quadratic trends by investigating whether the slope from the computed linear equation is significantly different to zero. Using the simplest linear equation $y = x + b$, where b is the random shock of the data set, the linear equation for the observed rainfall is $y = 0.0357x + 95.466$ and for the flow it is $y = -0.0007x + 21.297$. It is observed that with a slope of 0.0357, there is a linear trend in the observed rainfall. There is, however, no significant linear trend in the observed 372 monthly flow since the computed slope is -0.007. The 372 monthly rainfall recording were detrended to eliminate a linear or quadratic trend. Use was made of a log transformation to stabilise the mean and variance.

Seasonality is analysed in the autocorrelation function (ACF) and correlogram. The residuals are denoted by the equation (Senter, 2004):

$$r_k = \frac{\sum_{t=1}^{N-K} (x_t - \bar{x})(x_{t+k} - \bar{x})}{\sum_{t=1}^N (x_t - \bar{x})^2}$$

4.6.5 Wavelet analysis of rainfall and flow in Kano Plain

Wavelet analysis is becoming a common tool for analyzing localized variations of power spectra within a time series (Torrence and Compo, 1998). Torrence and Compo (1998) postulate that through decomposing a time series into time-frequency space, one is able to determine both the dominant modes of variability and how those modes vary in time (Torrence and Compo, 1998).

The wavelets mathematical functions divides the time series data into different frequency components, and each component is studied at a resolution matched to its scale. Wavelet analysis is a tool well suited to the study of multi-scale, non-stationary processes occurring over finite spatial and temporal domains (Lukiya, 2003), and it has found a wide application in different fields of earth sciences. A number of scientists have successfully made use of this analysis tool (Myers *et al.*, 1993; Weng and Lau, 1994; Gollmer *et al.*, 1995; Mpeta, 2002 and Lukiya, 2003) to measure the climate dynamics, especially how the ocean temperature and the wind pattern influence rainfall and flow in Africa.

Researchers have used Fourier Transformation (FT) in detecting periodic signals in stationary data sets. However, FT can not provide information on changes in

frequency with time. A wavelet transform gives such information and a slow or fast oscillation that may have taken place at certain times may be detected. Wavelet Transform (WT) normally allows wavelets to be scaled to match most of the high and low frequency signals so as to achieve the optimal resolution with the least number of base functions. This means WT has the ability to resolve a time series within the frequency domain. WT has advantages over traditional Fourier methods in analyzing physical situations where the signal contains discontinuities and sharp spikes (Torrence and Compo, 1998).

The use of wavelet transform is not unique in this study area. The methodology has successfully been used in numerous studies in that include tropical convection, the El Nino-Southern Oscillation (ENSO), atmospheric cold fronts, the dispersion of ocean waves and wave growth and breaking. Although there has been lack of quantitative results by some studies, which portrayed wavelet transform as a diversion that produces colorful pictures Torrence and Compo (1998) and Torrence and Webster (1999) have noted that the use of wavelet interactive programme provide an easy to use wavelet analysis approach that yield quantitative description of wavelet spectrum density. In addition the approach allow for the testing of statistical significance. The Morlet Wavelet Function among other functions is used, and the transform is performed in Fourier Space using the method described in Torrence and Webster (1999). Each time series is padded with zeros in order to reduce the wraparound effects. The Morlet Wavelet used in this study consists of a complex exponential modulated by a Gaussian envelope:

$$\psi_0(\eta) = \pi^{-1/4} e^{i\omega_0\eta} e^{-\eta^2/2}$$

where Ψ is the wavelet value at non-dimensional time η , and w_o is a nondimensional frequency (wavelet number), which is the basic wavelet function.

The wavelet scales is almost identical to the corresponding Fourier period of the complex exponential, and the terms “scale” and “period” is used synonymously. The “scaled wavelets scale” is defined as:

$$\psi\left[\frac{(\eta - \eta_0)\delta t}{s}\right] = \left(\frac{\delta t}{s}\right)^{1/2} \psi_o\left[\frac{(\eta^i - \eta)\delta t}{s}\right]$$

Where s is the “dilation” parameter used to change the scale, and n is the translation parameter used to slide in time. The factor of $s^{-1/2}$ is normalization to keep the total energy of the scaled wavelet constant. When given a time series X , with values of X_n , at time index n , each value will be separated in time by a constant time interval dt . The wavelet transform $W_n(s)$ is referred to as the inner product (or convolution) of the wavelet function with the original time series denoted with the function:

$$W_n(s) = \sum_{m=0}^{N-1} x_m \varphi^* \left[\frac{(n^i - n)\delta t}{s} \right] \quad (\text{Torrence and Compo, 1998})$$

Where the asterisk (*) denotes complex conjugate. The above integral can be evaluated for various values of the scale s (usually taken to be multiples of the lowest possible frequency). It also includes all values of n between the start and end dates, which allow a two dimensional picture of the variability to be constructed by plotting the wavelet amplitude and phase. The wavelet power spectrum is defined as the absolute value squared of the wavelet transform and gives a measure of the time series variance at each scale (period) and at each time. To test the significance of peaks in the wavelet power spectrum, a background Fourier spectrum is chosen, while non-stationary changes in variance is tested through choosing the global wavelet spectrum (GWS), given by the time average of the wavelet spectrum. The results are presented in Section 5.2.8 of Chapter 5.

4.6.6 Correlation analysis

The measure of association between two variables is computed using correlation analysis. The coefficient of correlation (r) is defined by the following formulae:

$$r = \frac{S_{xy}}{S_x S_y}$$

Where S_x , S_y and S_{xy} are standard deviations of x , y and their product (xy) respectively. Correlation analysis is used in this study to investigate the relationship between rainfall and the Nyando River flow. The results are presented in Section 5.2.9.

4. 6.7 Analysis of flood frequency and magnitude in the Kano Plain

Flood frequency and magnitude was analyzed by means of the use of a probability model using the Weibull Probability Plotting Position, which Kumar (1993) contends has been successful in analyzing flows in both large and small basins in India. It has been used in the present study to compute the recurrence interval of flows from a 31-year time series for the hydrological period between 1970 and 2000. The Weibull Model is described as below:

$$P = \frac{m}{N+1}, \text{ and } T = \frac{N+1}{m} \text{ is the recurrence interval;}$$

Where m is the flood ranking; (N) is the total number of peaks [the number of years of record], and p is the probability of an event (floods). Detail of the results is presented in Section 5.2.10.

4. 6.8 Analysis of anecdotal (perceptions of households) data

The fourth objective of this study is to describe the anecdotal data in order to support the impact assessment of flooding characteristics on cotton cultivation in the study area. The anecdotal data were first coded before they were used as input into a Statistical Package for Social Science (SPSS). The analysis made use of descriptive statistics where individual responses (variables) were generated in frequency tables, while cross tabulation was used to compare more than two cases. The analysis captured the number of times (frequency) the respondents (households) responded (citing) to a specific answer that is listed in the structured questionnaire. The frequency (percentage) of responses to the specific issues on flooding and cotton cultivation is summarized in tables and graphs, and is relied upon heavily in the presentation of anecdotal results in Section 5.3 of this study.

4. 7 Limitation of the field research

It is important, in general, to emphasize at the outset that in any research study, whether in social, physical and natural sciences, the cost and time spent in carrying out research poses great limitations. Tashakori and Teddlie (1998) contend that research data in physical and natural sciences is a lot more difficult to obtain, verify and analyse than in social sciences. Indeed, physical and natural sciences are specific, and are more unstable in relation to many social conditions. This makes the process of data gathering relatively difficult in the physical sciences as there are many cases of inconsistencies of the data sets that occasionally requires the use of selective models to test for their reliability. Similarly, a few instances of missing data especially monthly rainfall data for Kano (IGD03) gauging station were witnessed. The December rainfall records for the period under investigation are suspicious, and this

affected the annual average rainfall. Also, most of the rain gauge stations upstream were found to be non-operational and there was a general lack of recent records, since the majority were destroyed during the 1996/1998 El-Nino related weather changes associated with the destructive floods in Kenya (Njogu, 2000; ICRAF, 2001).

The majority of the surveyed cotton farmers have not kept records of their farm activities; hence it was difficult to assess farm sizes, cotton output, use of inputs, as well as consistency in cotton production by individual households. This problem was however, solved by seeking information about output and cotton inputs sold to farmers by officials of the Lower Kano Cotton Co-operative Societies, the Area Chief, and the Kisumu District Agricultural Research and Extension officers. The missing data was mainly derived by means of interpolation through computing averages with other stations within the basin. ICRAF provided data for the five rain stations (Kipkure, Coreng, Kaisugu, Kibwari and Ahero (Kano) that are used in measuring the spatial variation of rainfall within the basin.

4.8 Summary

This chapter set out to present the detailed procedures and data sets that were used to conduct this study. Both qualitative and quantitative approaches have been explored in data acquisition and analysis of the characteristics of the drainage basin as well as in computing the variability in rainfall and flow. Flood frequency, magnitude and the trend of rainfall and flow was part of the quantitative research methods used, while anecdotal data was used in as a qualitative assessment of the impact of flooding characteristics on cotton cultivation.

CHAPTER 5: ANALYSIS, INTERPRETATION AND PRESENTATION

5.0 Introduction

This chapter presents an analysis and interpretation of the results of the study as subsumed under the three broad objectives that the study set out to investigate. The chapter begins by describing the physical characteristics and areal variability of rainfall in the Nyando River Basin.

5.1 The physical characteristics of the Nyando Basin

The physical characteristics of the Nyando River are illustrated in the Digital Elevation Model (DEM) in Figure 5.1. The network of the streams flowing within the Nyando Basin (Figure 5.1) are evidently from the upland (upstream) and discharge downstream through joining the wider channel (Nyando River) that empties into Lake Victoria. Although it is not within the scope of this study to examine the geomorphic characteristics of the stream network and there contribution to flow it is worth pointing out from the previous literature that the observed hierarchy of streams contributes together to the volume of discharge downstream (Jolly, 1982; Aryadike and Phil-Eze, 1989; Breinlinger *et. al.*, 1993; Jensen, 1999 and Nogami, 1995).

The impact of flow that exceeds the channel capacity of Nyando River in the plain has been noted to be controlled by numerous fluvial processes that interrupt the long profile of the river and flow over time (ICRAF, 2006). It is speculated in this study that the changing regime of rainfall and flow, and subsequent floods draw there spontaneous physical characteristics from the response of the Nyando River Basin.

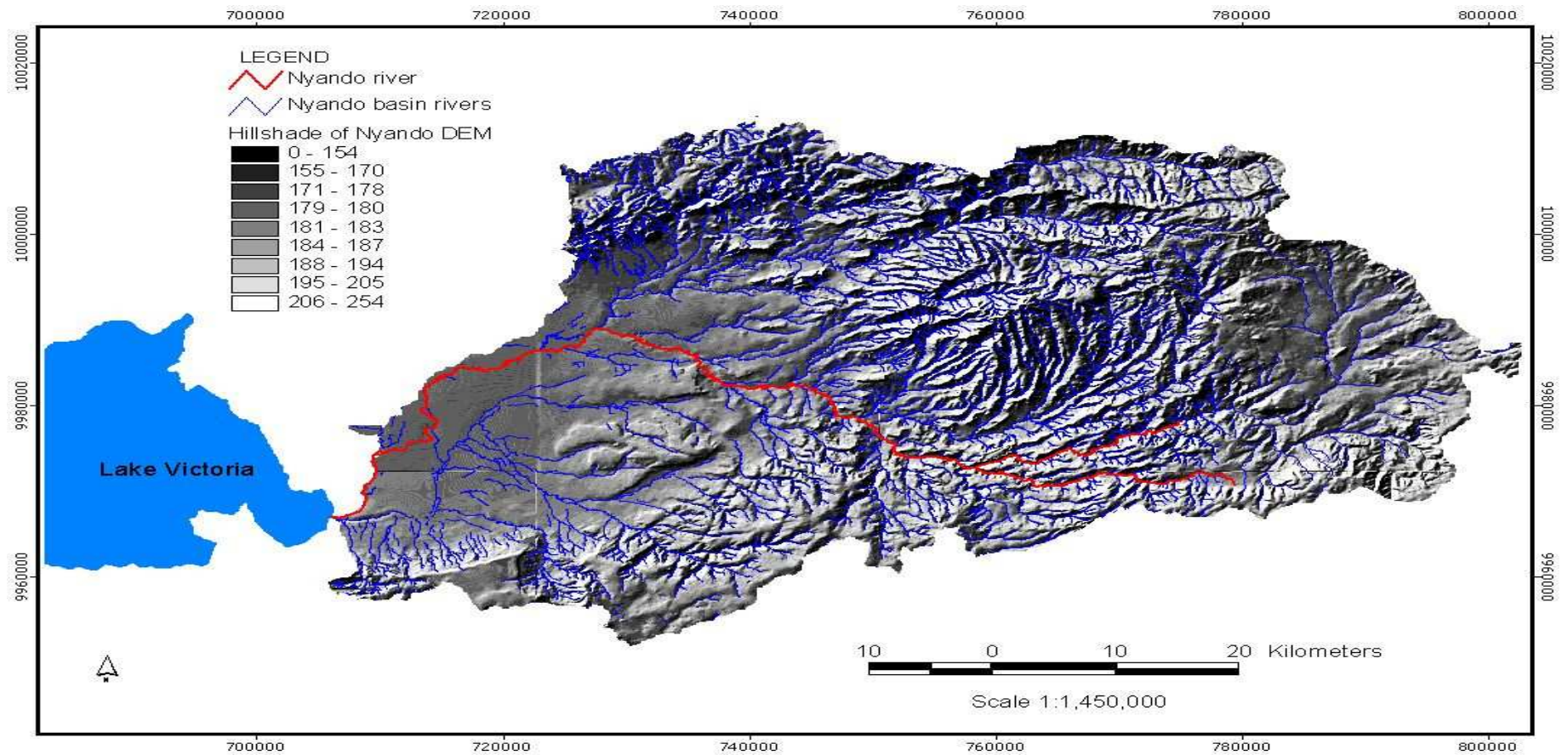


Figure 5.1: The DEM of the Nyando Basin showing stream density

Other reports, such as those by NEMA (2004) and the ICRAF (2006), note a possible shift in the channel downstream, which results in the intrusion of floods into the dry cultivable land in the lower reach. This finding is observed to correspond with the results of a study on the rate of erosion and sediment yield by the river's draining into Lake Victoria. It was found that the Nyando River recorded the highest rate of turbidity (Figures 5.2) and contributed the largest tonnage of sediment over the past four years (NEMA 2004; ICRAF 2006) relative to other rivers. The increasing rate of turbidity and sediment yield by the Nyando River as ascribed by previous studies is evidence to support the hypothesis that there is continued catchment degradation, which has exacerbated erosion as a result of runoff. This is further evident by the amount of estimated sedimentation rate which had the highest peaks recorded in 1964, 1986 and 1997. It is therefore not coincidental that the variability of rainfall and flow regime presented in this chapter has so far revealed that these are also some of the highest flow peaks of the Nyando River during the hydrologic period between 1970 and 2000.

The high yield of sediment into the channel is argued in this study to lower the river depth and hence reduces the streams competency to carry sediment further downstream. The deposition of sediment in the Nyando River over time raises the river bed, and reduces its ability to discharge the excess flow downstream, which exacerbates inundation of the floodplain causing damage.

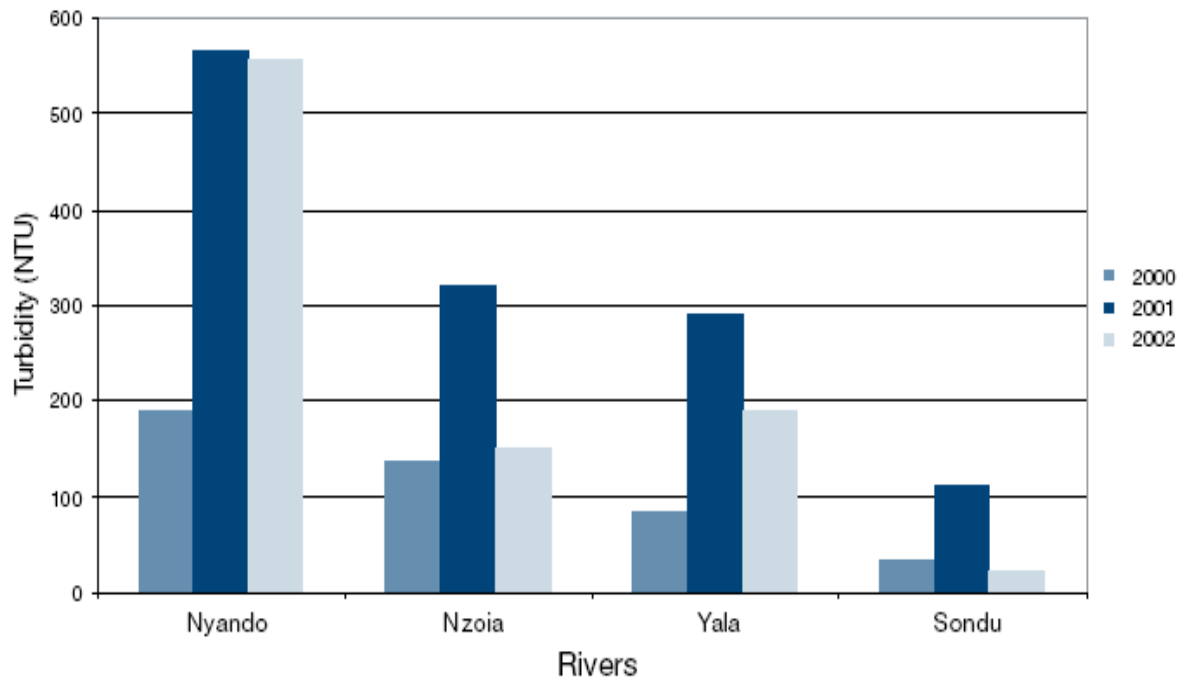


Figure 5.2a: Turbidity of four rivers draining into Lake Victoria in Kenya

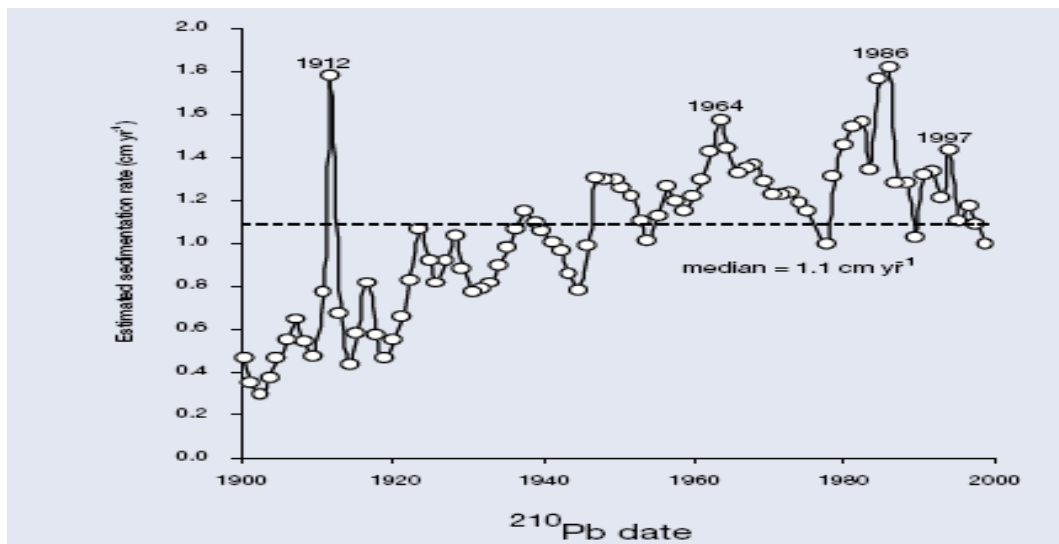
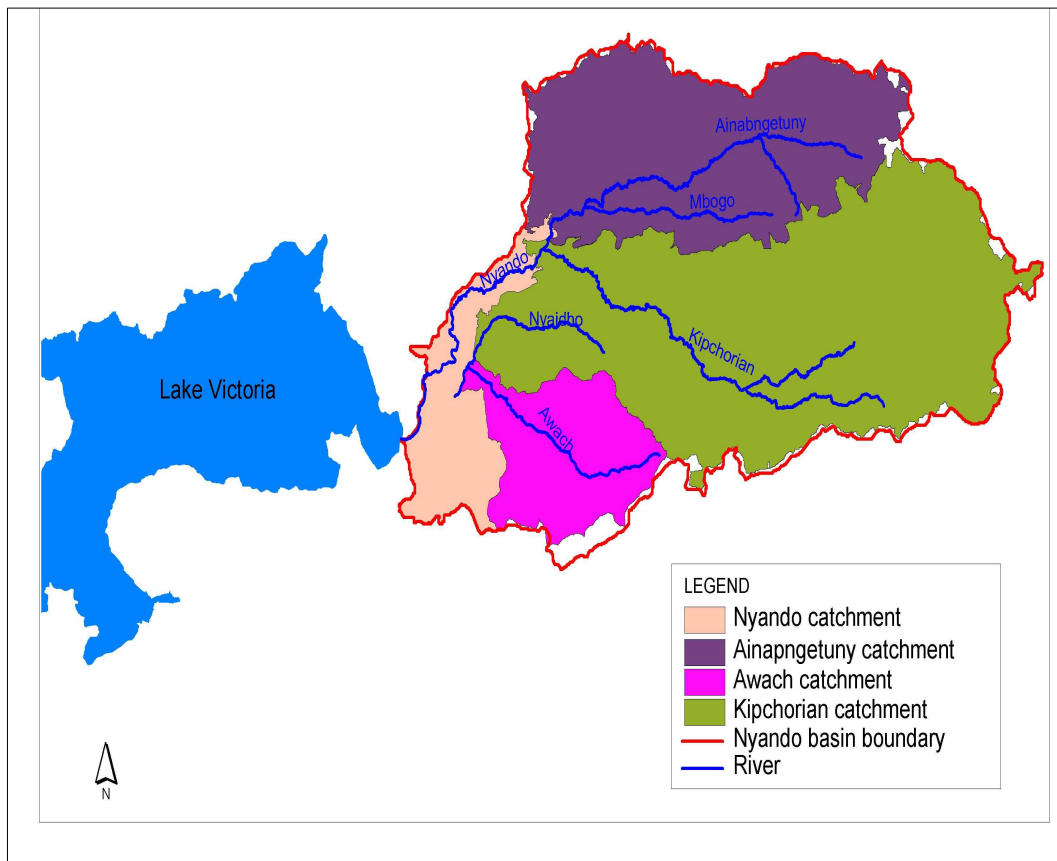


Figure 5.2b: Sediment yield by the Nyando River into Lake Victoria

Source: ICRAF (2006)

5.1.2 The areal rainfall characteristics over the Nyando Basin

The areal mean rainfall of the basin is computed from the five rain gauge stations that are located within or very close to the sub-catchments of the Nyando Basin boundary (Ainabgetuny, Kipchorian, Awach and Nyando) presented in Figure 5.3. These stations have at least 29 years of consistent monthly precipitation record (1970 to 1998).



Source: ICRAF, 2001

Figure 5.3: The sub-catchments of the Nyando Basin

The monthly rainfall data acquired from eleven rain gauging stations (Figures 5.4a) are evenly distributed over the basin. For purposes of this study only five stations (Figure 5.4b) that had consistent monthly rainfall data were used for the analysis of rainfall variability as demonstrated in Table 5.1.

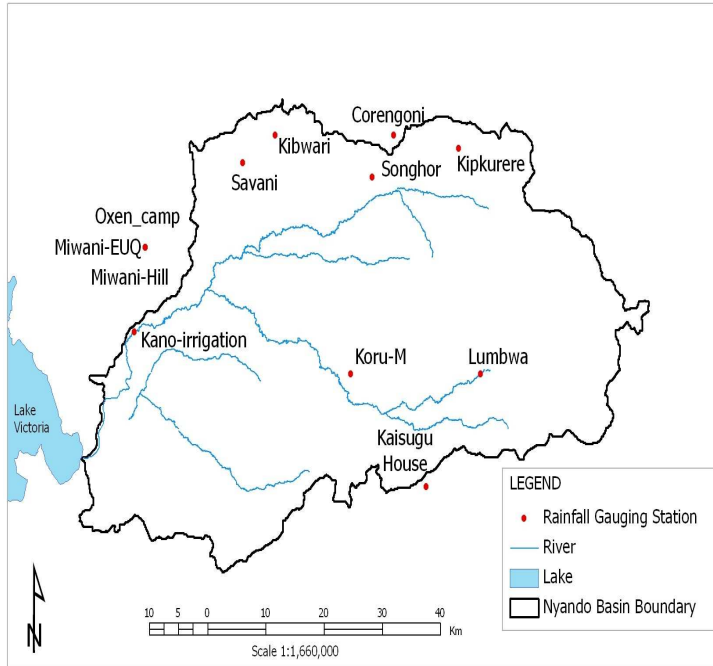


Figure 5.4a: Distribution of the 11 rain gauge stations in Nyando River Basin

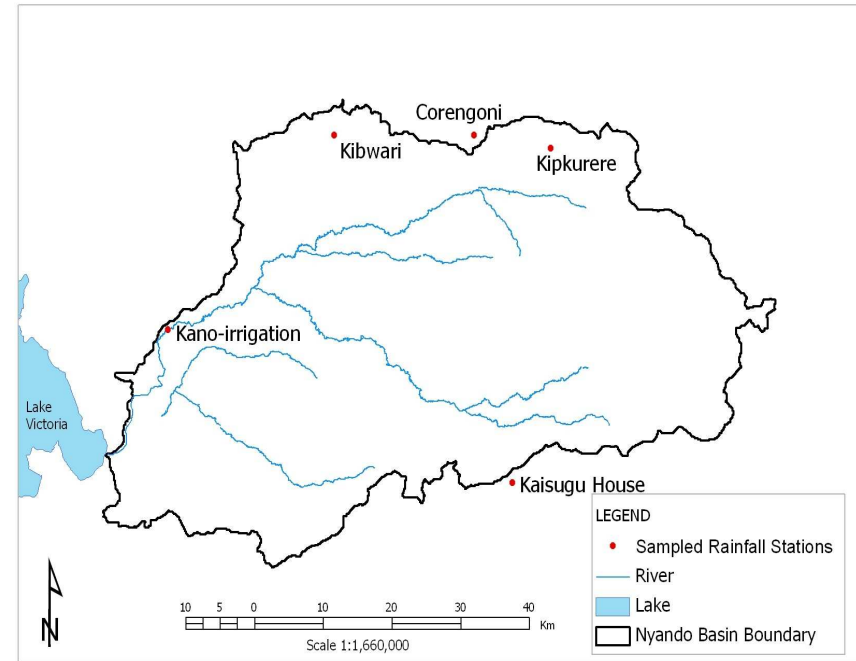


Figure 5.4 b: Sampled rain gauge stations for analysis

The areal distribution of rainfall as shown in Figures 5.4a and 5.4b are supplemented by the use of Thiessen Polygon described in Section 5.1.3 and summary statistics in Table 5.1.

Table 5.1: Statistical parameters of annual rainfall for 5 rainfall stations in the Nyando Basin

Station	Period of record	Altitude (m.a.s.l)	Mean rainfall (mm)	Total Annual Rainfall (mm)	Std. Deviation	CV (%)	Max (mm)	Min (mm)
Kano	1970-1998	1159	102.25	2859.00	13.51	13	131.58	81.17
Kibwari	1970-1998	2048	116.25	3371.32	21.23	18	177.84	69.67
Kaisugu	1970-1998	2144	143.69	4167.28	24.08	17	179.82	92.99
Corengoni	1970-1998	2458	101.24	2936.01	22.03	22	154.45	47.96
Kipkurere	1970-1998	2346	98.49	2856.46	23.52	24	153.89	41.95

Annual rainfall average for Kano, Kibwari, Kaisugu, Corengoni and Kipkurere are 102.25, 116.25, 143.69, 101.24 and 98.49 mm with coefficient of variations of 13, 18, 17, 22 and 24 % respectively, showing a weak inter-annual and spatial variability in the catchment.

The computed coefficient of determination (r^2), which is the proportion of the variability in total annual precipitation explained by the mean altitude of the rain gauge stations (Figure 5.5), is poor (2.8%), which confirms the convective influence of the rainfall pattern in the study area. Besides, the weak, r^2 shows that each of the 5 rainfall stations exhibits similar characteristics except for the magnitude for most of the period. Kaisugu had the highest rainfall and Kipkurere displaying low rainfall.

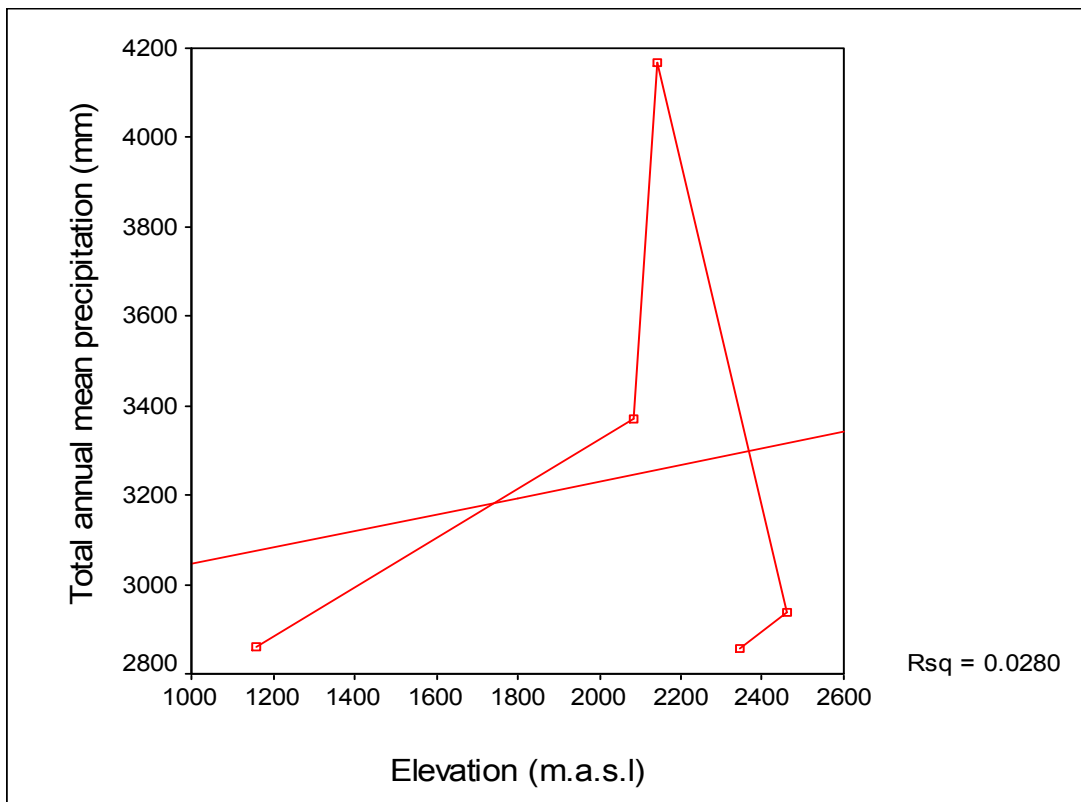


Figure 5.5: The topographic influence on annual rainfall

The variability of the mean annual rainfall in the Nyando Basin is shown in Figure 5.5. There is generally high rainfall totals recorded from the high altitude catchments in the northern part of the Nyando Basin that are predominantly highland zones that experience relief rainfall compared to the low artificial convective rainfall characterized in the low altitude in the southern parts of the catchment that stretches to Lake Victoria (Figure 2.2). The high precipitation and discharge into the Nyando River downstream have a greater volume originating upstream that occasionally overtops the river banks and inundates the dry cultivable land. The continued runoff into the dryland in Lower Kano Plains has caused destruction.

There is a weak correlation between altitude and annual rainfall in the Nyando Catchment as revealed by the computed coefficient of determination ($r^2 = 0.0280$). The weak correlation demonstrates that the cyclic characteristics and pattern of rainfall in the Kano Plain is highly convective. The convective characteristic of precipitation in the Kano Plains is largely the interaction of the lake and land breeze that modulates the weather patterns around the Lake Victoria region and Kano Plains causing afternoon storms characterised by lightening and thunderstorms (Anyah *et al.*, 2003).

5.1.3 Areal distribution of rainfall in the Nyando Basin using Thiessen Polygon

Thiessen Polygon has widely been used as one of the objective methods of interpolating rainfall depths over an area (Cheung *et al.*, 2008). In this study the method involved weighting rainfall measurement at individual gauges by the fraction of the catchment area that is represented by the gauges, and then summed as described in the previous chapter (Shaw, 1994, Cheung *et al.*, 2008). The tabular attributes of

Thiessen Polygon is summarized in Table 5.2, whereas the configuration of rain gauge stations is plotted on the catchment map as shown in Figure 5.6.

Table 5.2: The Attributes of Area from Thiessen Polygon

Station Name	Latitude	Longitude	Area (Sq.Km)	Precipitation (mm)	Perimeter (km)	Precipitation Area (km)
Kano-irrig	-0.15	34.933	1196.1	102.3	149656.1	12230.4
Corengoni	0.083	35.333	408.7	101.2	86176.3	41381.9
Kipkurere	0.067	35.433	358.9	98.5	82645.0	35347.2
Kibwari	0.083	35.15	756.5	116.3	123400.5	87946.2
Kaisugu	-0.333	35.383	969.6	143.7	126314.4	139329.6

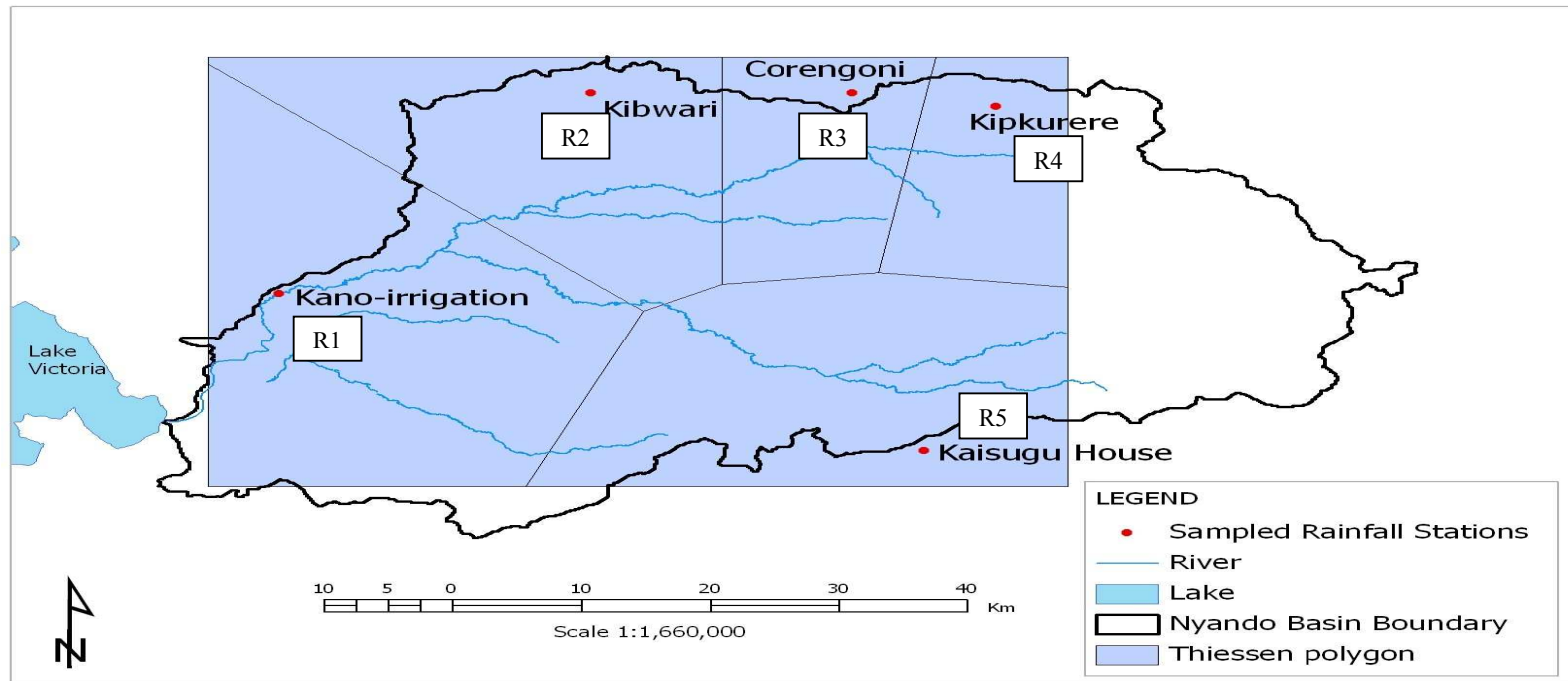


Figure 5.6: The hydrographic basin with the Thiessen Polygons distribution.

The polygons are showing the precipitation area of Kano (R1), Kibwari (R2), Corengoni (R3), Kipkurere (R4) and Kaisugu (R5) rainfall stations in the Nyando Basin. The calculated mean rainfall is 115.54 mm (Table 5.2).

5.1.4 The Runoff Coefficient of the Nyando River Basin

This description of the runoff capacity of the catchment is illustrated by computing the ratio between runoff and rainfall, commonly referred to as runoff coefficient. The monthly flow data for the Nyando River at two flow gauging stations, one (1GB03) upstream, and one (1GD0) downstream, was converted from m³/sec to mm/year. The area of the basin discharging through the two gauge points is used as the catchment area. The results are shown in Table 5.3a.

Table 5.3a: River Basin Runoff Coefficient for the period between 1970 and 1998

Flow Station	Catchment Area (Km ²)	Mean annual runoff (mm)	Annual Basin Rainfall (mm)	Runoff coefficient (%)
1GD0	2,500.0	267.7	1,225.7	22%
1GB03	835.0	201.0	1,600.0	13%

The runoff coefficients of the Nyando Basin at flow gauge station 1GD0 and 1GB03 are estimated at 13% and 22% respectively. The findings demonstrate higher runoff coefficients (22%) in the larger catchment area. The runoff coefficient for 1GB03 for the last 31 years between 1970 and 2000 from the 10% previously computed in 1992 (LBDA, 1992).

The degradation of the catchment through heavy deforestation activities (ICRAF 2001) could have speeded up runoff, resulting in the increase in runoff coefficients. In addition, the continued human occupation and economic activities in the flood plains

have also lowered infiltration and exacerbated runoffs into the main river, thereby causing ponding of the floodplains.

The abstraction of river water for either irrigation or for use in the sugar industries, which are mostly located upstream, could also explain the variability in the mean flow, and thus a lower runoff coefficient. There is also an effort by ICRAF to restore the lost forest cover through afforestation programmes upstream. This effort could improve land cover, enhancing infiltration into the soils and hence reduce runoffs into the Nyando River upstream causing the low runoff coefficient observed in some periods especially in 1976, 1982 and 1986.

The variability of peak flow over time from the long term 31-years (1970-2000) is determined by calculating the runoff coefficient for the catchment (Table 5.3b). The coefficient is also calculated in order to assess whether there are significantly high runoffs over the period examined. Apart from this, the computed results provide an explanation for the circumstances in which rainfall yielded the computed runoffs. The runoff coefficient for each year of the 31-year record was plotted and the trend determined through fitting a regression equation (Figure 5.7).

Table 5.3b: The Runoff Coefficient of annual flow (Gauging Station 1GD04 and catchment area 2,500 Km²)

Year	Annual discharge (in mm)	Annual rainfall (in mm)	Runoff Coefficient (%)
1970	319.51	1282.10	0.25
1971	258.46	1060.80	0.24
1972	200.03	1152.30	0.17
1973	204.19	1125.30	0.18
1974	245.59	1202.20	0.20
1975	321.57	1194.65	0.27
1976	131.41	1060.65	0.12
1977	438.17	1256.00	0.35
1978	431.06	1436.70	0.30
1979	362.72	1319.90	0.27
1980	167.20	974.00	0.17
1981	249.87	1159.73	0.22
1982	245.67	1326.50	0.19
1983	272.04	1029.30	0.26
1984	85.27	1010.00	0.08
1985	291.11	1148.20	0.25
1986	101.72	1309.50	0.08
1987	123.52	1180.60	0.10
1988	512.80	1310.40	0.39
1989	332.14	1461.20	0.23
1990	407.63	1260.90	0.32
1991	223.45	1167.40	0.19
1992	247.47	1059.00	0.23
1993	128.35	1077.90	0.12
1994	391.47	1224.12	0.32
1995	215.50	1162.20	0.19
1996	551.11	1578.98	0.35
1997	221.68	1493.08	0.15
1998	339.56	1560.64	0.22
1999	230.56	1287.65	0.18
2000	47.29	1126.10	0.04

Table 5.3b shows the variation in the annual runoff for the period with discharge between 391 mm year⁻¹ and 551.11 mm year⁻¹. The 31-year rainfall and discharge results demonstrate significant inter-annual variability of the runoff coefficient that shows a general variance of 8% and 39%. The wet period (values in bold in Table

5.3b) recorded high runoff coefficients ranging from 30% to 39%, which similarly recorded a high flood magnitude that is illustrated in the sections below. Significantly high runoff coefficients were recorded in 1977 (35%), 1988 (39%) and 1996 (35%).

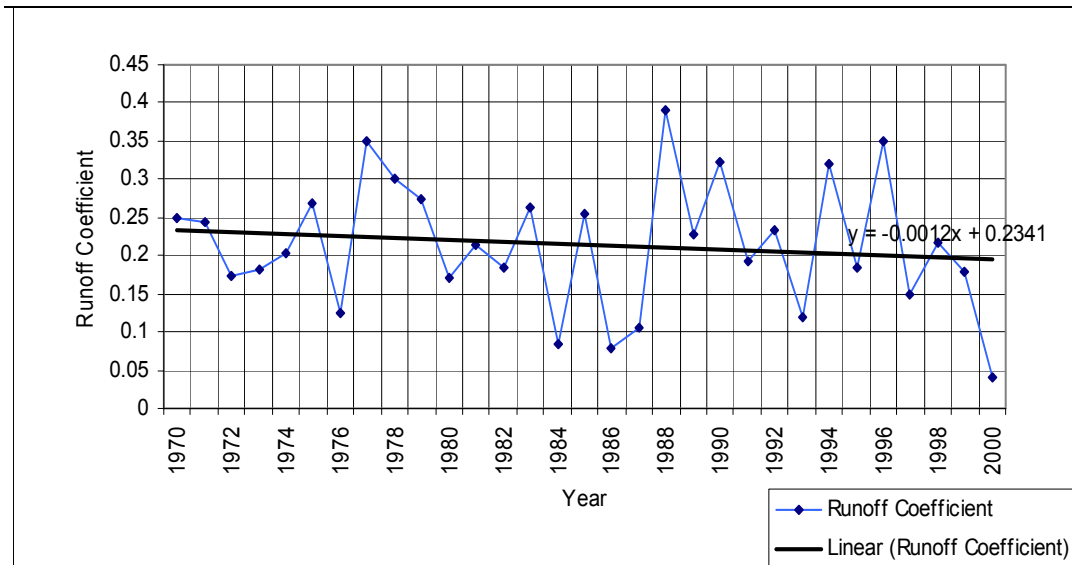


Figure 5.7: Runoff coefficient of flow of Nyando River

A plot of annual runoff coefficient over time reveals alternating periods of wet and dry years as shown in Figure 5.7. The regression equation $y = -0.0012x + 0.2341$ of runoff coefficient of 31-year time series of flow show an oscillating temporal trend that is not necessarily linear, suggesting an alternating periodicity of what ends up as runoff from the incoming precipitation. While the trend for runoff coefficient shows a declining runoff, the alternating high peak signals reveal the highly significant flow peaks in the study area. This could also be attributed to the non-random nature of time as an explanatory variable.

5.2 The impact of rainfall and flow regimen in the Kano Plains

5.2.1 Introduction

The main objective of this section is, first, to determine whether the flooding characteristics of the Nyando River have changed with time or whether they are variable in space; secondly, to describe the natural flooding regime that probably existed before extensive anthropogenic influence. The analysis of time series variability of rainfall and flow is used to determine intra-seasonal and inter-seasonal changes of flow and rainfall.

The analysis makes use of the 31-year (1970 to 2000) rainfall and flow data to investigate these variations. The flood cycle was determined by means of inter-seasonal analysis, while a 5-year moving mean was used to determine the trend and pattern in the long term time series data, and also to remove noise from data so that a smooth trend is shown.

5.2.2 Intra-Seasonal Variability of Rainfall and Flow

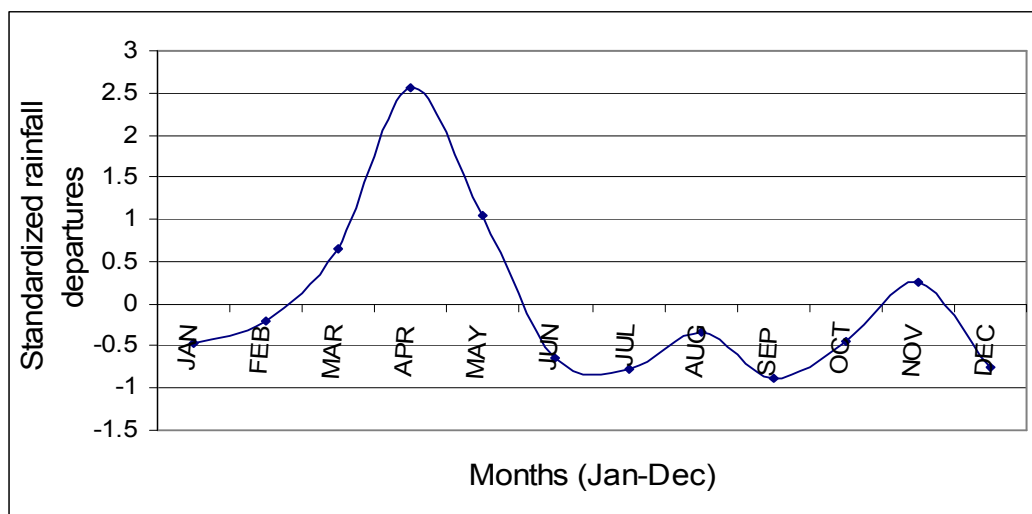


Figure 5.8a: Mean monthly deviations of rainfall for 31 year period.

Figure 5.8a reveals a bimodal nature in the seasonal rainfall. March and April (MA) represent the first rainfall cycle while October and November (ON) the second. Between June and August the first dry season is experienced, followed by another between December and February, as shown by the negative departures of the monthly normalized values.

The trend of the deviations of the monthly standardized values of rainfall and flow show positive departures that exhibit the (wet) periods and negative departures representing the (dry) period. The variability of the wet and dry periods is illustrated in Figure 5.8b.

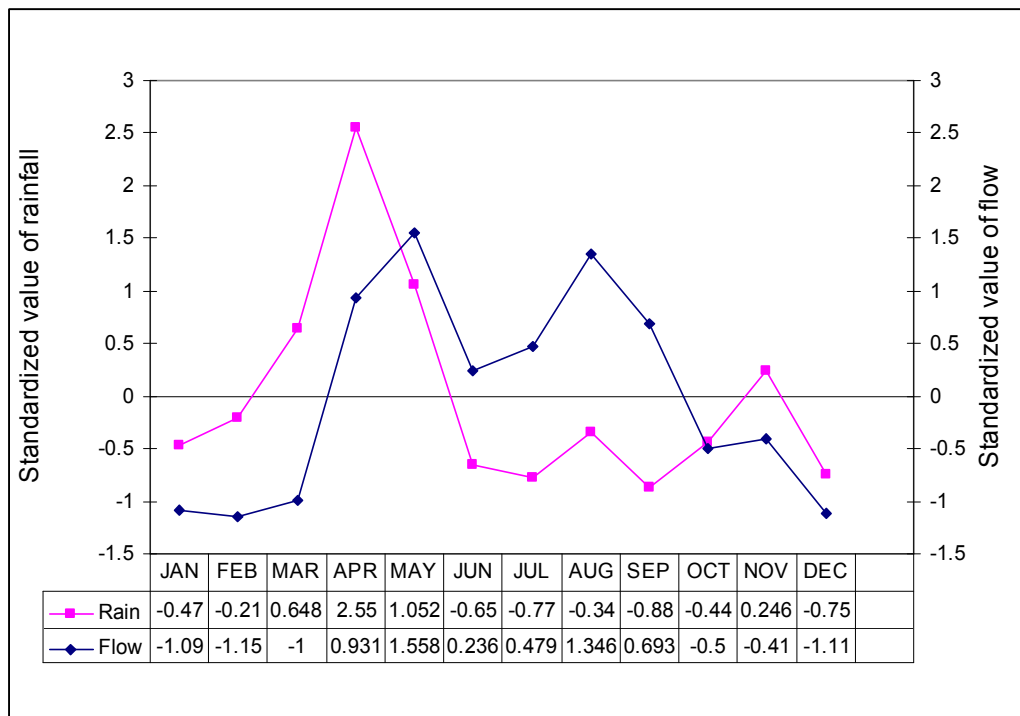


Figure 5.8b: Monthly mean cycle of rainfall and flow in the Lower Kano Plain between 1970 and 2000

The seasonal peaks for rainfall is in April and flow in May for the early (long) rains. However, the runoff peaks again in August when there is little rainfall which is the dilation effect of the long rainy periods between April and May. The peak discharge corresponds to the long and short rainy seasons. The lag time between the first peak in rainfall and the flow is one month.

5.2.3 Inter-Annual Time Series Variability of Rainfall and Flow

Inter-annual time series analysis is used to show the variability of rainfall and flow within the 31-year continuous record of stream flow and rainfall. The analysis aims at examining, first, the peak periods, and second, the association between rainfall variability on the one hand and flow on the other.

Karl and Knight (1998), in their study of secular trends of precipitation amount, frequency and intensity in the United States, acknowledge the difficulties in detecting and comparing year-to-year variability of rainfall. The variability of rainfall in the Kano Plain is shown in Figure 5.9. The standardised value exhibits periodicity of rainfall and flow, where rainfall peaks are generally observed to occur with flow peaks. However, anomalies do occur in this association between annual precipitation (rainfall) and flow.

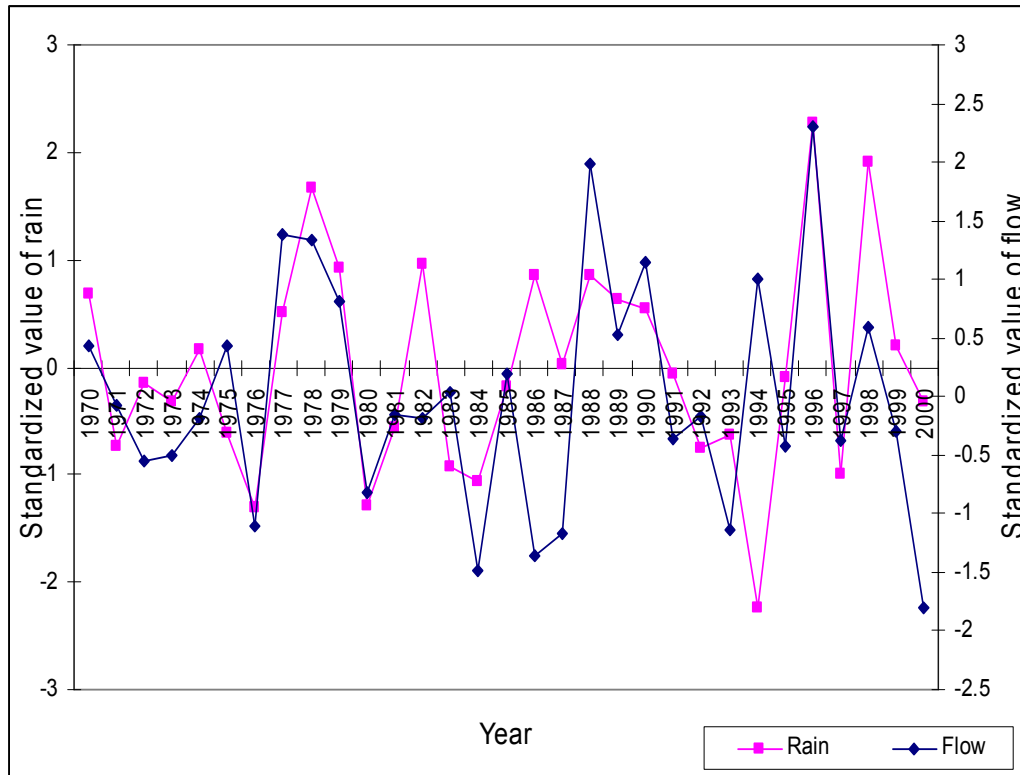


Figure 5.9: Annual mean variability of rainfall and flow at gauging station 1GD04

Inter-annual rainfall and flow time series were superimposed in order to identify the relationships. Discharge tends to lag the rainfall pattern, which indicates that flow heavily relies on rainfall characteristics in the Kano Plain. There is however, a negative departure recorded in the periods 1982, 1986, 1987 and 1994, as revealed in Figure 5.9. This variability could be attributed to, first, the afforestation programmes to improve land use in the upper catchments that contained runoff into the Nyando River. Second, the high flow recorded in 1994 despite a low rainfall is the manifestation of poor land use that exacerbated runoff, and thus increased flow. Third, the variability in the departures in rainfall and flow in the Kano Plains could be due to problems in the flow data for these particular periods.

5.2.4 Intra-Annual Variability of Rainfall and Flow

The intra-annual variability time series were constructed by recording the monthly rainfall and flow. The low rainfall and flow peaks were constructed for the periods 1976, 1984, 1986 and 1997. Results of the mean monthly departures are summarized in Figures 5.10a, 5.10b, 5.10c and 5.10d.

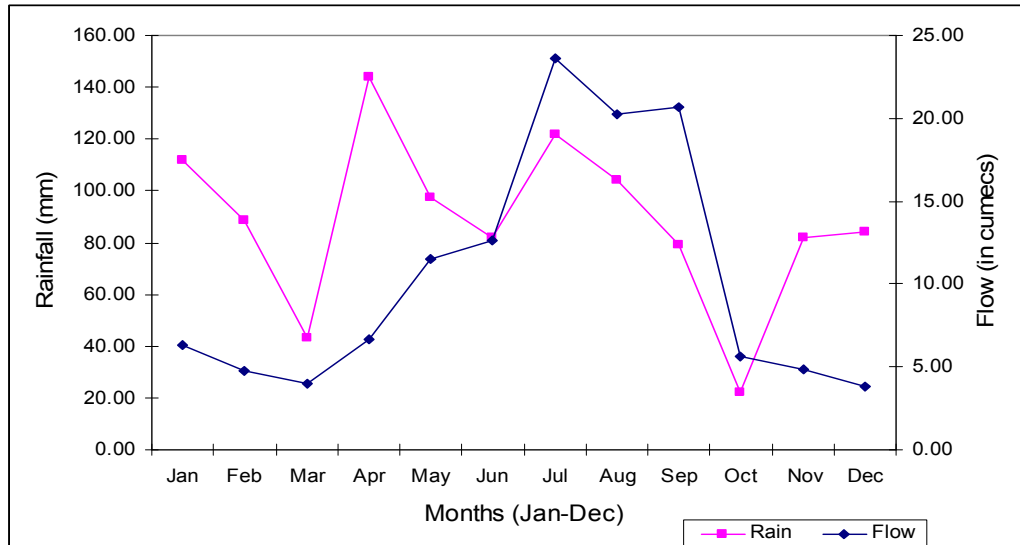


Figure 5.10a: The variability of rainfall and flow in 1976

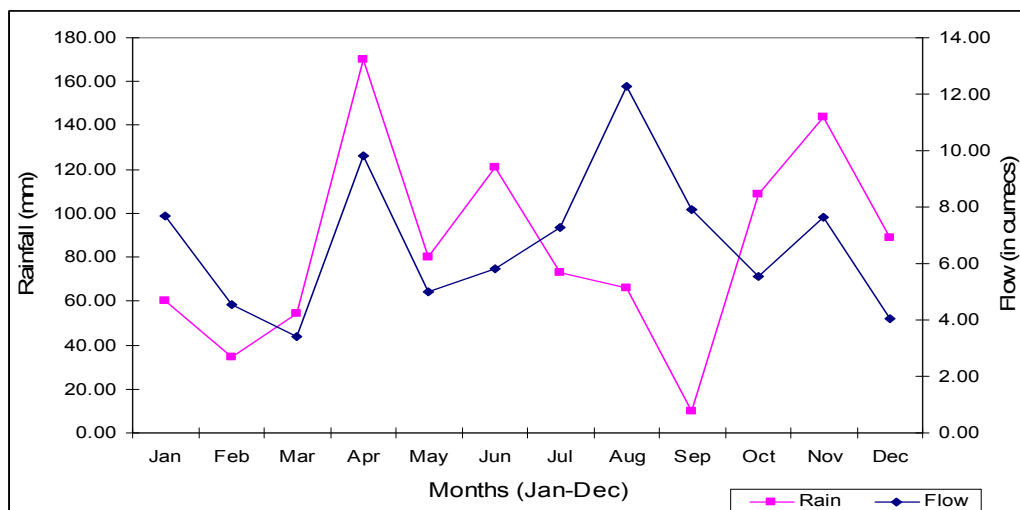


Figure 5.10b: The variability of rainfall and flow in 1984

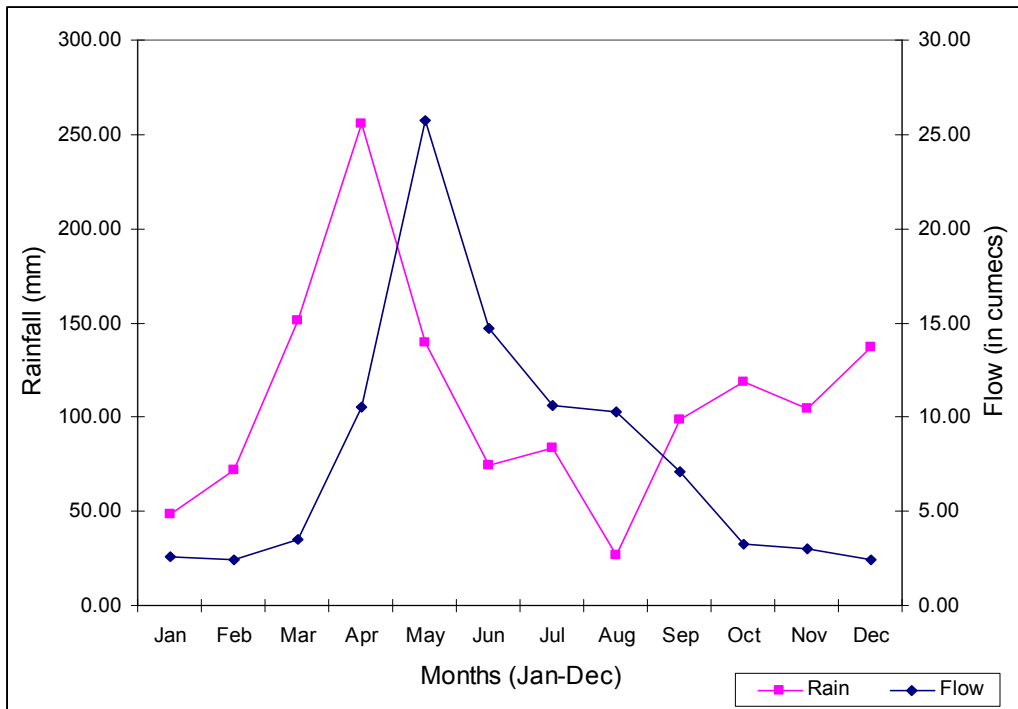


Figure 5.10c: The variability of rainfall and flow for 1986

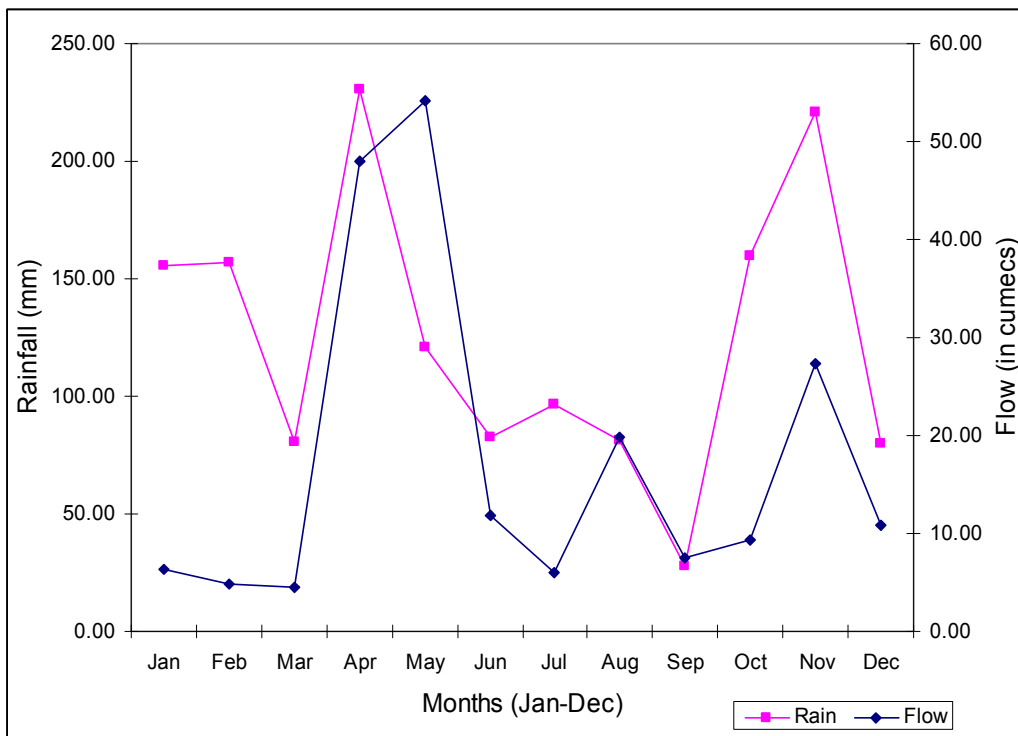


Figure 5.10d: The variability of rainfall and flow for 1997.

Intra-annual variability of rainfall and flow show a corresponding peak. Intra-annual variability of rainfall and flow shown in Figures 5.10 illustrates the differences in terms of rainfall and flow regime, and the possible lag time between the rainfall and runoff. In some years, for instance in 1976 (Figure 5.10a), rainfall exhibited three peaks: the first one being in April and the second in July. There was, however, one peak for discharge. During this period (1976) high flow generally concentrated in the third- quarter of the year (July and September).

5.2.5 The trend of flow using a 5-year moving means

The 5-year moving average was used to determine the trend of the 31-year time series data for annual rainfall and flow. Through damping out most of the random components of the annual precipitation the effects of longer term wet and dry cycles in the record is shown. The wet periods are recognised by comparing the 5-year mean line with the mean for the entire rainfall and flow record. The wet seasons (years) were determined by the 5-year moving mean lines being above the long-term mean, while the drought period was computed when the 5-year moving mean line was consistently below the long term mean.

The moving average was also used to assess to what extent rainfall explains the changes in stream flow, and thus the flooding of the Nyando River (Figures 5.11a and 5.11b).

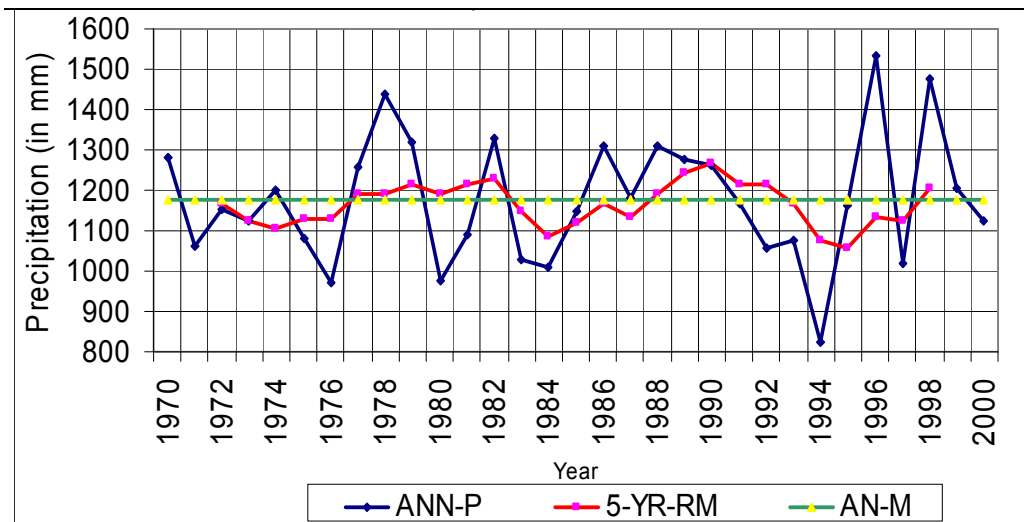


Figure 5.11a: 5-year running mean of rainfall showing the wet and dry periods

The wet years presented between 1976 and 1978, then 1988, 1990, 1994 and 1996. The wet rainy period is observed to correspond to the wet (flood) discharge period of the Nyando River, as illustrated by Figure 5.11b.

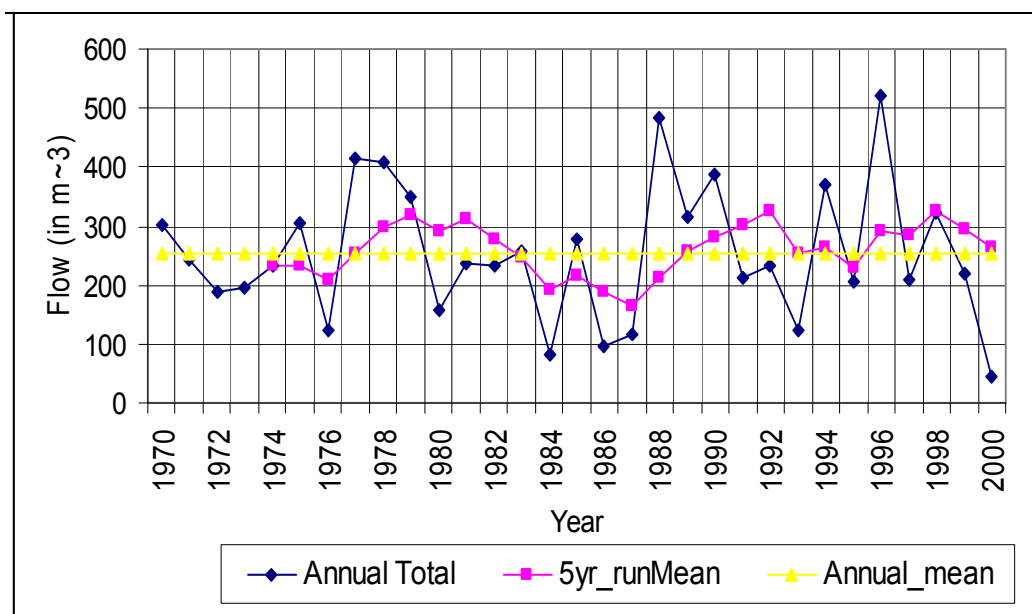


Figure 5.11b: 5-year mean showing the wet and drought discharge by the Nyando River.

A 5-year moving mean shows the means of rainfall to vary from 1171.7 mm (1970 to 1974) up to 1259.9 mm in (1975 to 1979). Likewise, the discharge exhibited a similar pattern with the annual mean increasing significantly from 239.22 m³/sec in (1970 to 1974), to 320.35 m³/sec in (1975 to 1979).

Between 1977 and 1979 both rainfall and flow have been rather steady, followed by a decline between (1980 and 1984). This was later followed by a sharp increase in the annual mean flow from 257.86 m³/sec between 1985 and 1989. Both rainfall and flow recorded high peaks between 1996 and 1998 that were also associated with greater flood magnitudes. The level of significant difference between the monthly annual rainfall and flow was calculated by means of an analysis of variance (ANOVA) as discussed below.

5.2.6 Regression Analysis of Rainfall and Flow using the F-Statistic

The analysis of Variance (ANOVA) was based on the data for 31 years of continuous

monthly rainfall and flow. The computation of $[F = \frac{Q_r^2}{Q^2}]$ was used to illustrate the relationship between rainfall and flow and also to determine whether both the hydrologic characteristics exhibited are from the same catchment (similar populations).

The F-statistic for the monthly rainfall and monthly flow for the 31-years of continuous data (1970 to 2000) was analyzed as described in section 4.6.3 in Chapter Four. The results of the analysis are summarized in Tables 5.4.

5.2.6.1 One-Way ANOVA for rainfall and flow for 31 year period

The ANOVA procedure used in this study is based upon a comparison of variance attributed to the independent variable (variable between groups or conditions) relative to the variance within groups resulting from random chance. The hypothesis being tested is that there is no relationship between the response (flow) and predictor (rainfall) variable. The significance of the relationship is tested against F-statistic at a predefined alpha value ($\alpha = 0.01$). The calculated and expected (F -value) are presented in Tables 5.4b and 5.4c.

Table 5.4a: F-statistics (ANOVA) for rainfall and flow

	Sum of Squares	df	Mean Square	F	Sig.
RAINFAL Between Groups	62510.106	30	2083.670	.558	.973
Within Groups	273380.648	341	3734.254		
Total	335890.755	371			
FLOW Between Groups	33854.216	30	1128.474	3.041	.000
Within Groups	126521.489	341	371.031		
Total	160375.705	371			

One-way ANOVA revealed that there were no significant differences in rainfall between the 31 years period, $F(1.696) = 0.558$, $P > 0.001$. The H_0 of no significance relationship between groups and within groups of rainfall in the 31 year period is accepted. Contrary, there was significant differences in flow between and within groups in the 31 year period as indicated by $F(1.696) = 3.041$, $P < 0.001$. The seasonal significance for rainfall and flow between and within groups is indicated in Table 5.4b.

Table 5.4b: F-statistics (ANOVA) for rainfall and flow between and within months in 31 years period.

	Sum of Squares	df	Mean Square	F	Sig.
RAINFALL Between Groups	62510.106	30	2083.670	.558	.973
Within Groups	273380.648	341	734.254		
Total	335890.755	371			
FLOW Between Groups	33854.216	30	128.474	.041	.000
Within Groups	126521.489	341	371.031		
Total	160375.705	371			

From Table 5.4b, One-way ANOVA revealed that there were significant differences in rainfall between the 12 month period, $F(2,185) = 14.647$, $P < .001$. The H_0 of no significance relationship between groups and within groups of rainfall in the 12 month period is rejected, and the alternative hypothesis of there is significant differences accepted. Similarly, there was significant differences in flow between and within groups in the 12 months in the 31 year period as indicated by $F(2,185) = 9.728$, $P < .001$.

The F -statistic demonstrates that the means of rainfall has no significant variability both between and within the 31 years period, although these are highly variable between and within months. Flow, however, reveals a high degree of periodic and seasonal variance, which explains the stochastic nature of floods in the study area. The significant differences in flow in both instances is attributed to the random nature of other factors that highly influence the flow of the Nyando River, and subsequent flooding even when there are no evidence of high variability in the magnitude of rainfall in the 31 years examined.

The pairwise comparisons of the means of annual rainfall and flow are computed using Duncan's Multiple Range Test (DMRT). The significant F -value computed from ANOVA table only indicates that there is a significant difference between groups for either rainfall or flow, but it does not indicate which groups in years or months are different as shown the Tables below.

Table 5.4c: Multiple comparisons of means of rainfall

				Subset for alpha = .05
YEAR			N	1
Duncan	a	1980	12	81.1667
		1984	12	84.1667
		1983	12	85.7750
		1992	12	88.2500
		1976	12	88.3875
		1971	12	88.4000
		1993	12	89.8250
		1973	12	93.7750
		2000	12	93.8417
		1985	12	95.6833
		1972	12	96.0250
		1981	12	96.6442
		1995	12	96.8500
		1991	12	97.2833
		1987	12	98.3833
		1975	12	99.5542
		1974	12	100.1833
		1994	12	102.0100
		1977	12	104.6667
		1990	12	105.0750
		1970	12	106.8417
		1999	12	107.3042
		1986	12	109.1250
		1988	12	109.2000
		1979	12	109.9917
		1982	12	110.5417
		1978	12	119.7250
		1989	12	121.7667
		1997	12	124.4233
		1998	12	130.0533
		1996	12	131.5817
		Sig.		

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.000.

The post-hoc test of comparisons of the means for groups of rainfall for 31 year period using Duncan's Multiple Range Test (DMRT) and LSD reveal that all the 31 years means were no significant different from each other besides the year 1980 and 1996 that significant difference in the means of rainfall were noted as (M= 81.17) and (M=131.58) respectively as illustrated in Table 5.4d.

Table 5.4d: Multiple comparisons of the mean of flow using (DMRT)

YEAR	N	Subset for alpha = .05							
		a	b	c	d	e	f	g	h
Duncan	2000	12	6.7525	6.7525					
	1984	12	8.0267	8.0267	8.0267				
	1986	12	9.7933	9.7933	9.7933	9.7933			
	1987	12	10.1475	10.1475	10.1475	10.1475			
	1988	12	10.3792	10.3792	10.3792	10.3792			
	1976	12	13.2050	13.2050	13.2050	13.2050	13.2050		
	1980	12	15.8283	15.8283	15.8283	15.8283	15.8283	15.8283	
	1972	12	16.2375	16.2375	16.2375	16.2375	16.2375	16.2375	
	1973	12	17.0392	17.0392	17.0392	17.0392	17.0392	17.0392	
	1995	12	17.5350	17.5350	17.5350	17.5350	17.5350	17.5350	
	1997	12	17.6383	17.6383	17.6383	17.6383	17.6383	17.6383	
	1991	12	18.2333	18.2333	18.2333	18.2333	18.2333	18.2333	
	1999	12	19.3758	19.3758	19.3758				
	1982				19.375	19.375	19.375		
	1974	1	19.415	19.415	19.415	19.415	19.415		
	1992	1	19.554	19.554	19.554	19.554	19.554		
	1981	1	19.693	19.693	19.693	19.693	19.693		
	1971	1	20.380	20.380	20.380	20.380	20.380		
	1983	1	21.476	21.476	21.476	21.476	21.476		
	1985	1		23.006	23.006	23.006	23.006	23.006	
	1970	1		25.284	25.284	25.284	25.284	25.284	25.284
	1975	1		25.377	25.377	25.377	25.377	25.377	25.377
	1989	1		26.266	26.266	26.266	26.266	26.266	26.266
	1998	1		26.941	26.941	26.941	26.941	26.941	26.941
	1979	1			29.049	29.049	29.049	29.049	29.049
	1994	1				30.931	30.931	30.931	30.931
	1990	1				32.3233	32.3233	32.3233	32.3233
	1978	12					34.0475	34.0475	34.0475
	1977	12					34.6242	34.6242	34.6242
	1988	12						40.3508	40.3508
	1996	12							43.4325
	Sig.		.072	.060	.056	.052	.053	.058	.054

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.000.

The DMRT and LSD comparisons between the means of flow (Table 5.4d) for all the 31 year period were significantly different from each other. The mean flow for the periods 1977 (M=34.62), 1978 (M=34.05), 1988 (M= 40.35), 1990 (M=32.32), 1996 (M=43.43) and 2000 (M=3.72) had significantly higher mean with the exception of the year 2000 (M=3.72) that had significantly low mean presented between the matrix *a* and matrix *h* of Table 5.4d.

Table 5.4e: Multiple comparison of monthly means of rainfall using Duncan's MRT

MONTH	N	Subset for alpha = .05				
		a	b	c	d	e
Duncan ^a September	31	70.373				
July	31	72.689				
December	31	76.596				
June	31	77.483				
October	31	86.564	86.564			
January	31	89.190	89.190			
February	31	93.762	93.762			
August	31	95.180	95.180			
November	31		109.085	109.085		
March	31			124.457	124.457	
May	31				141.061	
April	31					189.296
Sig.		.102	.121	.232	.197	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 31.000.

Table 5.5: Multiple comparison of monthly means of flow using Duncan's MRT

MONTH	N	Subset for alpha = .05					
		a	b	c	d	e	f
Duncan ^a February	31	9.2700					
December	31	9.6655					
January	31	9.8516					
March	31	10.8332					
October	31	16.0187	16.0187				
November	31	16.9200	16.9200	16.9200			
June	31		23.6126	23.6126	23.6126		
July	31			26.1332	26.1332	26.1332	
September	31				28.3626	28.3626	28.3626
April	31				30.8339	30.8339	30.8339
August	31					35.1294	35.1294
May	31						37.3338
Sig.		.160	.128	.063	.165	.081	.082

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 31.000.

The DMRT and LSD comparisons between the means for rainfall and flow (Table 5.4e and 5.5) for all the 12 months in 31 year period were significantly different from each other. September, July, December and June had significantly low mean rainfall and the highest were in March, April and May which is in agreement with the long dry spell and the wet season respectively. Similarly, significantly low flow in the Nyando River is in December, January, February and March, while higher peaks are in April, August and May. The seasonal and periodic variability of rainfall and flow regime in the study area is further discussed in Section 5.2.7.

5.2.7 Time Series Analysis of 31-years continuous data of rainfall and flow

A time series has been defined as a collection of quantitative observations that are evenly spaced in time and measured successively (Senter, 2004). Monthly rainfall and monthly flow data provide some of the climate and hydrologic parameters that are quantitatively observed, seasonally monitored and periodically forecasted.

This is done with an aim of understanding their trend (linear or quadratic) and seasonality (a trend that repeats itself systematically over time). In this study the use of a 31-year time series of rainfall and flow is sufficient to determine the trend and seasonal pattern for both rainfall and flow in the Kano Plain. The trend and pattern observed are useful in examining the flooding characteristics of the Nyando River in the study area.

The analysis of time series data for rainfall and flow, which is described in detail in Section 4.6.7 involved independently correlating the hydrological variables (rainfall and flow) with time by plotting the observed values against time. Through the visual inspection of the graphs generated a number of qualitative aspects that showed that

there is a 6 and 12-month pattern of seasonality for both rainfall (Figures 5.12a-c) and flow (Figures 5.13a-c).

Further results show no evidence of a linear trend. The study also made use of the same time series data set to perform analysis in the spectral domain, where a spectral density graph was used to explore the seasonal pattern as illustrated in Figures 5.14a, 5.14b, 5.15a and 5.15b. Further analyses of the spectral density of the first and second season for rainfall and flow are thereafter presented in Figures 5.14 in the section that follows.

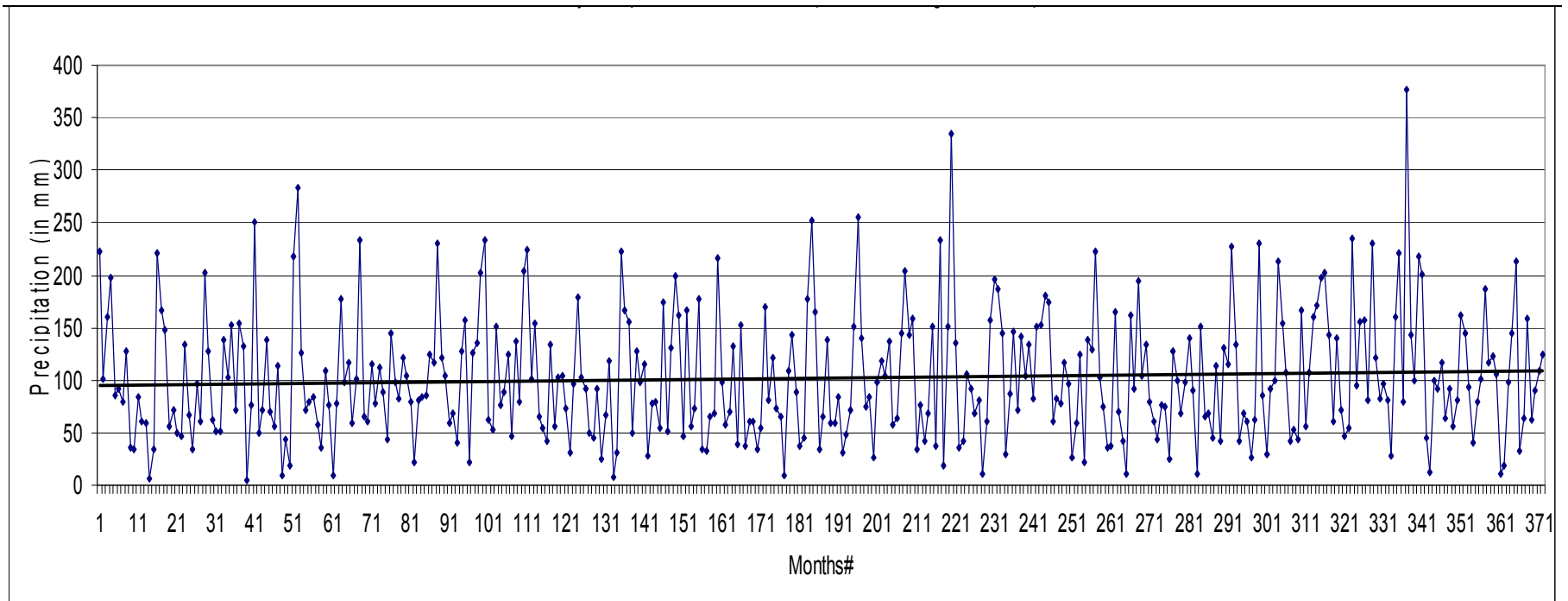


Figure 5.12a: Monthly precipitation for Kano Plains (Jan, 1970 to December 2000)

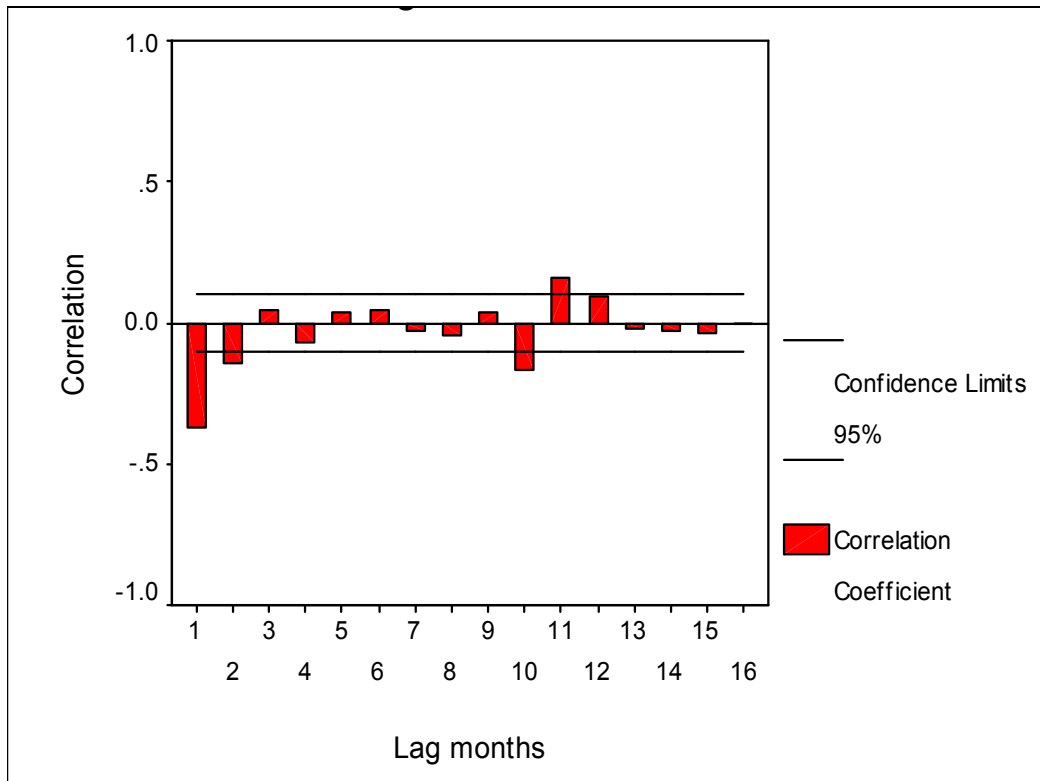


Figure 5.12b: Correlogram of monthly rainfall for station IGD04

Significant correlation is found at time lags 1, 2, 10 and 11, and very close at lag 12 at 95% confidence level. This indicates that the annual cycle is not a simple 12 month wave. The high correlation at 1 and 2 month lags suggests that the rainfall pattern is dominated by seasons (wet and dry) of two to three months.

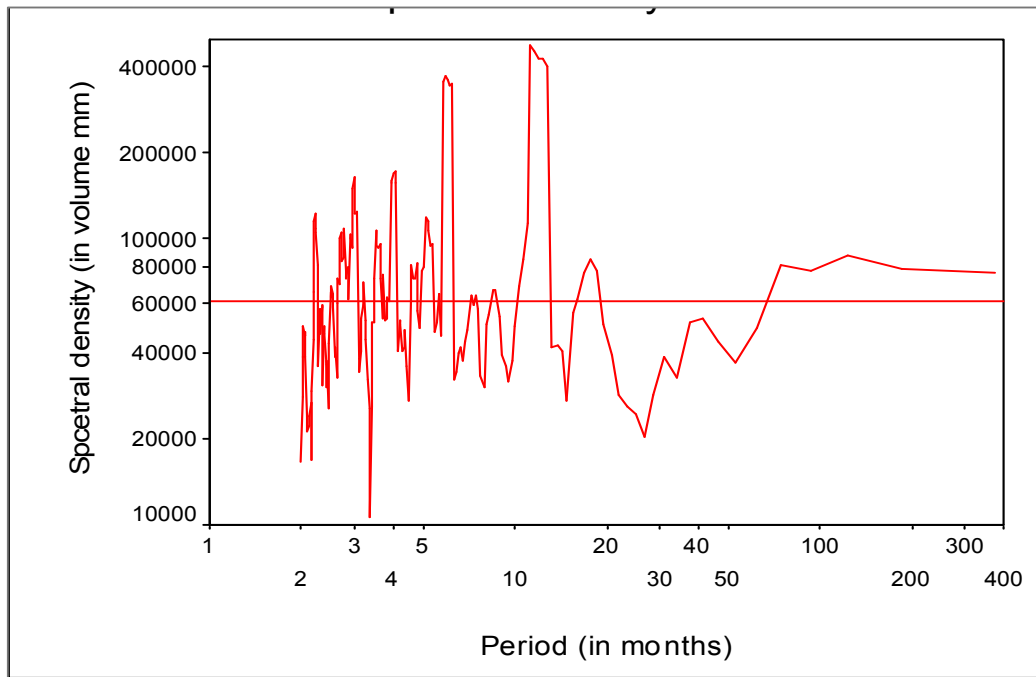


Figure 5.12c: Spectral density function for the monthly rainfall at 1GD04

The four largest peaks in the spectral density function occur at 3, 4, 6 and 12 months. There is a smaller peak at about $2\frac{1}{2}$ months which is attributed to aliasing. The peaks at 3, 4 and 6 months are all harmonics of the annual cycle and their presence indicates variability in shape and magnitude of the annual cycle.

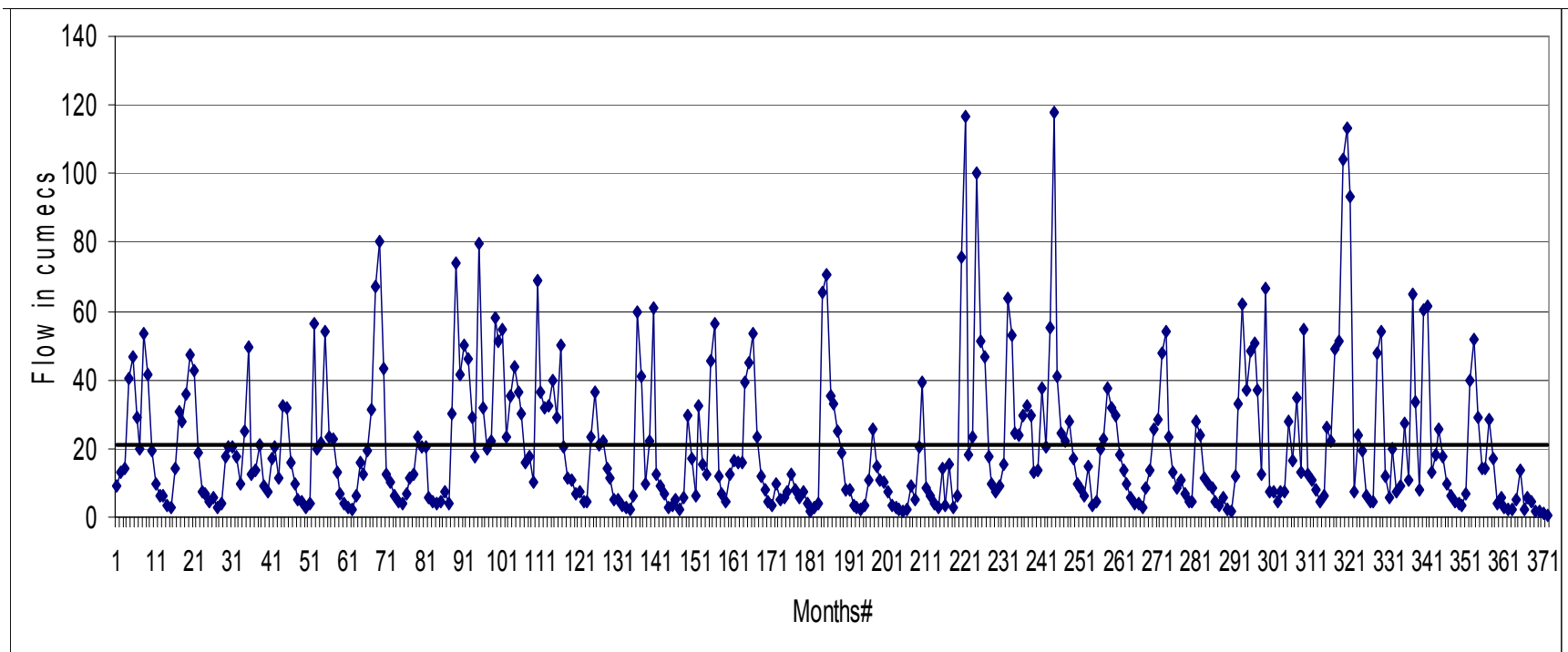


Figure 5.13a: Monthly flow for the Nyando River at weir IDG04

Qualitative inspection (Figure 5.13a) of trend reveals that there is an annual and biannual monthly cycle of flow. It is also evident from Figure 5.13a that April, which is the first peak flow of the Nyando River, falls on 4, 15, 28, 40 and 51 – that is, 12 months apart. Similarly, the second peak (August) appears on 8, 20, 32, and finally, November on 11, 23 and 35. Mean = 21.16 mm/month, standard deviation = 20.79, $n = 372$.

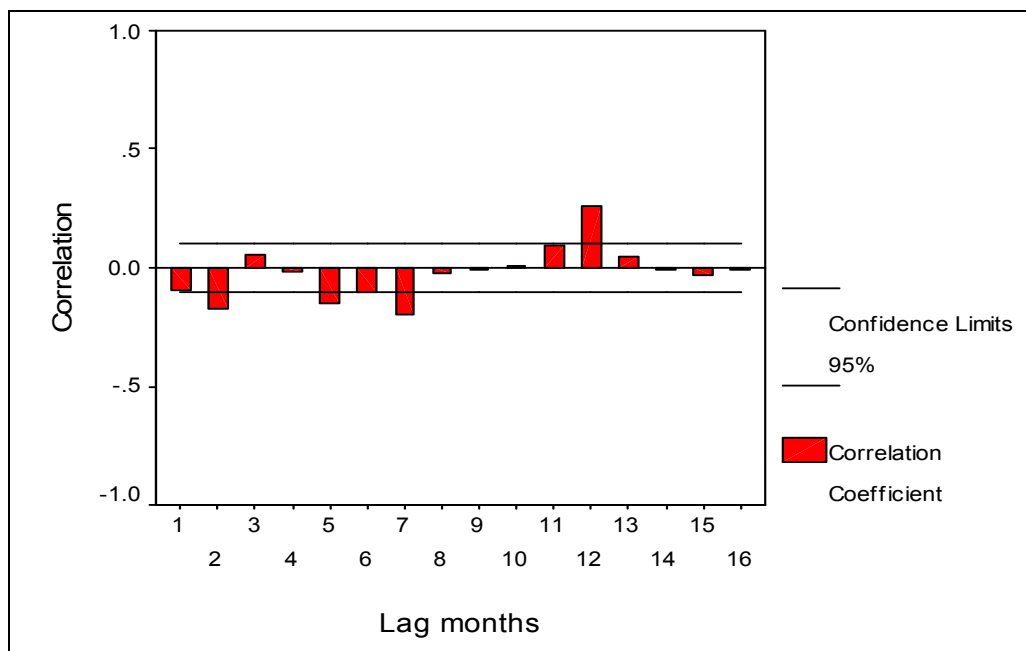


Figure 5.13b: Correlogram of flow

Visual inspection shows significant deviations from zero correlation at lag 1, 2, 5, 7 and 12, and very close at lag 4 and 13. There is statistically significant autocorrelation shown in the 2 plotted residual values, at lag 6 and 12, that lay more than 2 standard errors (at 95% confidence limits) from the zero mean.

In Figure 5.13c, the spectral density graph is used to determine the cyclicity of the flow data. The results (Figure 5.13c) show a strong annual cycle at a 12-month and a smaller harmonic at a 4-month level.

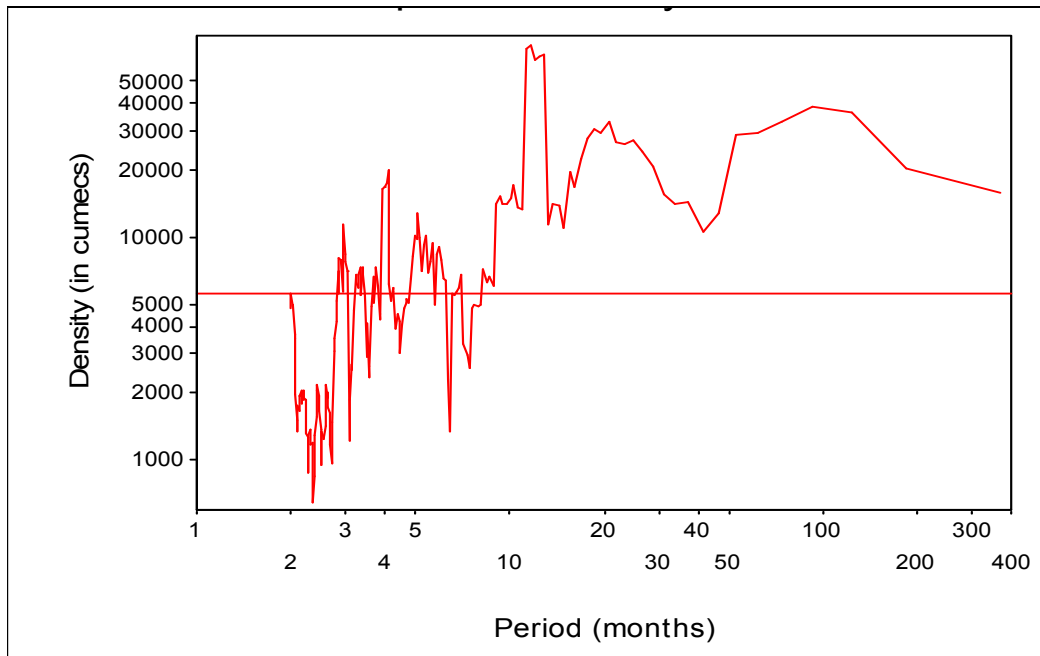


Figure 5.13c: The spectral density function for the monthly flow at weir 1GD04

The spectral density function of flow shows a peak near 12 months, with harmonic at 4 months. Unlike the rainfall there are no sub-harmonics at 3 or 6 months.

The results of the trend and seasonal pattern computed from the ARIMA model is further explored by performing spectral analysis. After analysing data in the spectral domain, both the periodogram and correlogram are inspected for the correlation of cycles and periodicity (Figures 5.14a, 5.14b, 5.14c and 5.14d).

The spectral of the frequency domain shows a strong signal at periods 6 and 12 and the 2.5 and 3.5 harmonics. These are the harmonics of 6-monthly cycle, which is also a harmonic of the annual cycle.

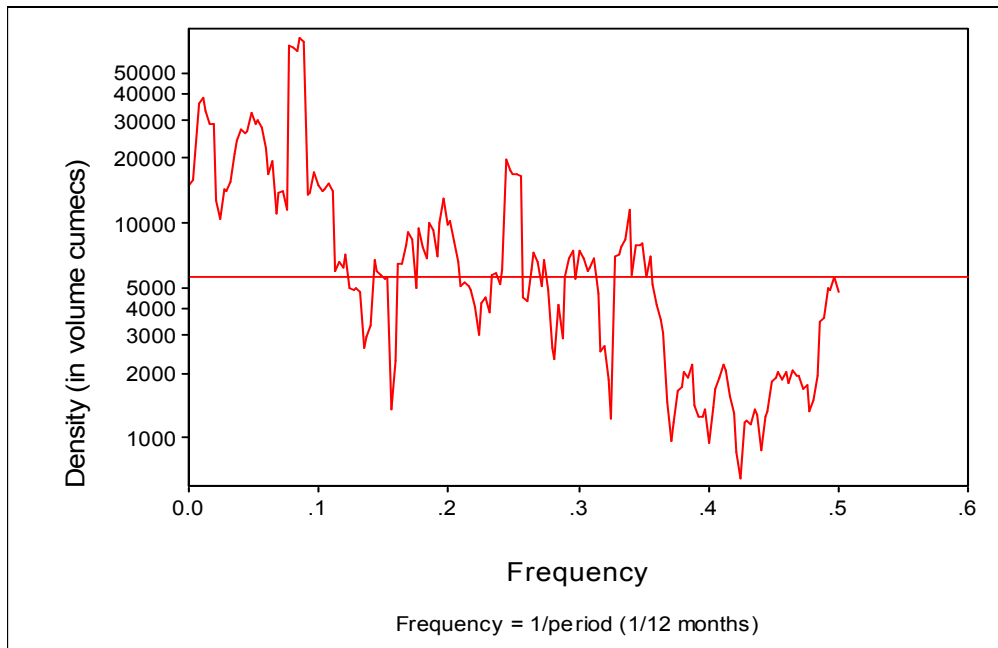


Figure 5.14a: The spectral density function of flow

Spectral results of flow confirm a 12-month cycle and harmonics of 4 months seasonality of flow. The 6-monthly cycle that features strongly in the rainfall, is missing in flow series, but is present when the flow data is split into two seasons. In order to determine the missing signal of the 6-month cycle of flow, the long term monthly rainfall and flow is split into two seasons, each having 186-monthly data series (so that the ordinate values of the spectral curve is decreased).

By decreasing the ordinate values of the spectral curve, the first season of the long term 372 data series only includes a 186-monthly rainfall and flow data series, while the second season includes data from 187 up to 372 (Figures 5.14b, 5.14c, and 5.14d).

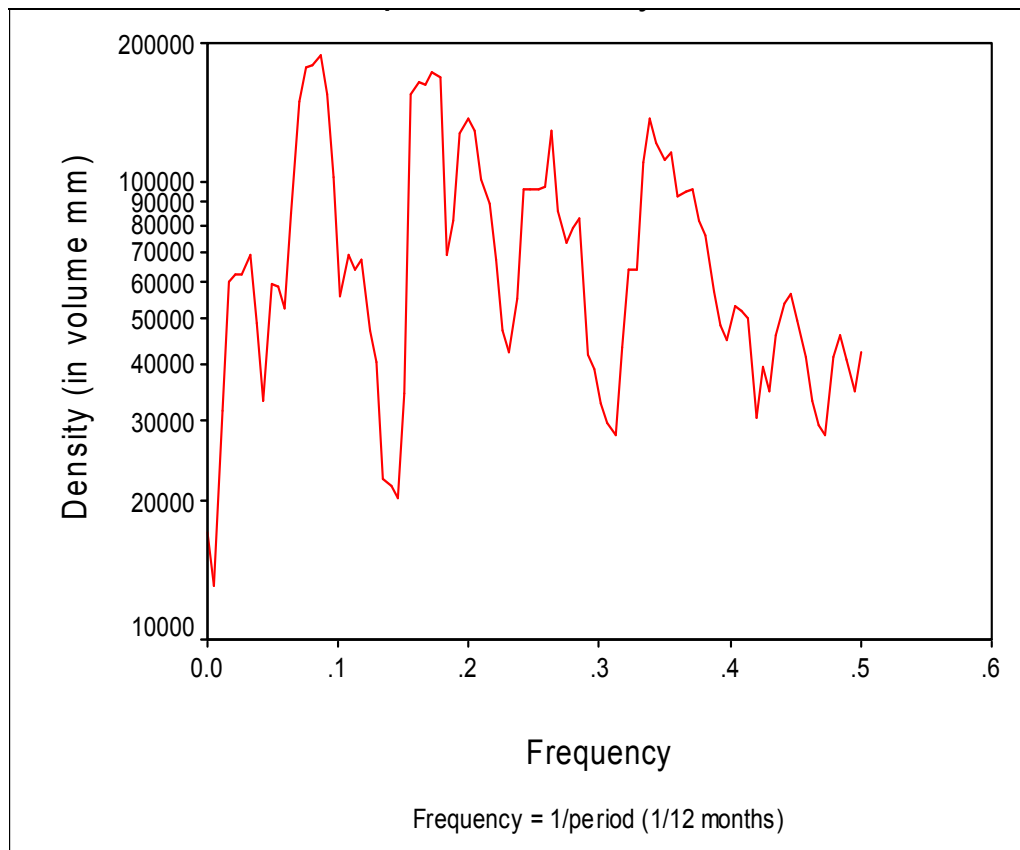


Figure 5.14b: Spectral density of rainfall from 1970 to 1984

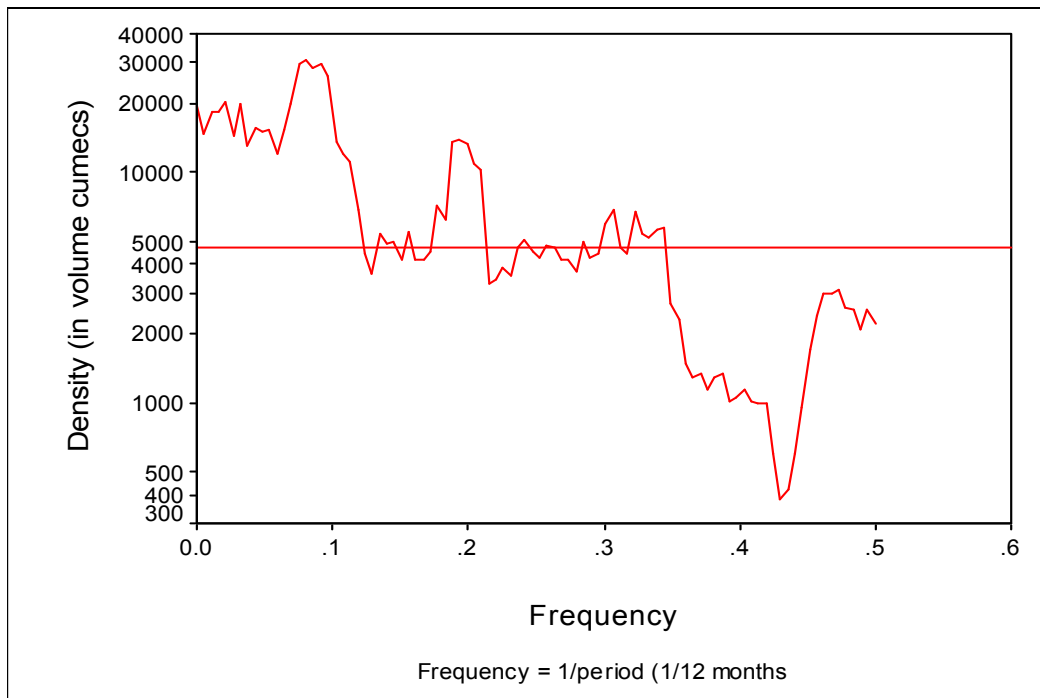


Figure 5.14c: The spectral density of flow from 1970 to 1984

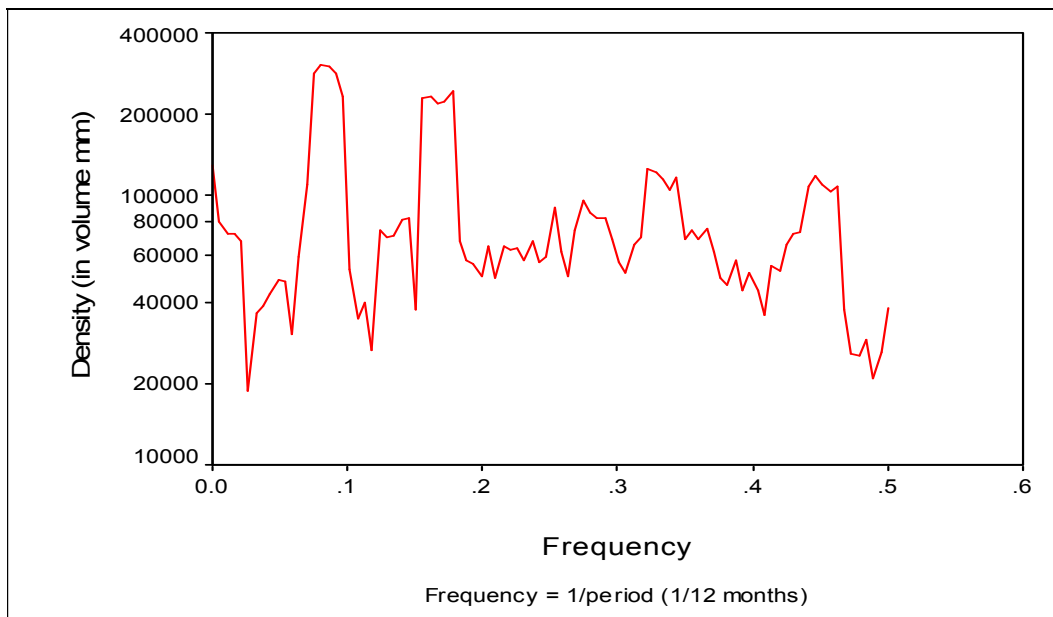


Figure 5.14d: The spectral density of rainfall from 1985 to 2000

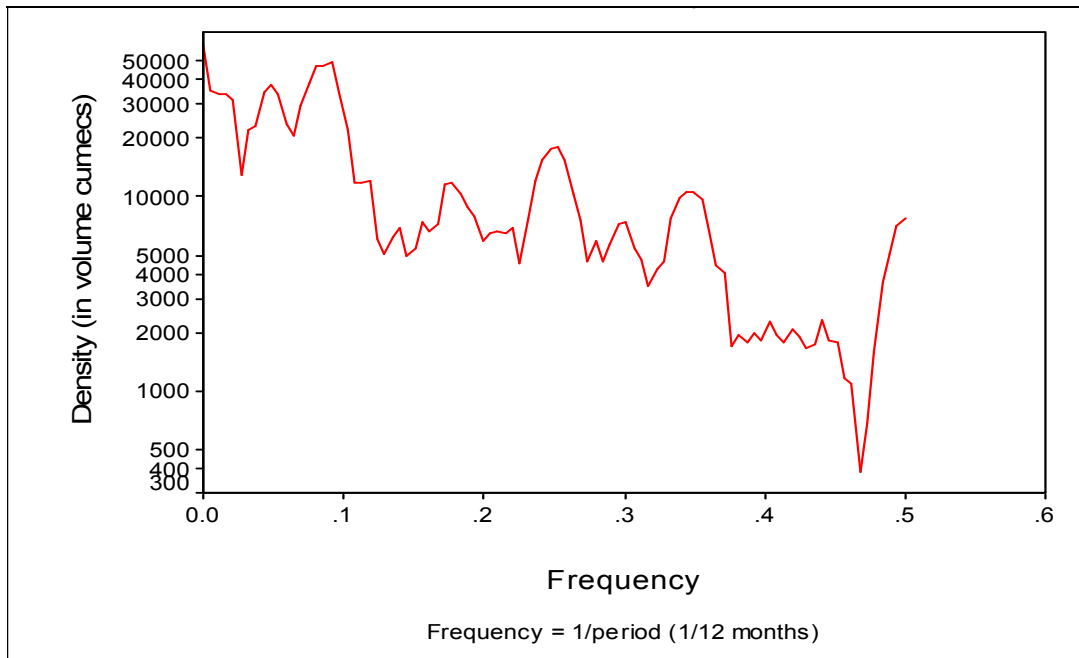


Figure 5.14e: The spectral density of flow from 1985 to 2000

The harmonics of 4 months are also shown (Figure 5.14e). The spectral results, after the rainfall and flow monthly data series was divided into two periods, reveal a significant trend in the spectral density of rainfall and flow.

The first harmonics (frequency peak) for both rainfall and flow shows a significant annual cycle. Further findings also reveal two maxima of rainfall and flow six months apart with the amplitude of the second harmonics being relatively large, while the rest of the harmonics (frequencies) are relatively small (Figure 5.14e).

The 6 month cycle is evident in the spectral density function for the first half series of both rainfall and flow (Figures 5.14 d-e). However, this is not as significant in the flow analysis for the second period. Instead there is an increase in the spectral density function for 3 and 4 month cycles. This suggests that there has been a change in the

cyclicality of the flow pattern in the second half of the analysis period. Flow in the catchment represents the integration of rainfall events that operate at a high frequency. The runoff process can be conceptualized as a smoothening process of rainfall events

The annual cycle of rainfall is not a simple 12 month wave since there is high correlation at 1 and 2 month lags, this suggests that the rainfall pattern is dominated by seasons (wet and dry) of two to three months. It is argued in this study that the largest peaks in the spectral density function are all harmonics of the annual cycle, and these indicate the variability of the magnitude of the annual cycle. Spectral density of flow exhibited a strong annual cycle at a 12-month and a smaller harmonic at a 4-month level, although there are no sub harmonics at 3 or 6 months. While there are presence of sub harmonics in rainfall and an emergence of August as the likely third peak of flow in Lower Kano Plain, there is yet to be a shift in the cropping pattern to adjust to the changing precipitation and flow regime. These are noted to have exacerbated the continued damage of farmlands by flooding.

5.2.8 Wavelet Analysis of Rainfall and Flow of Time Series Data

The wavelet power spectrum is used to analyze localized variations of power within a time series. The Morlet Wavelet is used, and the transform is performed in Fourier space using the method described in Torrence and Webster (1999). Each time series is padded with zeros in order to reduce the wraparound effects. Other wavelet bases, such as the Paul and Gaussian, were tested in this study and yielded the same qualitative results.

The Morlet Wavelet consists of a complex exponential modulated by a Gaussian, where t is the time, s is the wavelet scale, and w_0 is a nondimensional frequency. The wavelet scale is almost identical to the corresponding Fourier period of the complex exponential, and the terms “scale” and “period” are used synonymously in this section.

The wavelet power spectrum (defined as the absolute value squared of the wavelet transform) gives a measure of the time series variance at each scale (period) and at each time. To test the significance of peaks in the wavelet power spectrum, a background Fourier spectrum is chosen. Non-stationary changes in variance is tested through choosing the Global Wavelet Spectrum (GWS), given by the time average of the wavelet spectrum.

The GWS (Figures 5.15) is equivalent to the Fourier Power Spectrum smoothed by the Morlet Wavelet function in Fourier space. Since the width of the wavelet function is constant in period (the short horizontal lines), the number of smoothed Fourier components decrease with increasing period. This implies a decrease in the Degrees of Freedom (DOF) with increasing period, and corresponding increase in the width of the 95% confidence intervals (the error bars). The wavelet power spectra for rainfall and flow in the Kano Plain are shown in Figures 5.15a and 5.15b.

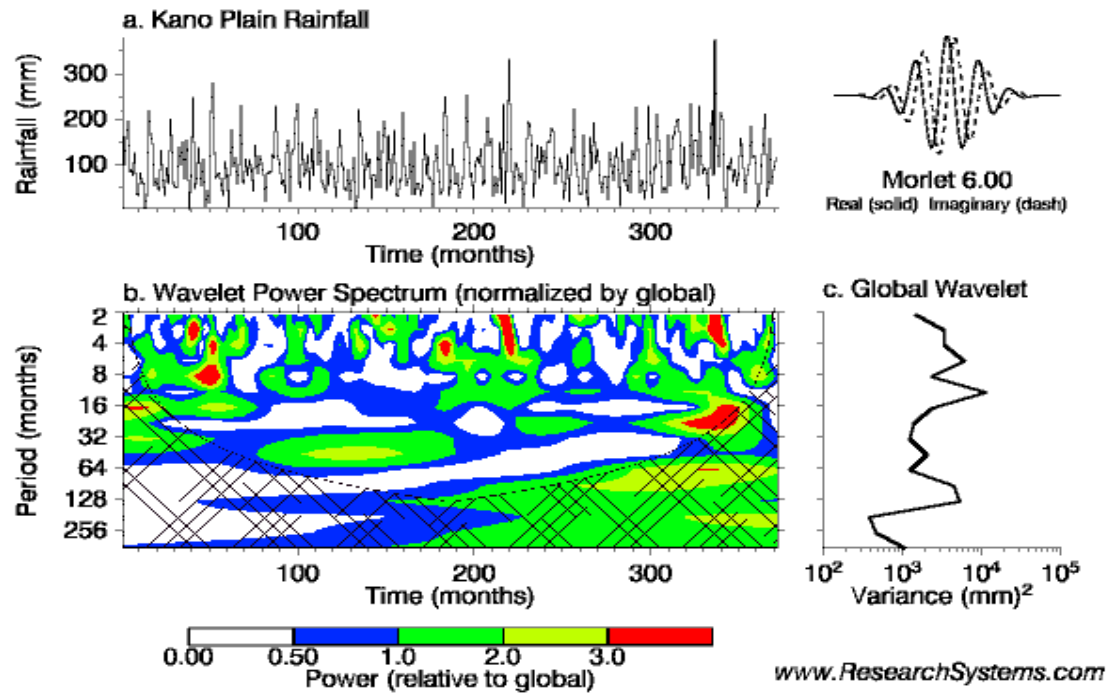


Figure 5.15a The Wavelet power spectrum (using the Morlet Wavelet) of rainfall

The wavelet power at each period is normalized by the global wavelet spectrum. The left axis is the Fourier period (in months) corresponding to the GWS scale on the right axis. The shaded contours are at normalized variances of 2 and 4, i.e., “equal to the GWS” and “twice the GWS,” respectively. Cross-hatched regions indicate the “cone-of-influence,” where zero padding has reduced the variance.

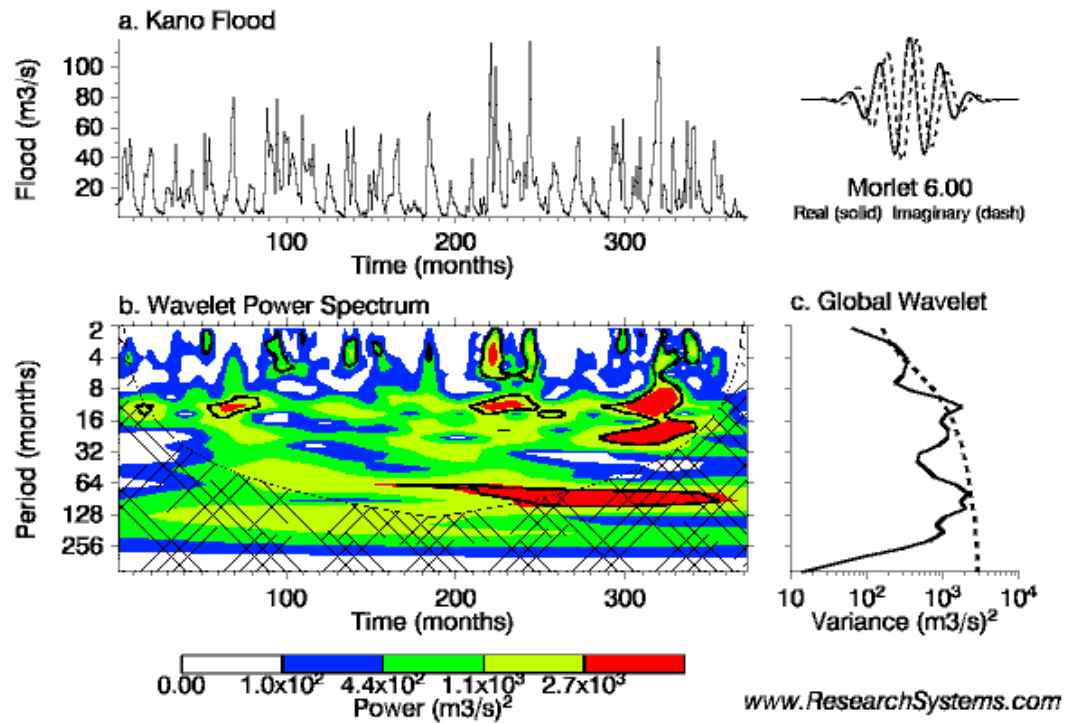


Figure 5.15b: The wavelet power spectrum (using the Morlet Wavelet) of flow

The wavelet power at each period is normalized by the global wavelet spectrum. The left axis is the Fourier period (in months) corresponding to the GWS scale on the right axis. The shaded contours are at normalized variances of 2 and 4, i.e., “equal to the GWS” and “twice the GWS,” respectively. Cross-hatched regions indicate the “cone-of-influence,” where zero padding has reduced the variance.

For rainfall and flow (Figures 5.15a and 5.15b), the power is broadly distributed, with peaks in 3-10 years of rainfall and flow bands. The 5% significance regions (the red areas) indicate that 1972 to 1973 and 1984 to 1987 contain intervals of higher rainfall variance, while 1974 to 1983 is a time of lower rainfall variance. Similar variance changes are found in flow, where significantly higher bands occurred in 1974 to 1975 and 1994 to 1997.

Comparing Figures 5.15a and 5.15b it is demonstrated that there is large power in the 6 and 12 month rainfall and flow period during the latter parts of the 31-year period [1970 to 2000]. In addition there are signals of 6 and 12 month rainfall and flood oscillations as well as power at even lower frequencies, which are in agreement with the performed spectra results. Similarly, the filtered satellite rainfall and flow of the Kano Plain exhibited a Quasi Biennial Oscillation (QBO) of the power spectrum of the long term frequency. The high frequency reveals 2 to 5 year cyclicality.

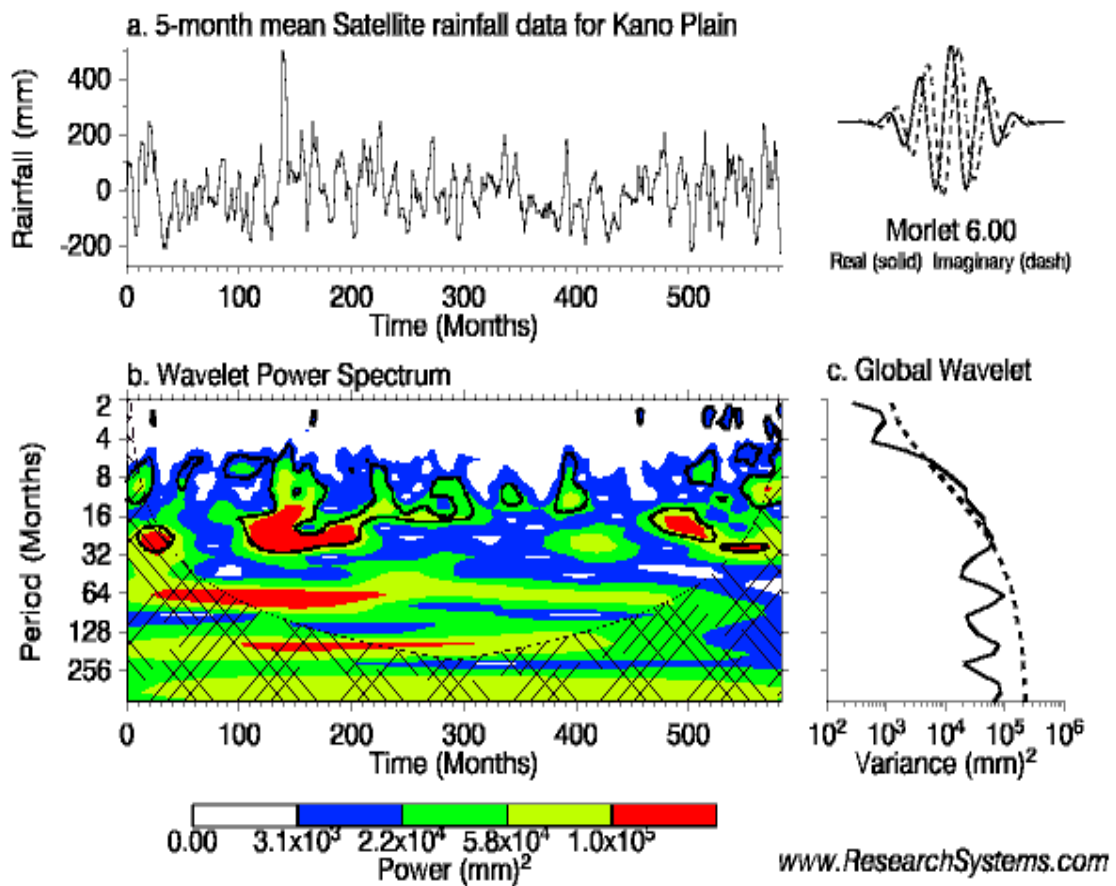


Figure 5.15c: The wavelet power spectrum (using the Morlet Wavelet) of 5-month mean satellite rainfall.

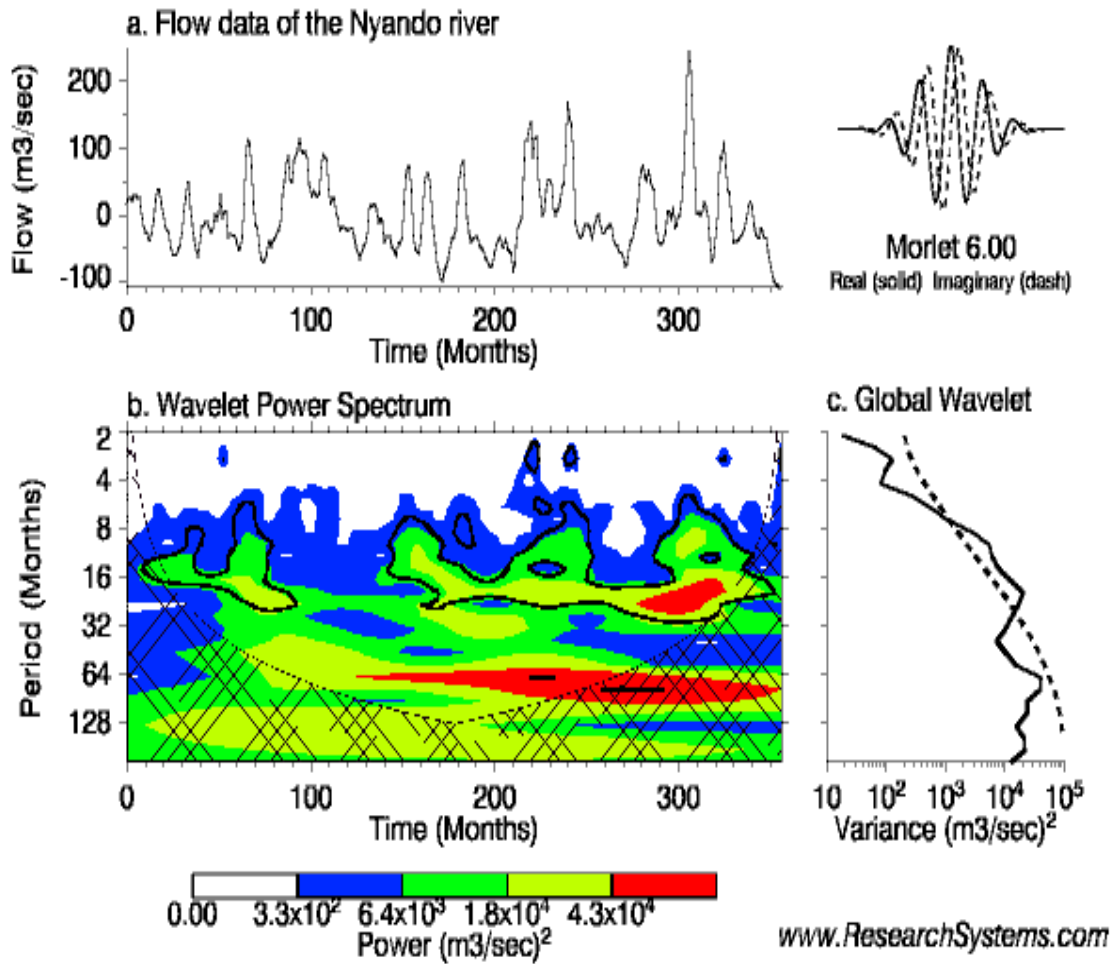


Figure 5.15d: The wavelet power spectrum (using the Morlet Wavelet) of 5-month mean filtered flow.

From Figure 5.15d there is much power in the 12 and 24 month flow period during the latter parts of the 31-year flow period. In addition there is evidence of a 24 and 64 month oscillation (which is equivalent to 2 to 5 years) cycle within the high frequency. Changes in the frequency are also evidenced from the hydrologic period between 1970 and 2000.

5.2.9 Correlation analysis of annual mean rainfall and flow

From the previous sections, this study argues that there is a significant change in flow as a result of change in rainfall. These changes have caused considerable variability in the regime of flow and subsequent flooding and inundation in the study area. In the previous analysis of the seasonal, inter-annual and intra-annual variability of rainfall and flow has been revealed. The relationships of rainfall and flow from the 31 years time series data is presented in Table 5.6, while the degree of the relationship between the monthly rainfall and flow characteristics is determined through performing a correlation coefficient as presented in Table 5.7.

Table 5.6: Regression analysis of rainfall and flow using (ANOVA)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	12410.757	1	12410.757	31.034	.000 ^a
	Residual	47964.948	370	399.905		
	Total	60375.705	371			

a. Predictors: (Constant), RAINFALL

The hypothesis being tested shows no relationship between the response (flow) and predictor (rainfall) variable. The significance of the relationship is tested against F -statistic at a predefined alpha value ($\alpha = 0.01$). From Table 5.6, the computed F (6.64) < 31.034 , The H_0 (there is no significant relationship) is rejected and the alternative H_A (there is significant relationship between flow and rainfall is accepted. The computed coefficient of determination is $r = 0.278$. The amount of variance of flow is explained by 27.8% of rainfall. The rest (71.2%) of the variability of flow is as a result of other factors.

Table 5.7: The Correlation Coefficient of annual monthly rainfall and flow

Month	Rain (mm)	Flow (m ³ /sec)	Correlation Coefficient (r)
Jan	85.79	9.85	0.32
Feb	93.25	9.27	0.29
Mar	124.12	10.83	0.28
Apr	192.82	30.83	0.41
May	138.73	37.33	0.40
Jun	77.39	23.61	0.14
Jul	72.87	26.13	0.13
Aug	88.37	35.13	0.07
Sept	69.13	28.36	0.23
Oct	85.00	16.02	0.81
Nov	109.61	16.92	1.00
Dec	73.74	9.67	1.00

The results illustrated in Table 5.7 show both positive and perfect relationships between monthly mean annual rainfall and flow. The correlation coefficients (r) of rainfall and flow between January and May exhibit a positive relationship with the computed (r) values recorded between 0.28 and 0.41. There is, however, a perfect positive relationship achieved in November (r=1.00) and December (r=1.00), and a high correlation in October rainfall and flow (r=0.81). The results in Tables 5.6 and 5.7 are nearly coherent; firstly, in terms of the rainfall not being the only key determinant of flow, and secondly, at least 17% of the peak flow in the Lower Kano Plain is from precipitation.

5.2.10 Flood Frequency and Magnitude

Due to the randomness of hydrological processes, the probability model is important in risk and uncertainty analysis. The models have successfully been used to predict future floods by making use of the available records of river flows in the past (Kumar 1993, Grover *et al.*, 2002, Ware *et al.*, 2003). The former author has, however, cautioned that for successful predictions of future floods, there is, firstly, a need for sufficient flow records, while secondly, the river in question (in the forecast) must not have undergone appreciable changes in its regimen, especially during or after the period of record.

These criteria are used in determining maximum flood that can be expected from the Nyando River within a given frequency using the 31-year time series flow data. The main purpose of the probability frequency analysis is to obtain a relationship between the magnitude of the Nyando flood and its exceedence. The analysis makes use of an empirical model, where the annual peak flood data for the 31-year time series is arranged in descending order. Thereafter, a ranking number (m) is assigned to each flow period. The most severe peak flow is placed at the top with its ranking denoted as 1, while the lightest peak is shown in the last place (N^{th} place), and its ranking is N . In this study the computation of flood frequency and magnitude was based on two levels (benchmarks) of flood discharges. The non-damage/ bank full discharge ($200 \text{ m}^3/\text{sec}$), and Flood discharge [$400 \text{ m}^3/\text{sec}$] (NEMA, 2004). The results of the analysis using the Weibull Probability Model are represented by the equation;

$$P = \frac{m}{N + 1}$$

Where m , is the annual flood ranking and $N+1$, is the total number of peaks.

Frequency (T) is denoted by the equation $T = \frac{N+1}{m}$ and the results are presented in

Table 5.8.

Table 5.8: Flood frequency and magnitude using the Weibull Probability Model.

Year (Column 1)	Total annual flood peaks m^3/sec (Column 2)	Flood ranking (m) (Column 3)	Frequency $T = \frac{N+1}{m}$ (Column 4)	% Chance $P = \frac{m}{N+1}$ (Column 5)
1996	521.0	1	32.00	0.03
1988	484.2	2	16.00	0.06
1977	415.5	3	10.67	0.09
1978	408.6	4	8.00	0.13
1990	387.9	5	6.40	0.16
1994	371.2	6	5.33	0.19
1979	348.6	7	4.57	0.22
1998	323.3	8	4.00	0.25
1989	315.2	9	3.56	0.28
1975	304.5	10	3.20	0.31
1970	303.4	11	2.91	0.34
1985	276.1	12	2.67	0.38
1983	257.7	13	2.46	0.41
1971	244.6	14	2.29	0.44
1981	236.3	15	2.13	0.47
1992	234.7	16	2.00	0.50
1974	232.9	17	1.88	0.53
1982	232.5	18	1.78	0.56
1999	218.8	19	1.68	0.59
1991	211.7	20	1.60	0.63
1997	210.4	21	1.52	0.66
1995	204.5	22	1.45	0.69
1973	194.9	23	1.39	0.72
1972	189.9	24	1.33	0.75
1980	158.4	25	1.28	0.78
1976	124.6	26	1.23	0.81
1993	121.8	27	1.19	0.84
1987	117.5	28	1.14	0.88
1986	96.3	29	1.10	0.91
1984	81.0	30	1.07	0.94
2000	44.7 N = 31 (No. of floods)	31	1.03	0.97

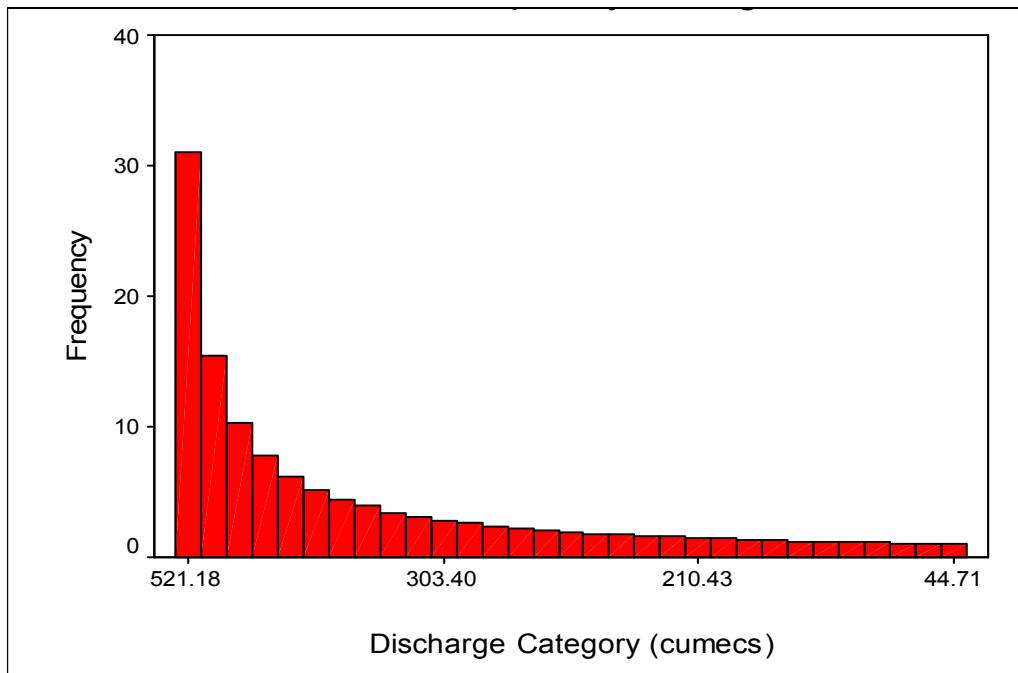


Figure 5.16a: The frequency histogram of flow

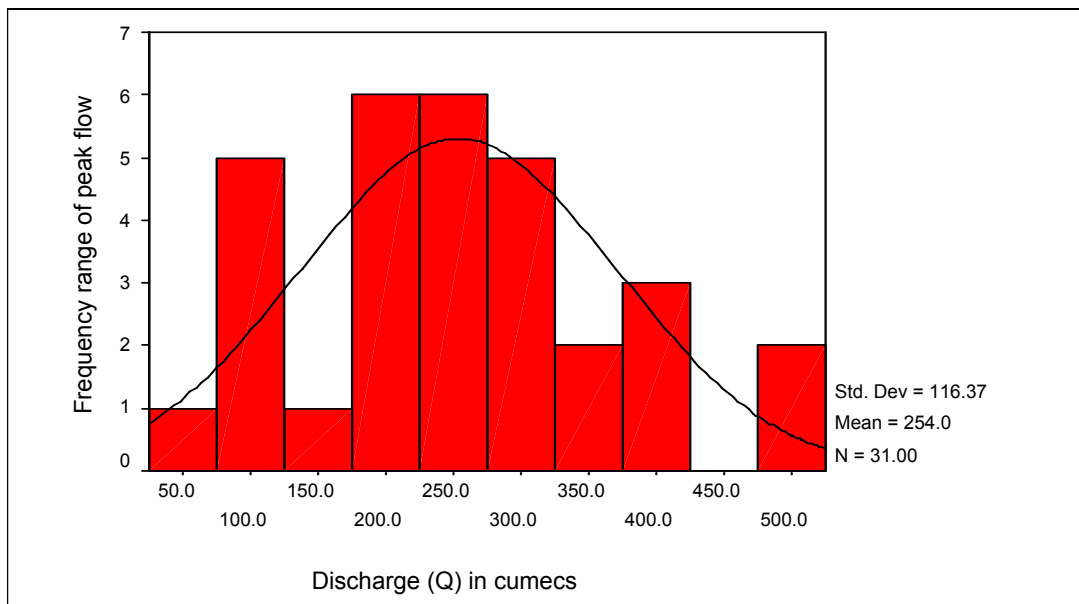


Figure 5.16b: The mean and standard deviation of discharge of the Nyando River

The highest mechanically measured discharge (Figure 5.16a) for the Nyando River is 521m³/sec (1996), a value not yet exceeded in the recorded period (1970 to 2000). The discharge values range between 44.7m³/sec (2000) and 521m³/sec (1996), with mean 254m³/sec, standard deviation 116.37m³/sec and skewness 0.41.

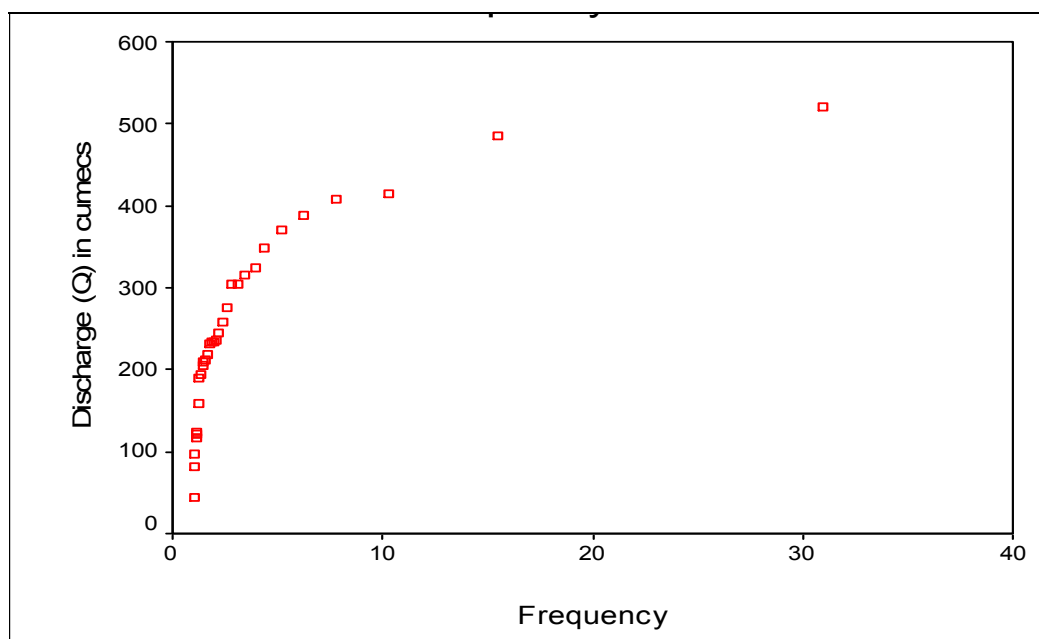


Figure 5.17: Recurrence frequency of peak flow

The results shown in Table 5.8 and Figure 5.17 represent the magnitude of a flood with a specific return interval. From the findings, it is evident that 1996, 1988, 1977 and 1978 recorded the highest total annual flows, with a return interval of between 1 and 4 years. The magnitude of these floods are computed as 521, 484.2, 415.5 and 408.6 cumecs respectively, as shown in Table 5.9 and Figure 5.17. The return period for the first three flow peaks are: 1996, 1988 and 1977, as presented in Table 5.9.

Table 5.9 Flood Frequency in the Lower Kano Plains

Return Period (Frequency)	Percent Chance	Flood magnitude (m ³ /sec)
10	9.7	415.5
15	6.5	484.2
31	3.2	521.0

It is evident that the Lower Kano Plain is highly prone to flooding of a higher magnitude (521- 415.5 m³/sec), with a recurrence interval of between 3 and 9 years. The results have also shown that for the 31 years of long term flow data, there were 18 years of non-damage discharge or bank full discharge (200 m³/sec) at a 1.7 year recurrence interval.

While flooding in the study area has been described as perennial (Mwaka, 1994; NEMA, 2004), it is possible that deforestation in the catchment area and erosion in the Lower Kano Plain (ICRAF, 2001) could have increased the annual mean sediment yield into the river bed. This exposes the channel bed to shallow discharge conditions that occasionally cause damage of land use downstream.

The increase in the rate of erosion and the destruction of arable land through gully development is evidence of increasing runoff into the floodplain. This also explains the 1.7 year recurrence interval of bank full discharge by the Nyando River, which the

current study reports to be responsible for the increasing perceptions of the annual floods reported in the Lower Kano Plain. The latter propositions are in agreement with Mwaka (1994) who describes the Nyando River as having limited channel capacity that exposes the Lower Kano Plain to the impact of spates.

Similarly, ICRAF (2001) reports an increase in the rate and impact of erosion on land use, which they associate with runoff and flooding in the Nyando Basin. Areas that suffer the most flooding impacts are settlements that are situated along the riverbanks and in the lower reaches of the Nyando River (Republic of Kenya, 2002).

The results presented in Section 5.2 have broadly demonstrated the seasonal and periodic patterns of rainfall and flow in the Kano Plain. Rainfall shows two dominant seasons, with March and April as the first season and October and November as the second. A lower peak in the second rainfall season is observed in August. The peak flows correspond to the rainfall peaks, although the high peak is evident in May, which demonstrates the smoothening effect of rainfall between March and April before floods are realized in May.

The computed runoff coefficient reveals significant variability of between 30 % and 39 %. Between 1977 and 1988 (10 year cycle), an increase in runoff was witnessed of between 35% and 39 %. This was followed by a steady trend up to 1996, when there was a repeated runoff coefficient of 35 %, which is comparable to 1977.

Although 1996 recorded the highest flow peak ($521.0 \text{ m}^3/\text{sec}$) it did not record higher runoff coefficient as the runoff trend has illustrated for the high flood peaks. This is

attributed to continued efforts to improve land cover through forestation programmes that were initiated in the 1990s by the World Agroforestry Centre. They aimed to improve land cover and soil quality in the Nyando River Basin.

This variability was equally evident in rainfall between the same periods, for instance the annual mean rainfall increased from 1171 mm (1970 to 1974) up to 1259 mm in (1975 to 1979). Between 1977 and 1979, both the variances of rainfall and flow were rather lower, which was followed by a decline between 1980 and 1984, and, a sharp increase between 1996 and 1998. In terms of variances, runoff has generally increased between 8 % and 39 %, and these correspond with high peaks.

Both rainfall and runoff has changed in pattern, specifically between 1990 and 1999 hydrologic period where the high frequency of rainfall and flow peaks were found. This is argued in this study to have shifted the flood pattern and magnitude in the study area. The shifts in rainfall and flow presented in the wavelet results have changed the seasonal flooding characteristics and exacerbated the hydrologic related damage on crops.

5.3 Impact of flooding characteristics on cotton cultivation in the Kano Plains

5.3.1 Introduction

Anecdotal results in support of the impact assessment of flooding characteristics on cotton cultivation in the study area are presented in this section of the study. The analysis involved exploring the history of flooding and associated impacts on cotton growing downstream of the Nyando River in the Kano Plains.

Anecdotal data was acquired from respondents who were able to recall the history of flooding and cotton production from 1964. The year 1964 was not selected coincidentally as a year of reference for the households interviewed, but due to the fact that most of the respondents had experienced and suffered the impacts of the prolonged rains and consequential flooding event of 1964 when Kenya attained its independence. Associated with attainment of independence made the flooding event historical and kept it fresh in the minds of the majority of the respondents. During the flood event, rivers in Kenya, including the Nyando River, recorded a flood discharge of $400\text{m}^3/\text{sec}$, which caused unquantifiable damage to crops, livestock and settlements (Republic of Kenya, 2001a; NEMA, 2004).

5.3.2 Perceptions about the characteristics of Nyando Basin and flooding

When respondents were asked to comment on the geomorphic characteristics of the Nyando River Basin, they responded as shown in Table 5.10.

Table 5.10: Perceptions about the causes of the flooding of the Nyando River (n=100)

Causes	No. of respondents citing
Inadequate river channel	54
Poor drainage	55
Low river gradient	75
Inland overflow from L. Victoria	28
High rainfall	60

The results presented in Table 5.10, suggest the following:

- Over three quarters (75) of the respondents, considered the low river gradient to influence flooding in the study area, while 60 of the respondents regarded high rainfall during the long rainy season to be the cause of flooding.
- Only 28 of the respondents attributed the rising levels of Lake Victoria as the cause of flooding at the river mouth in the Lower Kano Plains.
- Out of the total number of respondents, more than half (54) believed that the shallow riverbed was the cause of the limited channel capacity of the Nyando River.

In this dissertation, the low channel capacity is believed to be responsible for the increased frequency of bank full discharges, which is speculated to have exacerbated downstream flooding. Finally, 55 of the respondents pointed out that poor drainage in the floodplains of the Nyando River is due to the dominant

vertisols that drain poorly and are highly susceptible to pounding during the rainy season.

In terms of flood events, the respondents responded as recorded in Table 5.11 when asked to cite specific flood events that from they remembered to have caused damage in the Lower Kano.

Table 5.11: Major flooding events cited by respondents (n=100)

Flood Period	Proportion of respondents citing	
	Experienced floods	Not Experienced floods
1964	79	21
1977	74	26
1988	87	13
1996 and 1998	60	40

The above findings reveal that most (79%) respondents cite the floods of 1964, 1977 (74%), 1988 (87%) and 1997 (60%) as the most disastrous events in the flooding history of the Kano Plains. While the majority (over 75%) of the respondents remembered the devastating impacts of these floods, less than 26% of the respondents had experienced no similar flooding events. The flooding conditions cited between 1996 and 1998 (60%) were the consequence of El-Nino related long and intensive rainfalls during the months of October and November (Republic of Kenyan, 2004).

In this period (1996 to 1998), precipitation of up to 300 percent of the normal was experienced. The El-Nino related floods caused tremendous damage to the

environment and to settlements. The three most striking impacts of these floods included:

- a. destruction of a weir on Kipchoria River, a tributary of the Nyando River, which was washed away. This resulted in the silting up of the water supply dam in Kericho District.
- b. a vast area of the lower Kano Plain was inundated and completely destroying crops (Republic of Kenya, 2004);
- c. there was increased runoff as well as damage to 240 river gauging facilities due to bank erosion (Republic of Kenya, 2004), and
- d. the protective dykes were over-topped and breached at several places (Republic of Kenya, 2004).

Damage with regard to land use as a result of the flood events has, however, continued. Responses in relation to damage associated with the flooding events are summarized in the Tables 5.12, 5.13, 5.14 and 5.15.

Table 5.12: The perceived general damage caused by the 1964 floods (n=100)

General Impact	Number of Respondents recalling
Prolonged Inundation	82
Most Crops destroyed	80
Outbreak of famine & food insecurity	51
Settlements affected	54

Table 5.13: The damage caused by flooding of 1977 (n=100)

General Impacts of flooding cited	Number of Respondents citing
Crops destroyed	74
Settlement disrupted	71
Outbreak of diseases	63

Table 5.14: The damage caused by flooding of 1988 (n=100)

General Impact of flooding cited	Number of Respondents citing
Crops destroyed	74
Settlement disrupted	58
Inaccessibility of farms	86

Table 5.15: The Impacts of El-Nino Floods between 1996 and 1998 (n=100)

General Impact of floods cited	Number of Respondents citing
Destroyed crops	73
Settlement disrupted	54
Infrastructures destroyed	67
Outbreak of diseases	56

Tables, 5.12, 5.13, 5.14 and 5.15 indicate that crop destruction and impairment of settlements are generally the most cited impacts. Occupation of flood prone areas and crop cultivation in the river's lower reaches are cited as some of the reasons for the continued damage caused by floods.

5.3.3 Impact of flooding conditions on cotton cultivation

Further analysis sought to determine perceptions among the households on the ways in which certain flooding conditions impacted on cotton cultivation. Farmers' opinions were sought with regard to the following flooding conditions: flood depth, flood duration and flood extent. Their responses are represented in Tables 5.16 and 5.17.

Table 5.16: The average flood depths cited in the study Area (n=100)

Average flood depth	Number of respondents citing
(0.5-1m)	33
(1.5-2m)	17
(2.5-3m)	45
(others)	5

Table 5.16 reveals that 47.4 % (45) of the respondents cited an average flood depth of between 2.5 and 3 meters as dominant, while 34.7 % (33) cited 0.5 and 1-meter flood depths. About 5 % cited 3 meter flood depths as the most disastrous, both to settlement and crops. The damages associated with these depths are summarized in Table 5.17.

Table 5.17: The damage cited as a result of high flood depth (n=100)

Impact of floods	Number of respondents citing
Physical damage	90
Impedes germination	51
Destruction of cotton bolls	69
Destruction of seedlings	70

The findings above (Table 5.17) show that the majority of the respondents (90) cited physical damage to cotton and cotton fields as common during high flows. Over half (69) of the respondents viewed the destruction of cotton boll as the dominant problem in this regard, while nearly three quarters (70) of the respondents believed that damage to cotton seedlings was the worst. Slightly over half (51) attributed poor germination of the seedlings to prolonged inundation. As reflected in Table 5.18, half (50%) of the respondents said they were affected by two to four-day floods, while (22%) cited one-week period of inundation. The responses associated with such flood depths are summarized in Figure 5.18.

Table 5.18: The duration of flooding as recalled by respondents (n=100)

Duration of floods	Number of respondents recalling
A few hours	14
2 – 4 days	50
1 week	22
More than 1 week	14

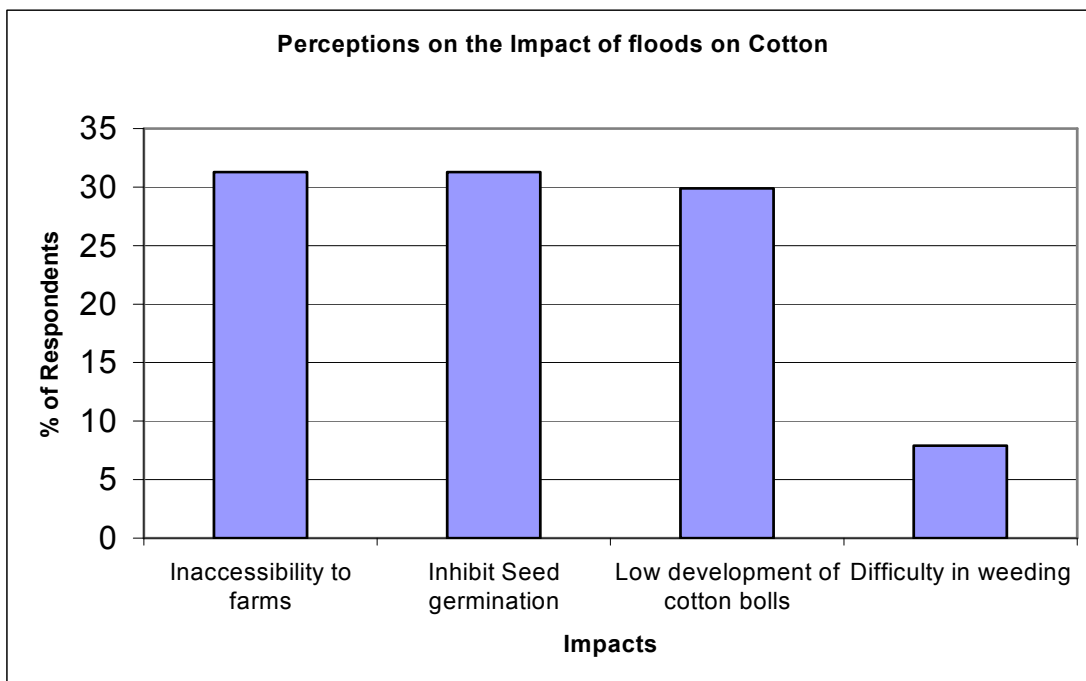


Figure 5.18: Perceptions on the impact of floods on cotton cultivation

5.3.4 Area under cotton cultivation and downstream inundation

The decline of the area under cotton cultivation cannot solely be attributed to flooding and inundation downstream. Some of the known anthropological factors, such as the patriarchal system of landownership (where land is privately inherited among the grandchildren), have evidently been ascribed as responsible for the growing number of land parcels in small holdings of between 1 and 6 hectares.

According to certain studies, the declining number of hectares under cotton is also blamed on the low price of lint, delays in payment and the increasing cost of farming input that have caused a shift in focus to the cultivation of other crops (i.e. sugarcane and rice) that are increasingly productive and higher rated in terms of remuneration, even in conditions of adverse impacts from floods.

While factors such as low lint prices, high production costs and competition have been singled out by McCormick *et al.* (2001) and Ikiara and Ndirangu (2003) as having influenced the decline in cotton production in Kenya and the Kano Plains in particular, flooding has also had adverse effects on cotton cultivation downstream of the Nyando River. The decline in crop growing in the river's lower reaches is mainly due to the seasonal variation between rainfall and flow, where prolonged inundation of farmlands is cited as the cause that sometimes forces farmers to either shift to the growing of flood resistant crops (i.e. sugarcane and rice), or to reduce the acreage planted under cotton. The relationship between total acreage owned by households and acreage that they cultivated under cotton is shown in Table 5.19 and Figure 5.19 respectively.

Table 5.19: The average cultivated land (ha) owned by households (n=100)

Land (ha) owned	Number of respondents citing
(1 – 2)	33
(3 – 5)	45
(6 –9)	15
(10 and above)	7

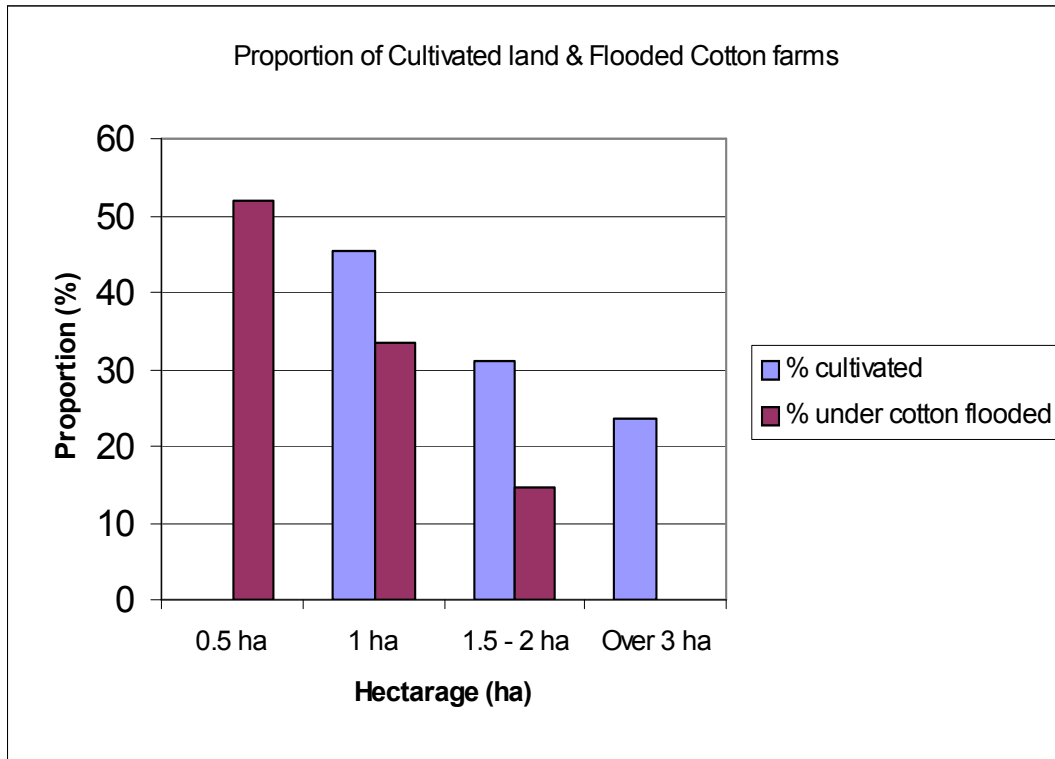


Figure 5.19: The portion of the cotton fields affected by flood

5.3.5 Flooding and Cotton Output

Cotton output was one of the components that proved very difficult to measure. This problem is due to the absence of documented records and the collapse of cotton co-operative societies that once had the mandate of collating this information from the cotton growing areas in the Kano Plains. It is important to note that most of the statistics on cotton output was reconstructed from the Nyando District Development Plan (1990 to 2004) that captures cotton growing trends and output for the previous years. The production trend is shown in Figure 5.20 below.

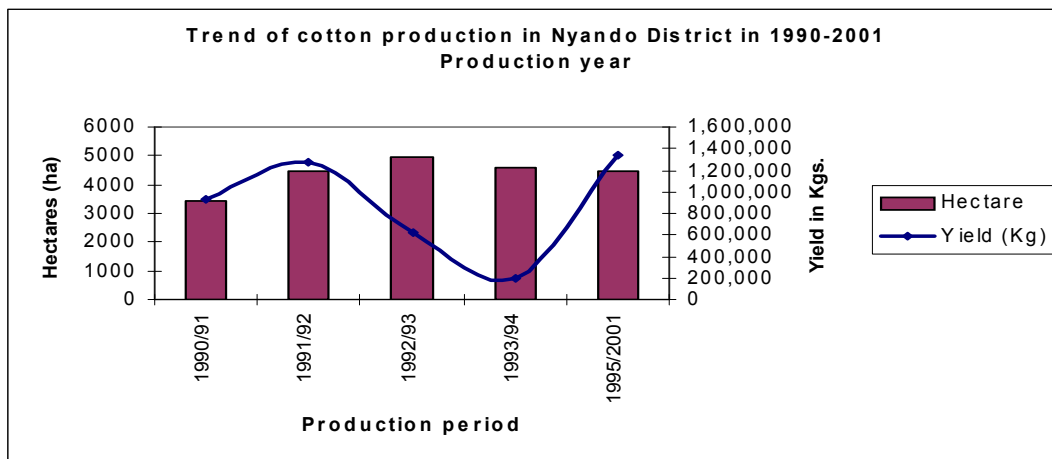


Figure 5.20: Trend of cotton production in Nyando District

Source: Computed from District Development Plan (Republic of Kenya, 2001a).

While numerous problems affecting cotton production have been cited, intercropping of cotton with other crops, particularly sorghum and maize, also takes place. Such relay cropping is said to minimize the cost of production, which is high if cotton is grown as a single crop. On average, acreage under cotton recorded a 10% decline from 5 to 0.5 hectares. Similarly, there was a 50% decline in yield per hectare (i.e. 4 bags from the previous 8 bags per hectare).

5.3.6 Trend of Cotton Production in the Nyando District (1990 to 2001)

Findings in Figure 5.20 show a sharp decline in yield for the period between the 1992 and 1994 production years. Between 1990 and 1992 there was a 36.7% increase in yield; yet there is a 50.9% decline between the 1993 and 1994 production year, despite an increase in hectares. Between 1995 and 2001 an increase in cotton output was recorded. Unfortunately, the area under cultivation continued to drop by nearly

3.5%. The increase in lint prices acted as an incentive to those farmers who planted in good time and who observed better agronomic practices.

It has generally been observed that the enormous market prospects afforded by the African Growth and Opportunity Act (AGOA) of 2000 and the African, Caribbean and Pacific European Union (ACP-EU) Cotonou Agreement have rekindled interest in the industry (EPZA, 2005). This is evidenced by a significant increase in Kenya's exports to the USA – from US\$39.5 million in 1999 to US\$ 277 million in 2004 (EPZA, 2005). Similarly, there is a significant rise in total investment from Kshs. 1.2 billion to Kshs. 9.7 billion (41% increase). Also reported is an increase in the number of jobs generated from about 26,000 in the year 2002, to 37,000 in 2003 – although this dropped to 32, 000 jobs by the end of 2004 (EPZA, 2005). The variability in hectare and output of seed cotton is presented in Figures 5.21a and 5.21b, while the trend in cotton output in the Lower Kano Plains is shown in Table 5.20.

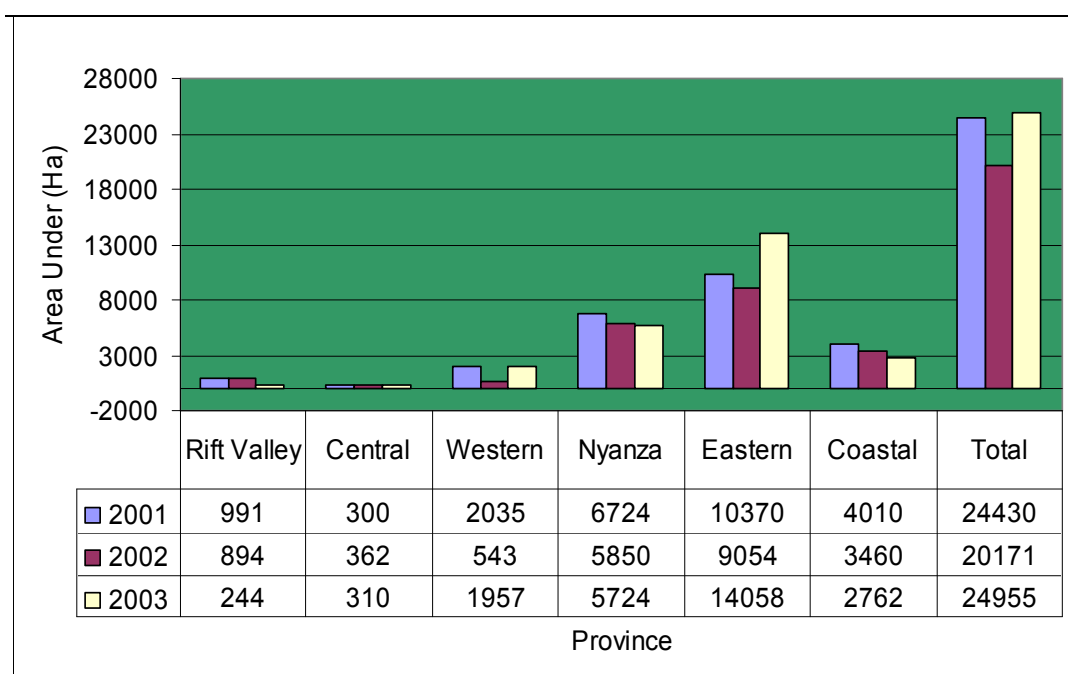


Figure 5.21a: Areas under cotton per province in Kenya

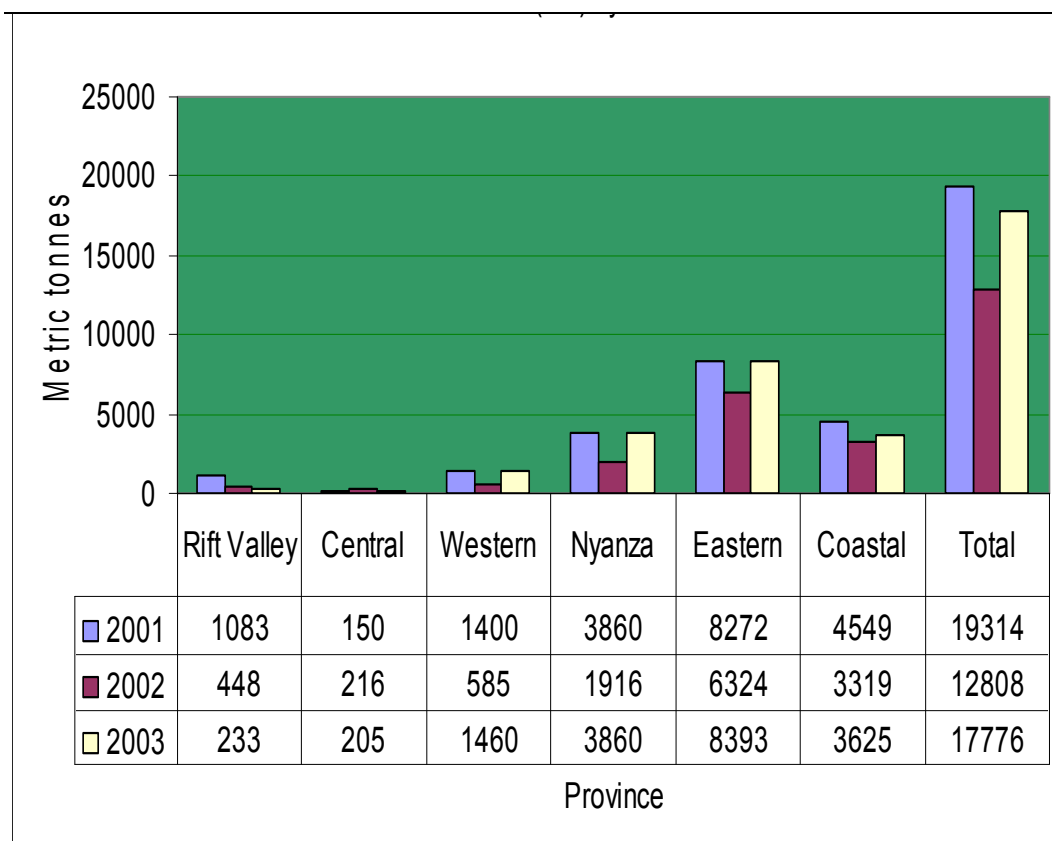


Figure 5.21b: Production of seed cotton by province in Kenya

There is an increase in hectare under cotton cultivation as well as a corresponding increase in output in Nyanza, Eastern and Coastal Provinces between 2001 and 2003 crop production year (Figures 5.21a-b). One is likely to argue that besides other factors that determinine crop output (i.e. appropriate use of farm inputs, well distributed rainfall), the results in Figure 5.19 is a pointer that while over 50% of farmers indicated having at least 0.5 ha prone to inundation during flooding it is also true that over 50% of these farmers experience a drop in output during flooding period and this explains the threat flooding has caused crop cultivation downstream the Nyando River.

Table 5.20: The perceived trend in cotton output in the Lower Kano Plain

Year	(3-4) bags/ha	(5-6) bags/ha	(7-8)/bags/ha	(9 and above bags/ha)
1990/1991	19	35	32	13
1992/93	0	37	39	24
1994/95	0	38	39	23
1996/97	0	41	38	19
1998/99	0	29	36	35
2000/2001	0	45	32	31

Notes: 1 bag of lint cotton is measured at 90 kilograms.

The trend in cotton output is illustrated in Table 5.20. It is evident that on average most households harvest between 5 and 6 bags of cotton. The highest output was recorded in 1995. As illustrated in Figure 5.18, prolonged inundation is said to limit access to cultivated lands and to delay planting. Disruption of the cotton growing calendar exposes the crop to the long dry spell and lowers the yield. Some of the cited implications of flooding characteristics on the cotton growth cycle are presented in Table 5.21.

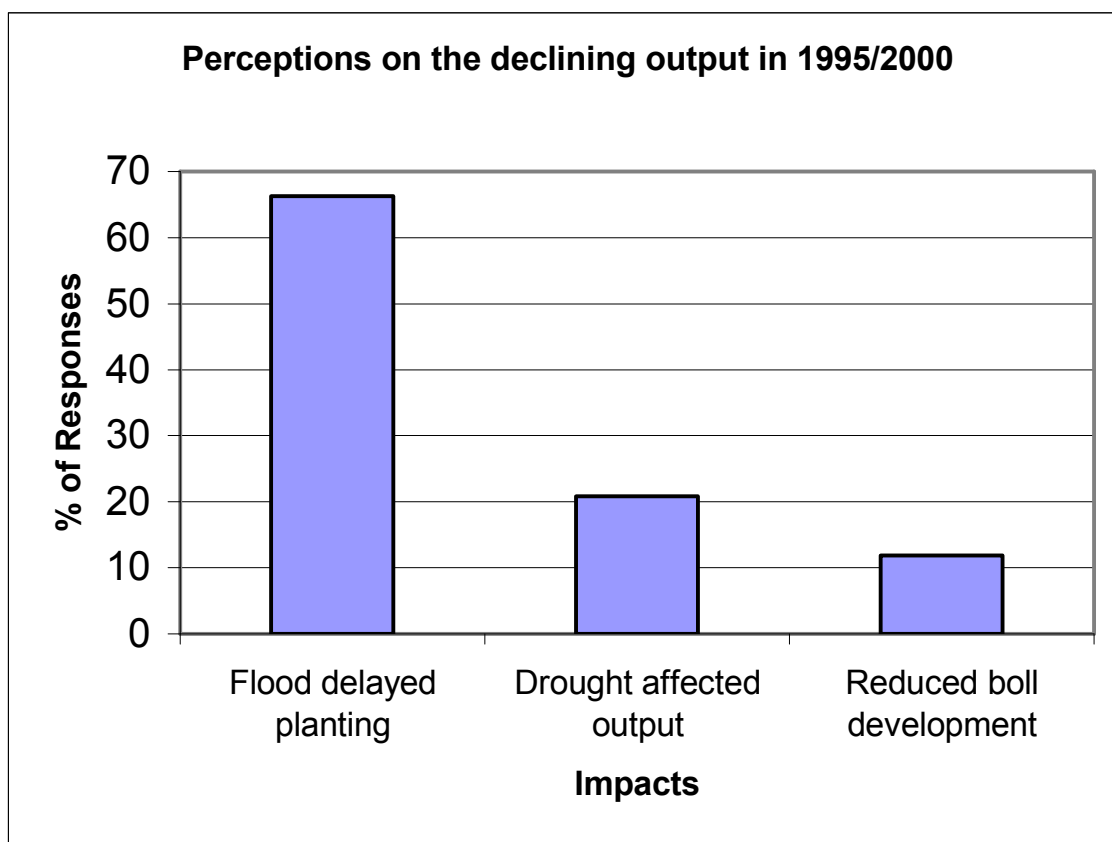


Figure 5.22: Perceptions about the decline in cotton output between 1995 and 2000

Table 5.21: Perceptions about the impact of flooding on the cotton growth cycle
(n=100)

Growth Cycle	Specific impacts cited	Proportion of respondents citing
Planting	Inaccessibility to farms	34
	Impedes germination	80
	Physical damage	69
Weeding	Increase in weeds	74
	Increased weeding cost	62
Flowering	Infection by pests	75
Boll development	Delay in boll growth and	62
	Boll infection	59
Harvesting	Destruction of lint and	77
	Quality of lint lowered	69
Marketing	Low quality lint fetches very low prices	70

According to Table 5.21, over three-quarters (80%) of the respondents stated that floods lowered seed germination. Physical destruction was cited by 69% of the respondents as harmful to cotton production, while less than half (34%) attributed low output to limited access to farmlands during prolonged inundation.

With regard to prolonged inundation, farmers stated that they were unable to prepare farms for planting. Physical damage to the bolls was mentioned by over half (62%) of the respondents as a common occurrence when inundation is prolonged.

5.4 Summary

The characteristics of the Nyando River and the significance of specific drainage characteristics on flow into the river and inundation in the study area are covered in this Chapter. The chapter furthermore examines the spatial variability of rainfall and flow as well as their pattern within the Nyando Basin and presents the rainfall and flow regimes in the Kano Plains. The cycles and the variability of rainfall and flow are illustrated, while the runoff coefficient for peak discharges is demonstrated. The cycles and periodicity of rainfall and flow are computed, and the anecdotal assessment of the impact of flooding characteristics on cotton cultivation is described.

In describing the characteristics of the Nyando Basin and its impact on flooding, it is evident that streams contributing runoffs and flow into the Nyando River originate from high altitude (1000 to 2000 m.a.s.l) and high rainfall (1200 to 2400mm) areas of the Nyando Basin. High runoffs into the main channel are the result of heavy storms, which cannot easily be contained within the channel of the Nyando River. This has contributed to bank flow and consequent inundation into the dry land. The convective storms caused by the anabatic and katabatic effects of the land and lake breezes have generated precipitation within the floodplain.

Rainfall causing runoffs downstream and into the flood plains are significantly influenced by human activities, which are not limited to deforestation at the watersheds. This has contributed to flooding and inundation of the lower reaches of the Kano Plains. The mean annual rainfall is higher for the large sub-catchments (Ainapngetuny and Kipchorian Rivers) than for the relatively smaller sub-catchments (Nyando and Awach Rivers).

The seasonal peaks for rainfall and flow show a strong relationship. The highest peaks are noted in April and May, thereafter in August and September, and finally in November. The long rainfall and flow peaks correspond to the planting season of cotton in the study area.

The results also show a significant inter-annual variability of flow with the coefficients of variation ranging between 30% and 39% for the high peak periods. The high peak period shows a strong correlation ($r^2 = 0.73$) between high peaks of rainfall and flow. The trend of flow shows evidence of a significant increase in the annual means of flow in the period 1970 to 1974, and 1975 to 1979. Similar increases are witnessed between 1985 and 1989, and finally between 1996 and 1998. These increases are attributed to lowered infiltration due to both low land cover and indiscriminate land use practices. Spectral analysis of the seasonality and periodicity of precipitation and flow reveal an annual and biannual monthly cycle. This is further confirmed from the wavelet results where a Quasi Biennial Oscillation (QBO) of rainfall and flow of a higher frequency in the later hydrologic period is evident. The high wavelet spectrum in the later period is attributed to a shift in the cycles of rainfall and subsequently flow as witnessed in the crossed hatched area of the spectral band in the mid 1980's and 1990s where flooding is highly signaled. Other significantly cited factors that affected cotton cultivation include;

- a. seasonal inundation,
- b. the long dry spell,
- c. low remuneration, and
- d. delay in payment mainly because of poor marketing mechanisms (details are discussed in Chapter 6.

CHAPTER SIX: SUMMARY AND DISCUSSION

6.0 Introduction

This section of the study presents a summary and discussion of the main findings that have been presented in Chapter 5. The discussion is based on the three research questions that this study has set out to investigate, namely:

1. have there been any quantifiable changes in flood frequency and magnitude with time and variable in space?
2. what flooding regime probably existed before anthropogenic influence, and
3. what anecdotal data (perceptions of cotton farmers) exists to support the assessment of flooding on cotton cultivation?

The impact of flooding characteristics on cotton cultivation in the Lower Kano Plain has not received much attention among researchers. The interactions of the fluvial characteristics in the Nyando Basin have been addressed by other researchers mostly the assessment of the destruction of forest cover and erosion (ICRAF, 2001) at the catchment, rainfall variability (Ochola and Kerkides, 2003) and flooding (NEMA, 2004) in the Lower Kano Plain. The degradation of the Nyando River watershed has to a large extent been blamed on the destruction of forest cover that has exacerbated runoff causing flooding that affect households living in the study area. The geomorphic (change in land cover) and hydrologic (change in flow regime) response in the Nyando Basin influence farming decisions, crop output and settlement patterns among the surveyed households.

It is, in general, evident from the results that most farmers living in the Lower Kano Plain are highly vulnerable to the impacts of the changing flow regime of the Nyando River particularly flooding and inundation. The seasonal variation of rainfall and flow has been demonstrated, and the trends of the variances are evidently not coincidental, as flooding tends to occur between the first and second rainy cycles. The extreme rainfall variation that causes either droughts or floods has negatively impacted on the majority of land use practices, including cotton growing. Cotton has continued to register a decline in terms of both hectare and total production, which has broadly been attributed to economic and environmental factors.

The economic factors that have hampered the growth of cotton production in Kenya, in general, and on the Kano Plain, in particular, include: delay in payments to farmers; the low price of cotton lint; the liberalization of the market for textile products, which has created competition from synthetic products and the sale of second hand clothes, all of which has resulted in the collapse of many textile industries in Kenya. In addition to this, climatic and hydrological factors such as drought and flooding have repeatedly been cited as having negative effects on the growing of cotton in the Kano Plain. The most important effects of such hydrologic variability are: variability of rainfall, and increased runoffs resulting in increased flood frequency and magnitude. These factors act solely or together to impact on cotton growing downstream. The most salient findings are discussed in the following sections.

6.1 Characteristics of the drainage basin of the Nyando River

The characteristics of the drainage basin of the Nyando River have been inferred from DEM (Figure 5.1). Streams discharging into the Nyando River are highly dissected and originate from the high rainfall zones within the sub-catchments of the Nyando Basin, whereas each of the sub-basins contributes significant amounts of flow into the main river channel as it flows downstream.

The spatial variability of rainfall shows the mean to be lower (between 800 mm and <1200 mm) downstream as compared to the rainfall volume in the upper zones (Nandi Highlands), where rainfall averages between 1,200 mm and 2,400 mm. In addition to this, precipitation is concentrated within the flood plain, mainly because of the effect of the Lake and land breezes that cause rainfall in Lake Victoria and the surrounding inland of the Lower Kano Plain.

Further findings show, generally, the decline in the annual rainfall from catchments to the west (Ainapngetuny) of the basin to those in the east (Awach). Although the sub-basins show similarity in the rainfall peaks, both the means and standard deviation demonstrate a decrease from east to west. Kipchorian Sub-Basin has, however, shown both an increase in amplitude and duration that is attributed to high storage and the smoothening effect of rainfall at the catchments.

Similar results have been recorded by Semazzi and Indeje (1999) and Song *et al.* (2004), all of whom have cited the incursion of the ITCZ as an influence in the rainfall volume between the highlands and the floodplain. The Kipchorian Sub-Basin is predominantly situated in a higher altitude and occupies a large expanse of the

plains compared to other sub-catchments. Thus, it records a fairly large annual mean rainfall. The declining precipitation from east to west can be explained by three factors:

- a. the influence of both the free (convictional rainfall) and forced (relief rainfall) convection on the trough;
- b. the drop in topography from the escarpments to the west to the plains in the east;
- c. the impacts of convection on the Congo airmasses and ITCZ (Lukiya, 2003).

The results suggest that rainfall is the significant driving mechanism, and that runoff causing flooding and inundation originate in the high altitude zones with an annual precipitation of between 1600 and 2400 mm.

In confirming the variability of flow within the catchment, the results of the runoff coefficient (C_r , which is the ratio of rainfall to runoff) is computed as 22%. This result, when compared to the computed runoff coefficient at the same gauging station (1GD04) in 1992 (LBDA, 1992), demonstrates 12% increase from 10% to 22%, which could suggest that there has been an increase in the rainfall event causing runoff or indiscriminate land use practices in the catchment has lowered infiltration, and thus exacerbating flooding in the last ten years.

This study therefore concludes that the high settlement density in the Kano Plains, as described by previous researchers (Muhia *et al.*, 2001; Mungai, 2001), has increased pressure on land use, mainly by means of increased farming, grazing, housing,

construction and deforestation of the catchment. This has disturbed land cover and the water absorption mechanism. The destruction of the catchment explains the increase in runoff coefficient and subsequent rise in frequent flooding of the Lower Kano Plain. Most significant is the reported increase in flood damage, even when rainfall is not significantly higher, which exacerbates runoffs and inundation.

According to this study, the non-damage discharge [$200\text{m}^3/\text{sec}$] cited by NEMA (2004) could as well be contributing to the flood damage recorded in the recent past. This is due to frequent floods and damage witnessed in the 1990s, which occurs almost on an annual basis. This could further be explained by the fact that other factors other than rainfall are responsible for the change in flow regime and peak flows by the Nyando River.

In addition, it is speculated in this study that the long profile of the Nyando River must be responding to geomorphic changes in land use that occasionally causes spate downstream. For instance, although the channel capacity of the Nyando River was estimated at $87\text{m}^3/\text{sec}$ in 1994 (Mwaka, 1994), there is evidence that the channel could have since recorded further decline as the sediment discharged into the Nyando River is reported to have increased (ICRAF, 2006) that is attributed to poor land use, which has exacerbated erosion in the floodplain (ICRAF, 2006).

6.2 The temporal and spatial variability of rainfall and flow

The regime of rainfall and flow as well as the trend (using 31 year time series continuous data (1970 to 2000)) are discussed.

6.2.1 Inter-seasonal variability of rainfall and flow

The results have revealed two rainfalls and flow cycles as the most dominant. The rainfall peaks identified are between March and April, representing the long rain season, while October and November are the second peaks. June, July, December, January and February are generally the dry months, with rainfall below normal.

Discharge shows a corresponding cycle in April and May (AM), where May recorded the highest peak, followed by the second flood peaks either in August and September or in October and November. The two dry seasons with flow below normal occur in December, January and February. July also recorded a below normal discharge, exhibiting a dry spell, and thus a low discharge.

There are, however, high levels of intra-seasonal variability of flow, the second flooding season could either occur early, between August and September, or in November – which demonstrates a shift in the rainfall cycles. Physical inspection of the partitioned 5-year monthly rainfall signals May, August and November as the most frequent peaks. This is further confirmed by transposing the partitioned 5-year monthly rainfall and flow for the 31-year time series data, which compare quite well with rainfall leading flow between one and two months lags.

The shift in rainfall and flow has affected the farming patterns in the Lower Kano Plains. Crops have become highly susceptible to the impacts of flood events as well as

the long dry spell. The shift in the hydrologic cycles, particularly rainfall hampers decisions on farming and affects the flood coping mechanisms among households. This is argued in this study to increase the damage caused by flooding. As cited in the anecdotal results, farmers have to cope with the changing rainfall and flood cycles, and sometimes are faced with the consequences of crop failure or poor cotton yield as a result of planting at the wrong times, since most of them follow the traditional cropping season that they have lived with since they started occupying the flood-prone Lower Kano Plain.

6.2.2 Inter-annual variability of flow

One factor that is evident throughout this study is the high level of variability of flow from one year to another. This variation is illustrated by computations and physical inspections of both the peak periods and the association between rainfall on one hand and flow peaks on the other. The variation is further illustrated by the results of the runoff coefficients for the high peak discharge from the 31 years long term flow data (1970 to 2000). The calculated runoff coefficient for the high peak years examined how the flood peaks have changed over time, and also to quantify how runoff has changed. The prevailing hydrologic and geomorphic mechanisms that yield the computed runoffs are then explained.

In the analysis, six periods (1977, 1978, 1988, 1990, 1994 and 1996) are inspected as years with the highest flow record. These years also exhibited high runoff coefficients compared to the rest of the periods within the 31-year time series data. It is evident that the mean annual runoffs for the above six periods show distinct variability, from 391 mm year^{-1} to $551.11 \text{ mm year}^{-1}$. There is a significant increase in annual runoff,

which is evidenced by variation in runoff coefficient between 30 % and 39 %. A significantly high runoff coefficient is observed in 1977 (35 %), 1988 (39 %) and 1996 (35%). Notably, there is also a strong correlation ($R^2 = 0.73$) between annual rainfall and runoff for the high peak period.

The spatial variability of runoff shows an increase in runoff coefficient for the ten years cycle, from 10% in 1992 (LBDA, 1992) up to 22 % in (2004), as revealed by the current results. Similarly, there is a steady increase in runoff between 35% and 39% in the six years of high peaks. The reasons cited earlier for the probable increase are: increased land use practices, deforestation, declining land cover, low absorption rates by the vertisols and an increase in runoff.

These results are in conformity with the findings by ICRAF (2001) and Shepherd *et al.* (2000), both of whom cite catchment degradation, particularly deforestation of the headwaters so as to exacerbate runoffs and erosion in the floodplains. Similarly, Mungai (2001) and Muhia *et al.*, (2003) speculate that with the high settlement density of nearly 237 persons per square kilometer, the floodplains of the Nyando River are highly susceptible to rainfall-induced runoffs.

This study has gone further by providing evidence of a significant increase in runoffs, both within the catchment (10 % to 22 %) and between years (35 % and 39 %). The increase in damage caused by flooding and inundation is also explained by the increase in the population occupying the floodplain – even when the danger of flood destruction of crops is known.

6.2.3 Intra-annual variability of rainfall and flow

While seasonal and inter-annual variability of rainfall and flow illustrate the variation of rainfall and flow cycles, it is observed that this variability is also reflected within the year. The peak flows examined were for 1976, 1977, 1983, 1988, 1990, 1994 and 1996. The variability of rainfall and flow within the peak years reveal a coherent pattern, which is similar in the regime of rainfall and flow where both exhibit three peaks (AM, August and October and November) for 1977.

In 1988, the rainfall regime and discharge mostly matched, apart from the lag time, which was fairly prolonged. The second and last cycle was also prolonged (3 months) from August to October (ASO). The trend of flow is explained more explicitly by the 5-year moving average.

6.2.4 The trend of rainfall and flows

The use of a 5-year moving average in trend analysis demonstrated an increase in rainfall from a mean of 1171.7 mm between 1970 and 1974 up to 1259.8 mm for the period 1975 to 1979. Similarly, discharge exhibits the same pattern with an annual mean increasing significantly from 239.2 m³/sec for 1970 to 1974, to 320.4 m³/sec for the period 1975 to 1979. A steady increasing trend in precipitation and flow is, however, noted between 1977 and 1979, followed by a decline between 1980 and 1983, thereafter a sharp increase in the annual mean flow to 257.9 m³/sec between 1985 and 1989. Significantly high peaks were recorded for both rainfall and flow between 1996 and 1998. The declining trend in precipitation and flow between 1980 and 1983 is attributed to the drought that affected most areas in Kenya and the Kano Plain in particular. There was also a decline in crop production.

In addition, an increase is noted in flow and rainfall in most of the periods, with the highest peaks recorded in 1977, 1978, 1988 and 1996. The preceding findings together with the anecdotal results show these periods separately cited as having the highest flood magnitude and damage to crops, particularly to cotton planted downstream in the study area. The significant increase in the runoff coefficient for the high peak periods (Table 5.4 and Figure 5.4) illustrate that flooding and crop damage is increasing variably. This view is shared by ICRAF (2001), which cites an increase in the rate of erosion as a result of overland flows due to poor land use practices at the River's catchment.

The high flow spikes are attributed firstly to high rainfall at the watershed, and then to the increasing runoffs into the river channel. In this study, other factors such as water abstraction for irrigation or industrial use, anabranching streams and change in channel morphology are speculated to interfere with the natural flow of the Nyando River. These factors could be examined in more detail in order to determine the variability.

6.2.5 Time series of rainfall and flow

The time series analysis examined the trend (linear or quadratic) and seasonality (a trend that repeats itself systematically overtime) is applicable to the study area. The 31-year time series of rainfall and flow exhibits a seasonal trend of flooding, which could have continued to affect cropping decisions in the study area. Similarly, the use the ARIMA (Auto-Regressive, Integrated, Moving Average) model in computing the time domain, as well as the spectral analysis and the periodogram employed the Fast

Fourier Transformation (FFT) technique in the frequency domain complemented the findings.

The results from ARIMA reveal that rainfall presents a strong annual and semiannual monthly cycle, which is followed by the oscillating spikes. The periodogram shows that April, August and November form the dominant rainfall peaks and that a strong annual and bi-annual cycle is also evident in discharge, whereas May, August and November form the frequent flow (flood) peaks in the study area.

The correlogram of rainfall show significant deviations from zero correlation at time lag 1 and 12, and very close at lag 2 and 10. These findings suggest a strong annual and bi-annual rainfall patterns spaced about 4 months apart, with an oscillating third cycle spaced about 8 and 10 months apart. Similar results are presented in the spectral density function (periodogram). A strong signal appears at about 6 and 12 months, corresponding with the annual and semi-annual cycle of rainfall. Visual inspections shows significant deviations from zero correlation at lag 1, 6 and 12, and very close at lag 7 and 13, which suggest that there are two seasonal patterns (flood discharge and drought discharge) spaced about 6 months apart, as well as an emerging 4 month cycle that is attributed to be the harmonic of the 6 month cycle.

Further results in the spectral domain using the periodogram and correlogram are used to inspect the cycles and periodicity. Findings from the spectral domain are similar to those from the time domain, which is presented by means of the ARIMA model. The correlogram of rainfall shows a strong correlation at lag 1 and 12, which is significant at a 95% confidence level. Flow also exhibits a strong correlation at lag 1, 6 and 12,

which confirms 12-month and 6-month seasonality, while the interrupted oscillations suggests instability. A significant relationship between the spectral density of rainfall and flow is evident as the spikes strongly correspond; this suggests that rainfall is the driving mechanism and that both rainfall and flow demonstrate 12-month and 6-month seasonality.

6.2.6 Results from Wavelet Analysis

The power spectrum of rainfall and flow is broadly distributed, with peaks signaled between 2 and 10 years band. The 5% significance regions (the red areas) indicate that 1972 to 1973 and 1984 to 1987 contain intervals of higher rainfall variance, while 1980 to 1983 is a time of lower rainfall variance. Similar variance changes are found in flow, where significantly higher bands occurred in 1974 to 1975 and 1996 to 1997, where flow were relatively higher. Both the spectra of rainfall and flow demonstrate that there is large power in the 6 and 12 month rainfall and flow period during the latter parts of the 31-year period [1970 to 2000]. In addition there are signals of 6 and 12 month rainfall and flood oscillations as well as power at even lower frequencies, which are in agreement with the performed spectra results.

6.2.7 Results from Analysis of Variance

The findings from the analysis of variance (ANOVA) of annual mean rainfall and flow reveal that there is a significant relationship between flow and rainfall as the computed $F(6.64) < 31.034$ at ($\alpha = 0.01$). Further results show no significant relationship both between and within groups of rainfall in the 31 year period, $F(1.696) = 0.558$, $P > .001$, while flow exhibited significant differences, $F(1.696) = 3.041$, $P < .001$.

Post-hoc test using DMRT revealed no significant differences in the multiple comparisons of the means of rainfall with each other but highly significant differences was shown in flow. The LSD and DMRT results are in doubt confirm the stochastic nature of flow as well as the seasonal and periodic regime of flow. The means of rainfall however, demonstrates that there has not been any significant variability of precipitation over the years that could subsequently alter the periodic changes in the flow regime.

The calculated R^2 (0.278) value means that 27.8% of the variation in flow of the 31 time series data is explained or predicted by rainfall. The rest (72.2%) of the variability is as a result of other factors mainly land use practices in the study area. The latter finding means that rainfall could explain only up to 17% of high flows. Most importantly, high precipitation (rainfall) at the catchment is found to predict flooding of the Nyando River. The most cited factors that are likely to exacerbate runoff causing floods are degradation at the headwaters due to poor land use, low channel capacity of the Nyando River as a result of increasing siltation downstream and poor drainage of the vertisols, which increases flood wash.

6.2.8 Flood frequency and magnitude

In terms of the magnitude and frequency of flooding, it is evident that in 1996, 1988, 1977 and 1978 recorded the highest flood magnitudes from the 31-year time series data. The magnitudes of these flood events were recorded as discharge of 521, 484.2, 415.5 and 408.6m³/sec. respectively.

It is also evident that the Lower Kano Plain is highly prone to flooding, with between three and nine year return intervals. Furthermore the results show that for the 31-year time series continuous flow data, bank-full discharge (200 to 387.9 m³/sec) nearly occurred for 18 years, while cases of inundations were reported on an annual basis downstream. It is argued in this study that bank-full discharges in the Nyando River have continued to cause spate as a result of the limited channel capacity. While the computed channel capacity downstream is 87m³/sec (Mwaka, 1994), there is evidence that bank-full discharges have caused damage on an annual basis with regard to land use downstream. The highest mechanically measured floods for the Nyando River are 521m³/sec (1996), a value not yet exceeded in the record period (1970 to 2000). The discharge values range between 44.7m³/sec (2000) and 521m³/sec (1996), with a mean of 254m³/sec, standard deviation of 116.37 and a skewness of 0.41.

The increasing variability of rainfall has also made it difficult to predict flows (floods) with great reliability. This variability was attested to by some of the previous researchers (ICRAF, 2000, Ochola and Kerkides, 2003). The authors studying rainfall variability in the Kano Plains at different times concur that, despite the paucity and poor recording of meteorological information in the study area, there is a high level of rainfall variability that makes flood forecasting relatively problematic. The results of this study reveal that the existing variability in rainfall and flow and the variability of flooding in Lower Kano Plains have subjected crop cultivation to damage caused by spates. Some of the problems associated with the variability flow and hence flooding were confirmed by anecdotal perceptions that are discussed in the section that follows.

6.2.9 Anecdotal perceptions of the impact of flooding characteristics on cotton cultivation in the Lower Kano Plains

This section reflects anecdotal data (the perceptions of farmers) that support the assessment of various characteristic impacts of flooding on cotton cultivation in Lower Kano Plains. The key anecdotal findings presented are the declining acreage under cotton cultivation; inundation of crop growing areas; poor drainage that encourages ponding; the poor response to rainfall and flow variability; low pricing of lint; delay in payment that discourages cotton farming; preference given to the cultivation of other crops, and the impact of a prolonged dry spell. Rainfall and flow variability often result in destructive flooding or a delay in planting that makes cotton vulnerable to the long dry spell. The anecdotal results are presented in more detail below.

6.2.9.1 Impact of flooding on cotton cultivation on the riverbanks

Increasing settlement density (Mungai, 2001; Muhia *et al.*, 2001) in the Kano Plains has resulted in forced settlement and crop cultivation next to the flood prone riverbanks. Most of the households grow horticultural crops near the river so that they are able to water them during the long dry spell. In spite of increasing pressure which sugarcane production exerts on cultivated land, in some instances maize, sorghum and cotton are also cultivated. In recent years infrequent flooding and inundation of the Nyando River has forced most farmers to grow crops that take short periods to mature. These crops can be watered easily by means of family labour, even when the long dry spells set in.

Households who have been expanding their cultivation of cotton along the riverbanks have recently seldom found cause for complaint about significant increases in inundation, low prices of lint and a delay in payment after the raw cotton has been sold. Such factors explain the low number (35%) of respondents who said that they grow cotton along the banks of the Nyando River.

Varying reasons are given by the respondents for the fluctuation in cotton production between 1994 and 2000. Although the majority of respondents (65%) cited periodic flooding and inundation downstream as reasons, it is the view of this study that much of the fluctuation has to do with economic parameters and poor marketing mechanisms. A significant proportion of the respondents specifically expressed disappointment with the continued delay in payments when speedy remuneration was required in order to pay for domestic needs and school fees for their children. This explains why there has been a dramatic shift towards the cultivation of sugarcane and rice. This is confirmed by over half (55%) of the respondents, who said that they have abandoned cotton growing and are now paying more attention to rice and sugarcane production. About 65% of the respondents furthermore said that the cultivation of cotton is labour intensive, and the remuneration per kilogram (USD 0.18/Kg) is relatively low compared with rice, for which they are paid (USD0.85/Kg) upon delivery.

6.2.9.2 Ownership of cultivable land and hectarage under cotton

While it has been pointed out that inundation is an environmental catastrophe that limits production in terms of acreage of cotton that can be actually harvested. Patriarchal and private land ownership practices in the study area have also

contributed to low production as a result of unrealistic apportionment of arable land. As evidenced by the results, the parcels are in smallholdings of between 1 and 6 hectares, with significantly few instances where individuals own more than 10 hectares. Apart from the physical damage caused by floods, over-cultivation as a result of high settlement density and poor crop husbandry are also to blame for the declining output.

This finding is not in any way unique, as previous studies (Obara, 1983; Republic of Kenya, 2002) have also pointed out that poor crop husbandry in the Kano Plains are exacerbated by low crop output. Furthermore, a feasibility study by LBDA (1992) attests to the increasing population density as a land use threat to improved agriculture, while ICRAF (2001) describes the study area as prone to serious environmental nexus due to catchment degradation.

This study therefore confirms the findings of the aforementioned studies, although the current study also demonstrates that geomorphic as well as hydrological entities in the River Basin, particularly the poor drainage, limited channel capacity and variability of flow, are prime geophysical factors that induce the overall impact of flooding on cotton cultivation in the Kano Plains.

The findings reveal that, while 45% of the households own on average 3-5 hectares of arable land, nearly 44% cultivate at least 1 hectare under cotton. About 30% of the households sow cotton on between 1.5 and 2 hectares of land, while only 23% plant more than 2 hectare. The findings indicate a manifestation of over-reliance on

smallholder agriculture, with only a few households (23%) preferring and practicing large-scale commercial cotton production.

The findings also demonstrate that while cotton is relayed with either maize or sorghum, which are normally planted before the onset of the long rains, much valuable time is spent in preparing the latter crops. This is noted to limit the time spent on effective cotton cultivation; sometimes it also limits the usage of adequate land that could have been used for effective cotton cultivation.

Further observation suggests that areas with limited cotton (about 1 ha) are usually prone to flooding and are thus avoided. This is unlike most arable lands upstream, where floods are contained and where farmers are able to cultivate large farms. Yet, about 44% of the households cultivate small parcels of land (about 1 ha) and they account for more than 72% of the cotton production. This category of households reiterates that they experience perennial floods that continue to impact negatively on crop production, particularly on cotton. Those farming on the raised grounds (28%) are free from severe damages by spate and as a result view only specific flood magnitudes as devastating. Among such floods are those that had affected the whole Kano Plain, such as the floods experienced in 1964, 1976, 1977, 1978, 1979, 1988, 1994, 1996, 1997 and 1998. The flood events cited by 28% of the respondents correspond to results of the time series, which point to the same flood periods as the ones that were most devastating.

6.2.9.3 Flooding and Cotton Output in Nyando District and Kano Plains

From the previous findings it is evident that despite the limited arable land available in the study area, the households examined in the study have continued to grow cotton through relay cropping. Relaying cotton with either maize or sorghum has both limited the area and output under cotton over the years (1980-2000). In the Nyando District, cotton is rated third as the most important crop, occupying a vast portion of arable land (6,000 ha), and as the most important cash crop in the Lower Kano Plains. In spite of this significance, the output records a decline of 655 tonnes of cotton compared to other crops (viz.; maize, sorghum and rice), where productions have remained comparatively steady despite the vagaries of the climate (Republic of Kenya, 2002).

Poor crop husbandry, relay of cotton with other crops and crop destruction by annual spates were cited as some of the main causes of the decline in cotton output and production in the study area (Obara, 1983; Lake Basin Development Authority, 1992; Republic of Kenya, 2002).

The actual cotton output registered a steady increase reaching its peak in 1980 (7000 tonnes), before a sharp recession of up to 2000 tonnes in 1983. A further increase in output was registered in 1989 where the output was 8000 tonnes of cotton, followed by a sharp decline the year 2000. The rise in output in 1980 and 1989 is attributed to the fact that the area under cotton was also significantly large, and recorded an increase of 2500 and 2800 hectares respectively.

Such a steady rise in actual output is as a result of the good rainfall as well as an increase in the use of farm inputs. The sharp recessions between 1981 and 1983, and 1990 and 1992, are reported to have been as a result of poor weather, mostly the long dry spell experienced between 1980 and 1983, which was repeated between 1990 and 1993.

Further results (see Table 5.24) have revealed a continued fluctuation in yields as well as in the area under cotton. For instance, cotton production showed unsteady fluctuation for most of the period. A key observation from the table indicates that yields increased by about 36.7% between 1990 and 1992, and recorded a 50.9% decline in 1993, in spite of an increase in hectares under cultivation.

A corresponding relationship between the acreage and cotton output is explicitly depicted in 1994, where both the acreage and output of the crop receded. The floods and resulting inundation in 1994 is attributed as one of the main causes. In the 1994/95-production years, a large increase in output was observed despite a drop (3.5%) in cultivable area between 1993 and 1995. This increase was induced by the high lint price that encouraged farmers to cultivate more land and to use better agronomic practices.

6.2.9.4 Flooding and Cotton Output in the Study Area

Generally, cotton production has registered a substantial decline in productivity in the period 1985 to 1994. The decline has been attributed to the variability of climate, which has caused meteorological drought and floods, as well as poor lint prices. The variability of climate in the study area is also echoed by Ochola and Kerkides (2003).

These researchers reveal that March, April and May form the prolonged wet period, while June and July make up the long dry spell. The two seasons are associated with either flooding or the long dry spell, both of which affect crop (cotton) cultivation. Flooding hampers planting and occasionally causes physical damage to cotton.

The findings show a high level of variability of cotton output between the years. Between 1990 and 1992 an increase of between 5-8 bags of lint was recorded. On average, the majority of households harvest between 5 and 6 bags (450-540 kg) of lint with the highest output being over 810 Kg of lint recorded in 1995, which was about 16.9% higher than the previous year.

It is to be noted that the frequent occurrences of adverse weather conditions, both the prolonged rainfall causing floods and the long dry spell, causing drought, impacted on cotton cultivation in the study area. Flooding and inundation cause water stress and inhibit accessibility to cotton fields. Limited access to farmlands due to ponding delays planting and exposes cotton to the long dry spells from June to October, which affects the crop productivity. The response to these climatic adversities is limited. The results show that most households respond to flood damage by cultivating rice and sugarcane, which are considered resistant to water stress and able to withstand poor drainage. Even when the long dry spell sets in, the ponded farms are still able to sustain rice and sugarcane, unlike cotton that is highly vulnerable to poor drainage. Economically, rice and sugarcane cultivation is seen as a profitable undertaking, and the remuneration is always prompt.

Conditions of well-distributed rainfall and absence of flooding between 1990 and 1992 contributed to the increase in output of cotton from 55,908 Kg to 72,357 Kg. More land was cultivated and there was an increase in the use of hybrid seeds as the government stepped in to encourage cotton production. A sudden decline in both the acreage and output under cotton was again witnessed between 1993 and 1995. The crop (cotton) was at an early growth stage when it suffered both physical and biological damage as a result of pounding. The flood damage forced the majority of the households to repeat in whole, or in part, the work already performed.

The above results call for the implementation of earlier proposals by the Kisumu District Annual Report (1992), the Kisumu District Development Plan (1998-2001) and the Nyando District Development Plan (2002-2008). These proposals suggest the need for improving the cropping pattern to cater for climatic adversities (floods and droughts) in the Kano Plains. The shift to the cultivation of rice and sugarcane is echoed by the majority of the households as one of the coping mechanism to flooding and inundation. Besides, these crops are highly remunerating compared to cotton, which requires intensive labour and the application of insecticides, which are expensive.

The findings of JICA, the Kisumu District Annual Report, the Kisumu District Development Plan and the Nyando District Development Plan are however, comparable to those of the present study. There are three explanations for the differences encountered. Firstly, this study utilised the perceptions of the households over a short period of time; secondly, although floods are considered to cause physical damage to cotton, they are also seen as precursors to the eventual destruction of crops

by the long dry spells – after floods and inundation have delayed planting and have exposed cotton to drought. Finally, the choice of cotton was specifically meant to examine extreme cases of a crop that has not enjoyed the accredited potentials of the fertile valley floor (delta), despite its suitability and great significance in the study area. The illustrations in the subsequent sections simplify the impact of flooding on the cycle of cotton, as described by the respondents.

6.2.9.5 Flooding and the Cotton Development

The growth stages that are discussed include planting, weeding, flowering, boll development, harvesting and marketing. Marketing is here considered a growth stage in the context of the perception of the households, as it is the final stage when lint quality and quantity determine the revenue that accrues to farmers. The response of cotton to flooding depends entirely on the period of flood occurrence, the length of time that cotton has been produced on the farm, the crop growth stage, and its response to the magnitude of spate.

Specific damage to crops by the excess flows depends on the location of cotton fields in the flood-prone zones. The results, however, show that only a paltry 28 % of the respondents live on the raised grounds, which are only affected by floods of between $415\text{m}^3/\text{sec}$ and $521\text{m}^3/\text{sec}$ magnitude. The majority (72%), however, do their planting in the low-lying plain, which is prone to flows that exceed $200\text{m}^3/\text{sec}$.

6.2.9.6 Flooding and Cotton Planting

The findings in Chapter 5 reveal that over three-quarters (76%) of the respondents allude to the fact that the germination of cottonseeds is hampered during spate, despite the significance of the crop cycle in cotton development. More than half (56%) of the respondents said that physical damage from specific flood peaks caused damage to the crop, while the rest of the respondents cited inaccessibility to cultivated fields as the cause of difficulty in land preparation and planting. Also cited is an increase in the volume of weeds after floods have receded. Weeds retard crop growth and increase the cost of weed removal, as more man-hours are required. It is revealed that prolonged inundation not only limits access to farmlands but also prevents farmers from effective weeding, as poor drainage hampers the workability of the heavy clay soils, which exacerbate weed growth.

6.2.9.7 Flooding and cotton boll development

Boll development is a critical stage in the growth cycle of cotton. Rampant boll infections delay boll development, and the majority of the respondents (62%) ascribe boll damage to the wet weather conditions. The destruction of cotton bolls lowers the lint quality and output.

6.2.9.8 Flooding and Cotton Harvesting

While physical destruction by floods results in a lowering of cotton lint yield, it is also evident that cotton picking becomes more difficult under flood conditions. Most of the lint gathers dust, which makes selection more difficult, resulting in poor quality selection, grading and, hence, remuneration. In many instances the remuneration from

the sale of cotton is not commensurate with the cost of labour and the production inputs used by farmers in cotton growing.

The anecdotal results reflect people's responses to adverse hydrological conditions in the Lower Kano Plain. Flood damage also affects other crops, but cotton is said to respond the soonest to flooding and inundation and cotton is also more susceptible to damage caused by the long, dry spell. Its poor resistance to adverse conditions makes its cultivation difficult in the flood prone areas – even more so in high settlement density areas where competition for land uses is rife.

The results are in accordance with the views of most of the respondents as well as the theoretical literature. While over three quarters (80%) of the respondents blame the failure of cottonseeds to germinate on inundation, a significant 69 % ascribe physical damage of cotton to floods that destroy the plants. This destruction takes place in three stages. The first, takes place between March and May, during the long rainy season. Most of the damage cause then is related to limited seed germination, physiological changes and retarded growth. Secondly, when flooding delays planting, or when the running water washes the entire crop away. Re-planting exposes the crop to the long dry spell that is documented (LBDA, 1992) to set in between June and October, when the high November peaks finally impact the mature crop.

A study on the agronomic and environmental determinants of clay soils on cotton production in the Kano Plains conclude that poor drainage and inundation of the floodplains has curtailed smallholder cotton cultivation mainly by limiting access to farmlands (Obara, 1983; LBDA, 1992; Kenyaweb, 2003). Similarly, inhibition of

seed germination, retarded shoot and root growth, arrested reproductive development, morphological changes, as well as death of cotton plants, are some of the observable indicators of prolonged flood duration revealed in the present study. The rapid growth and cultivation in this context is associated with the capacity of cotton for free growth. The formation of new leaves is observed to have been inhibited during the flood period, and this was likened with a marked decrease in height and root growth observed in studies conducted elsewhere (Kozlowski, 1984).

The negative impact of stagnant water on cotton was recognized by earlier researchers (Kozlowski, 1984; Obara, 1983). In his experiment on the adaptability of crops to water stress, Kozlowski (1984) found that flooding with standing water, more so than with moving water, reduced the formation of the seedlings in the less resistant plant species, for example cotton. He further documented that height growth and dry weight increment were lowest in crops found in stagnant water, which has the lowest oxygen count and the highest carbon dioxide content. Similar findings were also made in the current study and it is concluded that flooding adversely influences shoot development as well as the root growth of cotton.

As documented in an earlier study by Kozlowski (1984) and as revealed in this study of the Kano Plains, there is general consensus that the depletion of oxygen in the flooded soils limits the physiological activity of cotton shoots, which in turn retards its growth. The mechanical support of the root system is substantially reduced, especially in the flooded soils of the Kano Plains, where cotton plants are exposed to physical damage by high flood depths.

6.3 Summary

The discussion of the results presented above shows that there is a relative decline in cotton production in the study area. This is attributed to persistent cultivation of cotton in the flood-prone areas and to economic factors that contribute to the decline in production and a shift to more productive crops. Ikiara and Ndirangu (2001) cite low lint prices and poor cotton marketing chains as the main culprits for declining production. Other factors mentioned in this study are delays in payments, the high cost of farm in-puts, variability of rainfall and floods. The anecdotal results indicate that floods (23.5%), drought (21.6%) and low prices (19.6%) act together to negatively impact on cotton growing.

Persistent inundation and flooding lower the acreage under crop. Apart from direct physical flood damage to cotton, there is every reason to believe that the declining area of cultivable land further explains the persistent decline in cotton output. This is due to limited access to arable land as a result of prolonged inundation. The fear of high flood depths and physical damage to cotton has limited its cultivation closer to the riverbanks, which has increased small-holder cotton growing near to homesteads and far away from the riverbanks. In terms of availability of land for cotton cultivation it was revealed that:

- a. Small-scale cotton production is predominant as compared to limited large-scale commercial cotton production;
- b. Limited land availability, due to competition with other arable crops, as well as land under temporary inundation causes a decline in acreage under cotton farming. This has increased the relay of crops, and lowered productivity and output of cotton, and

- c. Large-scale cotton production is predominant in the raised zones that experience limited flood damage.

Generally, a persistent decline in cotton output to (655 tonnes) was experienced between 1987 and 1989 (Republic of Kenya, 2001c). Between 1989 and 1992, the output increased steadily, and was attributed to good rainfall and an increase in the use of farm inputs and better seeds through a campaign to improve cotton production in the Nyando District by the Kenya Ministry of Agriculture (Republic of Kenya, 2002-2008). Between the 1990 and 1992-production years, cotton registered another increase in yield by 36.7%, before a significantly sharp decline of 50.9% was experienced in 1993. This decline was registered despite an increase in hectares under crop. This decline is attributed mainly to vagaries of the weather, mainly the long dry spell. A farther decline in 1994 was as a result of damage by floods ($371.2 \text{ m}^3/\text{sec}$), while an increase recorded in the 1994/95 production years is mainly seen as a result of improved lint prices. Most farmers picked between 270 and 360 kilograms/ha of lint, which is comparatively higher than the previous years.

This study has further shown that, in spite of poor drainage, flooding and the long dry spells are to blame for the decline in both the acreage and output under cotton. Low remuneration, the collapse of cotton marketing societies, the high cost of insecticides and delays in payment have all contributed to the shift towards rice and sugarcane production, although some households are still hanging on to cotton farming in order to subsidize the high paying rice and sugarcane.

CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS

7.0 Introduction

The present study set out to investigate the impact of the flooding characteristics of the Nyando River on cotton cultivation in the Lower Kano Plain in the Nyando District of Western Kenya. The temporal and spatial variability of flow was examined and the regimen of rainfall and flow was determined. The study included the flooding regime that probably existed before large anthropogenic influence became manifested in the study area as well as anecdotal data (perceptions of farmers) in support of the impact assessment of flooding, and in particular certain flooding characteristics on cotton cultivation.

The aim of the study was to arrive at meaningful and useful conclusions that would pave the way for plausible and relevant recommendations for the benefit of local farmers, policy makers and future researchers alike, in a bid to enhance flood management and crop production decision-making in the flood prone areas of the Lower Kano Plains and elsewhere, with similar hydrological conditions.

A comprehensive list of conclusions derived from relevant research findings as well as pertinent recommendations is presented in the light of the research objectives and questions that were set to be investigated in Chapter 1. In addition to this, specific contributions made by this study with regard to the set objectives are presented.

The specific objectives of this study were as follows:

- (i) to describe the characteristics of the drainage area and drainage density of the Nyando River, and explain how they have influenced the nature of flooding, its magnitude and frequency in the Lower Kano Plains;
- (ii) to determine whether the flooding characteristics have changed with time, or whether they are variable in space;
- (iii) to describe the natural flooding regime that probably existed prior to large anthropogenic influence, and
- (iv) to describe anecdotal data (cotton growers' perceptions) in support of the impact assessment of certain flooding characteristics on cotton cultivation in the study area.

Four research questions were formulated from the objectives mentioned above:

- i. has the drainage basin characteristics (drainage area, density and land use changes) of the Nyando River influenced the nature of flooding, its magnitude and frequency in the Lower Kano Plains?
- ii. has there been any quantifiable change in flood magnitude and frequency with time or in space?
- iii. has there been any change in the flooding regime between 1970 and 2000?, and
- iv. what anecdotal data (perceptions of cotton growers on the impact of flooding characteristics on cotton cultivation in the study area) is available to support the assessment of flooding impacts on cotton cultivation?

7.1 Conclusions

7.1.1 The first objective of the dissertation was to describe the impact of the drainage basin's characteristics on flooding in the Lower Kano Plains. The following conclusions were drawn from the results of the study:

1. The large drainage area of the Nyando River contributes (in terms of flow and flooding downstream) mainly from streams dissecting the sub-basins and which discharge into the main river.
2. There is variability of rainfall and flow to be found in the Nyando Catchment. Runoff generating floods are concentrated downstream and in the floodplain. This suggests that flooding in the Kano Plain is influenced by high storms and runoff from the Nandi Hills downstream to the impermeable plain, which causes ponding of the dry lands and cultivated fields.
3. There are corresponding spikes to be found in graphs for both rainfall and flow. The long rainy season (March to May) corresponds with the high flood peaks, which are repeated in November during the short rains. August has significantly been noted to emerge as the third flood peak in the study area. This marks the unstable conditions in the spectral results, where annual and bi-annual rainfall and flow are signaled. The 6 and 12 monthly cycle of rainfall corresponds to the cycle of flow from the spectral domain, although flow shows between 1 and 2 months lag.
4. The vertisols (black clay soils) are the dominant soil type and are characterized by poor drainage and water logging conditions. These soil types are difficult to work after a prolonged rainy season and are occasionally inundated for a long period of

time, hence the limitation to the area under crop. The plasticity and stickiness of the vertisols subject farmlands to waterlogged conditions and flooding during the long rainy season, making land preparation and cotton planting very difficult.

5. The geomorphology of the Lower Kano Plain shows that it is drained by numerous lower tributaries. The streams discharge into the main channel (Nyando River) and sometimes overtop due to the channel's limited capacity to hold excess flows. This causes spate in the adjacent dry-cultivable land, which subsequently interferes with cotton production.

7.1.2 The second objective of this study was to determine whether flooding characteristics have changed with time, or they are variable in space. From the results it is concluded that:

- a. High variability of flow is evident throughout the period under study, namely the flooding periods ($400\text{--}521\text{ m}^3/\text{sec}$) recorded in 1977, 1978, 1988 and 1996. The same periods also reflected higher rainfall peaks. From the 31 years of time series flow data, 18 years of bank-full flow ($200\text{--}387.9\text{ m}^3/\text{sec}$) were recorded.
- b. The 31-year time series data reveal that the Lower Kano Plain has so far experienced flooding nearly every year. While $400\text{--}521\text{ m}^3/\text{sec}$ are the flood discharges computed, it is argued in this study that the annual floods and inundation are the results of bank-full flows that are unable to be contained in Nyando River low channel. Discharges causing floods, however, have between 3 and 7 year recurrence intervals, with an average $400\text{ m}^3/\text{sec}$ discharge.

- c. Further evidence reveals that the variability of rainfall could only predict up to 17% of the flooding in the study area. It is, however, observed that flooding follows the rainfall pattern and lags between one and two month periods.

7.1.3 The third objective of this study was to describe the natural flooding regime that probably existed before large anthropogenic influence became evident. It was concluded that:

- a. There was a significant increase in runoffs in the last decade. The runoff coefficient shows runoff to have doubled from 10% computed in 1992 up to 22% revealed in this study. This is further supported by significantly a high runoff coefficient for high flow peaks that was revealed to be between 35% and 39%. The increase in runoffs is attributed to land cover change and deforestation that hinders the infiltration of rainfall.

7.1.4 The fourth objective of this study was to describe cotton grower's perceptions, or anecdotal data, in support of the impact assessment of certain flooding characteristics on cotton cultivation in the study area. From the anecdotal results the following conclusions were drawn:

- a. Flood depths of between 2.5 and 3 meters are the most dominant, and they affect 46 percent of the households. These are followed by flood depths of 0.5 and 1 meter, which affect 34.7 percent of the households in the study area. On average, the study area experiences between 1 and 3 meters of spate during any period of flood peak. These flood depths cause severe damage downstream of the Nyando River.

- b. Physical destruction (37.1%) of cotton is predominantly the result of high flood depth rather than impeded seed germination and destruction of cotton bolls, which account for 18.2, 24.6 and 25% of the negative impacts, respectively. This finding suggests that spates of high depths encourage the velocity of flows, which is instrumental in causing physical damage (viz: uprooting and washing away of seedlings) in the study area.
- c. Inundation of the study area has resulted in numerous setbacks in terms of cotton production in the Lower Kano Plains over the years. From the 85% of households that sow cotton, nearly half experience low yields and cotton destruction as a result of spate, with the result that some 15% of the respondents had shifted from cotton cultivation to other crops (i.e. sorghum, sugarcane, rice). These crops are considered more resistant to flooding conditions, as well as to water stress, which is notorious in the study area.
- d. More specifically, the factors that have led to the decline in the cultivation of cotton are: flooding, drought, low prices of cotton and limited arable land. Among the factors thought to affect cotton production, floods account for the highest percentage, namely 23%. Nearly, half of the households grow cotton away from the banks of the Nyando River, especially in areas that are less affected by excess river flows. This is due to the dangers posed by high flood depths along the riverbanks and the general fear of physical ravages to crops caused by spate.

- e. The majority of households harvest between 5 and 8 bags of seed cotton, with a fluctuation in output realised throughout the production period (i.e. 1990 to 1995). The declining output from 87,048 (1994) to 57,357 (1995) was caused by delay in planting (67%) due to prolonged rainy seasons and flooding, which is succeeded by severe drought.
- f. An increase in flooding conditions accounts for 67% of the reduction in cotton output in the area. It was further established that delays in planting, coupled to the emerging long dry spell, not only accounted for the other 21% of reasons cited for the decline, but also for the fluctuations in cotton production between 1990 and 1996. It is therefore important to note that the recent reductions in both area and cotton output mainly occurred as a result of continued loss of interest in cotton production by residents of the Kano Plains.
- g. It has also been shown that failure of the seeds to germinate and physical damage to cotton caused by floods, impact negatively on cotton after planting. For instance, an assessment of the relationship (s) between flooding, flowering and boll development, shows that flower destruction by pests account for most of the impact, while a delay in boll development constitutes 62% of the results ascribed to the impact of prolonged flood duration. The latter flooding condition limits the workability of soils in cotton fields, since limited access to cotton fields is not deemed a serious factor influencing cotton planting during flooding conditions.

7.2 Recommendation

The recommendations presented in this section are based on the research findings drawn from the foregoing sections.

7.2.1 Recommendation to cotton extension officers

- a) This study has established that concerted efforts have been made to improve drainage in order to reduce the severity of high flows in the study area. Uncontrolled flows are, however, dominant and cover a large portion of cultivable land at any time of peak flow. For example, the lower reaches are found to be prone to floods of three and nine year frequency, and particularly to discharges exceeding $87\text{m}^3/\text{s}$ that occasionally spill over the limited channel of the Nyando River. It is recommended that cotton farmers change their previous cultivation patterns and consider re-organizing their cropping and settlement patterns in areas that are less prone to prolonged flooding.

- b) It was also found that the onset of the rainy season and flood periods influenced the cotton-growing calendar. This implies that farmers need to be made aware of the rainfall pattern, and specifically of rainfall peaks that are likely to interfere with normal cotton growth. In addition, land preparation could be done prior to long rains and flood peaks, in order to reduce over-delay in sowing, as this would help reduce cases of inaccessibility to cultivable land due to prolonged flood duration.

7.2.2 Recommendation for the Ministry of Agriculture

- a) According to this study, it is far from sufficient for individual cotton farmers to merely have knowledge of rainfall and flood peaks for any effective response to cotton cultivation in the poorly drained Lower Kano Plains. Although it is recommended that it is important for both farmers and extension officers to respond to the flood cycle through minimized cultivation of cotton in areas that are comparatively raised. This will help farmers to avoid the increasing cost of annual damage as a result of flooding.
- b) The Ministry of Agriculture could also help cotton farmers to improve on crop husbandry, particularly for the local agronomic and environmental conditions, by promoting the use of certified cotton seeds. Most important is the farmers' response to prolonged flooding conditions and dry spells that affect cotton growing in the study area.

7.2.3 Recommendation for farming policy

In addition flood preparedness, relief and recovery measures are recommended. This is necessary because the possibility of floods always persist despite viable flood control measures, including the construction of engineering structures and watershed management technology. Flood preparedness, relief and recovery have to be planned in advance to meet any disaster, and hence to minimize loss of crops and property. In this study, such preparations include flood forecasting, flood warning, flood fighting, evacuation and provision of community shelters and relief camps for people, to mention but a few. It is important to enhance timely flood warning, which is the

responsibility of the relevant Flood-forecasting Department in Kenya to execute flood preparedness mechanism. Some of the recommended measures in this regard are;

- a. emergency evacuation: this measure has been used before in Kano Plains. It is an important aspect of fighting floods and needs to be resorted to in cases when the Nyando River's water level seems likely to exceed the level of settlements built on its banks. All people, including their cattle and valuable belongings, need to be evacuated in order to be settled in higher and safer areas
- b. food, shelter and toilet facilities need to be arranged for those who are evacuated.
- c. after the flood has subsided, the resettlement of those who have been evacuated is another crucial task that has to be accomplished as soon as possible.

7.2.4 Follow-up and further Research

As a follow-up to this study, it would be of value to revisit the results of the impact of flooding of the Nyando River, and in particular the effect of flooding characteristics on crop cultivation in the Lower Kano Plains. This suggestion is made in anticipation that flood parameters examined would annually continue to cause significant damage to crops and cultivable land, and continue to vary from year to year. Areas that require further research include:

- a. Further assessment of the geophysical characteristics of the Nyando River and changes to the river regime, particularly with regard to the anabranching streams;
- b. Flood impact on other crops, especially on maize and beans, which also seem to fare poorly in the Kano Plains due to prolonged floods and following drought.
- c. A thorough investigation of an integrated catchment management model for short term decisions on crops and flood management in the Nyando River basin
- d. A detailed wavelet analysis of hydrological parameters and their impact on rainfall regime, river flow and flooding in the Kano Plains.

REFERENCES

- ADEC (1998): A diagnostic study on cotton ginning and textiles industry development. Final report to the Ministry of Industry Development and Ministry of Planning and National Development.
- Ahmed, T.A. (1998): Worth of rice cultivation in the Nile Delta: 24th WEDC conference on sanitation and water for all. Islamabad: Pakistan.
- Andah, K. (N.d): The River Basin as a Basic Unit of Integrated Water Resource Management (Available online)
- Anderson, R.J., dos Santos, N. da. R. and Diaz, H.F. (1993): An analysis of flooding in the Parana-Paraguay River Basin. LATEN Dissemination Note 5, Washington D.C.: World Bank, Latin America and the Caribbean Technical Department, Environmental Division.
- Andreo, B., Jimenez, P., Duran, J.J., Carrasco, F., Vadillo, I. and Mangin, A. (2006): Climatic and hydrological variations during the last 117-166 years in the south of the Iberian Peninsula, from spectral and correlation analyses and continuous wavelet analyses. *Journal of hydrology*, vol.324, Issues 1-4, 24-29. Retrieved June 15, 2006, from Science direct database.
- Anyadike, R.N.C. and Phil-Eze, P.O. (1989): Runoff response to basin parameters in southeastern Nigeria. *Geografiska Annaler, Series A*, V.71A, 75-84.
- Anyah, R.O, Semazzi, F.H.H., and Xie, L (2003): The Physical Mechanisms associated with the variability of Lake Victoria basin climate. *Theoretical and Applied Climatology*, 79, 55-69.
- Arnand, P., Bourier, C., Cisneros, L., and Dominguez, R. (2002): Influence of rainfall spatial variability on flood prediction. *Journal of hydrology*, 260, 1-4, 216-230. Retrieved June 01, 2006, from Sciencedirect database.
- Baker, V.R., Kochel, R.C., and Patton, P.C. (1988): *Flood Geomorphology*. John Wiley & Sons, Inc.
- Benda, L., Andras, K., Miller, D. and Bigelow, P. (2004): Confluence effects in river interactions of basin scale, network geometry, and disturbance regimes. *Water Resources Research* 40 (5), EPWO5402.
- British Broadcasting Corporation [BBC] (2000): Rivers of great flooding concern. Retrieved June 28, 2004, from <http://edcwzks.40cr.usqs.gov/sa.floods>.
- British Broadcasting Corporation [BBC] (2000): Floods cause massive destruction in East Africa. Retrieved June 28, 2004, from <http://news.bbc.co.uk>.
- Blume, T., Zehe, E. and Bronstert, A. (2007): Rainfall-runoff response, event based runoff coefficient and hydrograph separation. (In Kundzewicz, Z.W., and Koutsoyiannis, D. *Hydrological Sciences Journal*. 52, number 5.

- Biswas, A.K. (1990): Objectives and concepts of environmentally sound water management. In Environmentally sound water management, Ed.N.C. Thanh and A.K. Biswas. Delhi: Oxford University Press. 30-58.
- Breilinger, R., Duster, H. and Weingartner, R. (1993): Methods of Catchment characterization by means of basin parameters (assisted by GIS) empirical report from Switzerland. Report-UK Institute of Hydrology, V. 120, 171-181.
- Bruce, R.R. and Romkens, M.J.M (1965): "Fruiting and growth characteristics of cotton in relation to soil Moisture tension". *Agronomy Journal*; 57: 135-140.
- Calder, I.R. (1996): Forest and Integrated Water Resources Management. DFID Forestry Research on Forest and Water Interactions. Forests and Water.
- Calder, I.R. and Aylward, B. (2006): Forest and floods: Moving to an Evidence-based Approach to Watershed and Integrated Flood Management. IWRA. Vol. 31
- Chapman, G. (1994): Earthquakes and Natural Hazards: What is Floods?. Geohazards Factsheets, Geoscience Australia. Retrieved May 25, 2005, from <http://www.ga.gov.au/urban/factsheets/floods>
- Clarke, S.J., Bruce-Burges, L. and Wharton, G. (2003): Linking form and function: towards an eco-hydromorphic approach to sustainable river restoration. *Aquatic Conservation and Freshwater Ecosystems* 13, 436-50
- Clem Tisdell, (1993): Environmental Economics: Policies for Environmental Management and Sustainable Development, Edward Elgar Pub. Comp. 259.
- Cooke, R.U. and Doornkamp, J.C. (1990): Geomorphology in Environmental Management, Oxford Univ. Press, New York: 2nd Ed.
- Cui, X., Graf, H.F., Langmann, Baerbel and Huang, R. and Chen, W., (2007): Hydrological Impacts on the South Coast Tibetan Plateau. *Earth interactions*. Vol. 11 Paper no. 5. Available online. <http://earthinteractions.org>
- Daas, J. (2002): Hydraulic Conductivity measurement in the Katuk-Odeyo Watershed, Western Kenya. Its distribution over different type of Land use and its implications on hydrological response. World Agroforestry Centre Publication Series
- Dollar, E.S.J. (2001): Fluvial Geomorphology: In Vogt *et. al.*, 2002. Deriving drainage networks and catchment boundaries: a new methodology combining digital elevation data and environmental characteristics. Retrieved from Science direct database
- Dollar, E.S.J. and Rowntree, K.M. (2003): Geomorphologic Research for the Conservation and Management of Southern African Rivers. Vol 2. Managing Flow variability: The geographical Resource. WRC Report No. 849/2/03

- .Elkaduwa, W.K.B., Sakthivadivel, R. (1999): Use of historical data as a decision support tool in Watershed Management: A case study of the Upper Nilwala Basin in Sri Lanka. Colombo, Sri Lanka: IWMI. vi, (IIMI research report 26). Available online: www.iwmi.cgiar.org
- Elshorbagy, A., Panu, V.S. and Simonovic, S.P. (2002): Group-based estimation of missing hydrological data: I. Approach and general methodology. *Hydrological Sciences Journal*, 45 (6)
- Encyclopaedia Britannica (2004): Encyclopedia Britannica Premium Service. Retrieved July 30, 2004, from <http://www.britanica.com/eb/article.en-.11910>.
- Environmental Systems Research Institute [ESRI] 1996): ArcView GIS. The geographic information system for everyone. Redlands, California, USA: Environmental Systems Research Institute, Inc.
- FAO and WFP (1998): Crop and Food Supply Assessment Mission to Zambia. Retrieved June 04, 2004, from <http://www.fao.org/docrep/004>.
- FAO/WFP (2002): Crop and Food Supply Assessment Mission to Malawi. Retrieved May 29, 2004, from <http://www.fao.org/docrep>.
- Ferguson, R.I., Parsons, D.R., Lanes, S.N. and Hardy, R.J. (2004): Flow in meander bends with recirculation at the inner bank. *Water Resources Research* 39(11), WR001965.
- Gereffi, G. (1994): "The organization of buyer-driven global commodity chains: How US retailers shape overseas production networks. In KIPPRA (DP/24).
- Gibb, A. and Partners. (1956): Kenya Nile Basin Water Resources survey, 1954-1956 Mat Café and Cooper Ltd.
- Gollmer, S., Harshvardhan, R.F., Cahalan, and Snider, J.B (1995): Windowed and Wavelet analysis of marine stratocumulus cloud inhomogeneity. *Journal of Atmospheric science*. 52: 3013-3030
- Gregory, K.J. and Walling, D.E. (1973): Drainage basin form and process. London: Edward Arnold.
- Grover, L.R, Burn, H.D. and Cunderlik, M.J. (2002): A comparison of Index flood estimation procedures for ungauged catchments. *Canadian Journal of Civil Engineering*. Rev.can.genie.civ. 29(5):734-741. Retrieved June 23, 2006, from <http://www.pubs.nrc.cnrc.gc.ca/cgi>
- Halcrow and Partners (1994): Estudio de regulation del valle alluvial de los Rios Parana, Paraguay y Uruguay para el control de las inundaciones. Buenos Aires: Sir William Halcrow and Partners.

Hardy, R.J. (2005): Fluvial geomorphology: Progress in Physical Geography. Progress Reports. (Available online)

Hefny, K. and Shata, A. (1995): Strategies for Planning and Management of Groundwater in the Nile Valley and Delta in Egypt, SRP Working Paper Series No.31-1, MPWWR, Cairo.

Henderson-Sellers, A., McGuffie, K. and Pitman, A. (1996): The project for intercomparison of land-surface schemes: 1992-1995. Climate Dynamic. 12: 849-859. Available online: www.lmd.jussieu.fr/polcher

Ikiara, M.M. and Ndirangu, L.K. (2003): Prospects of Kenya's Exports under AGOA after 2004. The Kenya Institute for Public Policy Research and Analysis (KIPPRA). DP/24.

International Center for Research and Agroforestry [ICRAF] and Ministry of Agriculture and Rural Development (2000): Final technical report, Start-up phase, July 1999-2000, Improved land management in the Lake Victoria Basin: Linking land and lake, research and extension, catchment and lake basin.

International Center for Research and Agroforestry [ICRAF] (2002): Improved Land Management in the Lake Victoria Basin: Annual Technical Report, working paper-2, World Agroforestry Centre.

International Center for Research and Agroforestry (2001): Design Principles for Land and Watershed Management in Western Kenya. Discussion paper series (No.1).

IRIN (2004): Nearly 10,000 affected by floods in Western Province. Kenya: Retrieved from <http://www.irinnews.org/report.asp>

Jackson, I.J. (1975): Climate, Water and Agriculture in the tropics, London and New York: Longman.

Jaezoldt, R. and Schmidt, H. (1982): Farm Management Handbook of Kenya, Vol. II /B: Central Kenya. Ministry of Agriculture, Germany Team.

Jain, V. and Sinha, R. (2004): Fluvial dynamics of an anabranching river system in Himalayan foreland basin, Baghma river, north Bihar Plains, India. Geomorphology 60, 147-60.

Japan International Cooperation Agency (1992): Feasibility study on Kano Plain Irrigation Project, Vol. II. Annexes, No.86. (JICA).

Japan International Cooperation Agency (1985): Nyando Hydrology. Vol. II/B Annex 1, LBDA.

Jensen, S.K. (1999): Applications of hydrologic information automatically extracted from digital elevation models. *Hydrological Processes*, 5, 31-41.

Jolly, J.P. (1982): A proposed method for accurately calculating sediment yields from reservoir deposition volumes. In *Recent developments in the Explanation and Prediction of Erosion and Sediment Yield*, Proceedings of Exeter Symposium, July. IAHS, 137, 153-161.

Jury, M.R. (2003): The coherent variability of African river flows: Composite climate structure and the Atlantic circulation. ISSN 0378-4738. *Water SA* Vol. 29 No. 1. Retrieved August 06, 2004, from <http://www.wrc.org.za>.

Karl, T.R. and Knight, R.W. (1998): Secular Trends in the precipitation amount, frequency and intensity in the United States. *Bull. American Meteorological Society*, 79, 231-41.

Kates, R.W. (1962): Hazard and choice perception in Floodplain management; University of Chicago; Department of Geography, Research paper No. 78, 157pp.

Kelbe, B. (2008): Personal communication.

Kenyaweb.com (2003): Agriculture in Kenya. Retrieved August 05, 2004, from <http://www.kenyaweb.com/agriculture/cotton.html>.

Kenya Export Processing Zone [KEPZ] (2004): Problems of Apparel and Textile Industry in Kenya. The status of cotton production in Kenya (Nairobi-Kenya).

Kenya Institute for Public Policy Research and Analysis [KIPPRA] (2003): Prospects of Kenya's Clothing Exports under AGOA after 2004. Discussion Paper Series (DP/24).

Kinyanjui, M.N. and D. McCormick (2002): "E-commerce in the garment industry in Kenya: a preliminary review of usage, obstacles and policies". Paper presented at the international Conference on Clothing and Footwear in African Industrialisation. 5-6 July, Mombasa, Kenya.

King'oriah, G.K. (2004): Fundamentals of Applied Statistics. Jomo Kenyatta Foundation Publishers, 1st Edition.

Kriner, S. (2002): Disaster Relief Retrieved July 06, 2004, from <http://www.disasterrelief.org>.

Korytny, L.M., Bazhenova, O.I., Maranova, G.N. and Ilyicheva, E.A. (2003): The influence of climate change and human activity on erosion processes in sub-arid watersheds in southern East Siberia. *Hydrological Processes* 17, 3181-93

Kozlowski, T.T. (1984): Flooding and Pant Growth: Academic Press, Inc. (London) Ltd.

Kumar, S.G. (1993): Hydrology and Flood Control Engineering, Khama Publ. 8th. Eds. pp 608.

Kwamina, D.J.W. (1979): Environmental health aspects and Flood control in Bunyala Location; Busia District; Western province; Kenya. In John B. Castelino and P.M. Khamala Edition 'The role of Water Resources in Development'. Proceedings of the 13th Annual Symposium of the East African Academy.

Lake Basin Development Authority (1980): A feasibility study on the production and processing of cotton; final report. Industrial Technology and Engineering Trust (ITET), Nairobi. Vol. II-I ANNEXES, JICA.

Lake Basin Development Authority (1987): The study of integrated Regional Development Master Plan for the Lake Basin Development Area. Final Report Vol. 5. Sect: Rep. 3 Water Resources/ Transport/ Energy, JICA.

Lake Basin Development Authority (1985): Lake Basin River Catchment Development River Profile. Studies Vol. 1. General Summary: UNTCD contract CON. 5/83.

Lake Basin Development Authority (1992): Feasibility study on Kano Plain Irrigation Project, Vol. 1. Main text, JICA. No. 71.

Lang, A., Bork, H.R., Mackel, R., Preston, N., Wunderlich, E. and Dik, R. (2003): Changes in sediment flux and storage within a fluvial system: some examples from the Rhine catchment. Hydrological Processes 17, 3321-3334.

Leeden, F. van der, F.L. Troise, and D.K. Todd. (1990): The Water Encyclopedia. Chelsea, Michigan.: Lewis.

Leopold, L.B; Wolman, M.G. and Miller, J.P. (1964): Fluvial Processes in Geomorphology. W.H.Freeman and Company Publishers

Lotti, C. and Associates. (1985): Master Plan for the Drainage and Irrigation of Kano Plain Region. Vol. II/A. Lake Basin Development Authority (LBDA)

Lukiya, T. (2003): Satellite Derived Rainfall Over Tropical Africa: Its pattern, Variability and Calibration. Un-published M.Sc. Thesis, University of Zululand.

Matitu, M.R. (1999): The response of tropical African rainfall to zonal circulations over adjacent oceans (M.Sc. Thesis), University of Zululand.

Mazvimari, D., Burges, S.L.G.E., and Stein, A. (2005): Identification of basin characteristics influencing spatial variation of river flows. International Journal of

Applied Earth Observation and Geoinformation. Retrieved June 06, 2006 from Science direct database.

McArthur, D.S. and Hope, S.A. (1993): A physiographic streamflow model for small Sierra Nevada Basins. Year book of the Association of Pacific Coast Geographers, 55, 66-75.

McCormick, D; Kimuyu, P and Kinyanjui, M. (2001): Kenya's garment industry: An Institutional view of medium and large firms. IDS Working Paper 531. Institute for Development Studies (IDS), University of Nairobi.

McGuffie, K; Henderson-sellers, A.; Zhang, H. (1995): Global climate sensitivity to tropical deforestation. Results from the model evaluation consortium for climate assessment.10, 1-4. Available on-line: www.sciencedirect.com

Ministry of Water Resources and Regional Development (1984): Land resources Development and Irrigation in Nyanza Province, South Kano.Government Printers.

Moore, D.S. and McCabe, G.P. (1998): Introduction to the Practice of Statistics. New York, W.H.Freeman and Company.

Montgomery, C.W. (1992): Environmental Geology, 3rd Edition, Wmc..Brown Publishers

Montgomery, D.R. (2003): Predicting landscape-scale erosion rates using digital elevation models. Competes Rendus Geoscience 335, 1121-1130

Mpeti, J.E., and Jury, M.R., (2002): Intra-seasonal convective structure and evolution over tropical East Africa. Climate Research. 17: 83-92.

Mugenda, O.M. and Mugenda, A.G. (1999): Research Methods: Quantitative and Qualitative Approaches. African Center for technology Studies (Eldoret-Kenya).

Muhia, R.N., Nyantika, D., Nindo, W. (2001): The socio-cultural constraints and opportunities to the collective resource management of the Awasi and Awach catchments in Western Kenya. ICRAF, Nairobi.

Mungai, D.N. (2001): Hydrological modeling and development of decision support tools for the Nyando River Watershed, Western Kenya. ICRAF, Nairobi

Munro, J.P. (1987): Cotton expansion in Kenya. Empire Cotton Growing Review, 43: 140 – 143.

Mutua, F.M. (2000): Reducing the impacts of environmental emergencies on the Water resources sector through early warning and preparedness-The case of the 1997/1998 El Nino Southern Oscillation floods In Kenya. A paper presented at International Conference at Nairobi Safari Club, Nairobi-Kenya, 17th November, 2000.

Mwaka, B.M.L. (1994): Application of the Water Balance Analysis to determine

discharge errors on a Staff Gauged Catchment: A case study on Kibos Catchment. Unpublished Ph.D. Thesis Submitted in the Department of Civil Engineering, University of Massachusetts.

Mwendwa, H. (1984): Land Use in Kisumu District. A publication of Kenya Rangeland Ecological Monitoring Unit, Technical Report No. 104.

Myers, M.F., and White, G. (1993): The Challenges of the Mississippi Flood. *Environment* 35 (10): 7-35.

Nachamias, C.F. and Nachamias, D. (2000): *Research Methods in the Social Sciences*. 6th. Ed, Worth Publishers.

Nakumura, K., Amano, K., and Tockener, K. (2006): River and Wetland Restoration: Lessons from Japan, *Bioscience*, 56, 5, 419-429. Retrieved June 24, 2006, from EBSCO Research databases.

National Environmental Authority [NEMA] (2004): *Strategy for Flood Management in Lake Victoria Basin, Kenya*.

Nelson, S.A. (2004): Drainage density of the Tropical Rivers in Hydrologic cycle. Retrieved July 15, 2004, from <http://www.tulane.edu/sanelson/geo/204/riversystem>.

Neuman, W.L. (2003): *Social Research Methods: Qualitative and Quantitative Approaches*. 5th Edition. Pearson Publishers.

Njogu, A.K. (2000): An Integrated River Basin Planning Approach- Nyando Case Study in Kenya: In WARFSA/WaterNet Symposium: Sustainable Use of Water Resources; Maputo.

Nogami, M. (1995): Geomorphometric measures for digital elevation models. *Zeitschrift fur Geomorphologie*, supplement band, V.101, 53-67.

Nyandat, N.N. (1979): Gypsum as improvement of the permeability of glumisol in The Kano Plain of Kenya. *East African Agricultural and Forestry Journal*, 38(1): 1-7.

Obara, D.A. (1983): Environmental and Agronomic Factors Influencing Variations in Smallholder Cotton yields in the Kano Plain, Kisumu District, Western Kenya.

Ochola, W.O. and Kerkides, P. (2003): A Markov Chain Simulation for Predicting Critical Wet and Dry Spells in Kenya: analyzing rainfall events in Kano Plains. Agricultural University of Athens. Athens.

Ogunkoya, O.O.; Adejuwon, J.O. and Jeje, L.K. (1984): Runoff response to basin parameters in southwestern Nigeria. *Journal of Hydrology*, 72, 67-84.

Ogallo, L.A. (1997): Predicting Drought in Kenya. Prospects and challenges (In *Climate Change in East Africa*, ACTS).

- Ongwenyi, G.S. (1985): Problems of Flood Control within the Lake Victoria Drainage Basin in Kenya: Paper for the permanent Interministerial.
- Onyanyo, H.O. (2003): The Impact of Climate on Food Security in Kano Plains in Nyando District. Unpublished MA. Thesis. Egerton University. Pp 153.
- Owidi, S.A. (1996): The Impact of Cash Crop farming on Food Production: The Case Of Rice Cultivation in Ombeyi Location Kisumu District. Unpublished MA Thesis, Egerton University.
- Organization of American States [OAS]. (2006): Floodplain Definition and Flood Hazard Assessment. Retrieved June 06, 2006, Available online: <http://www.apastyle.org/elecsource.html>.
- Peckham, S.D. (2003): Fluvial landscape models and catchment –scale sediment transport. *Global and Planetary Change* 39, 31-51
- Penning–Rowse (1996): The Environment and Human Society in Risks Management: Hazard Risks Models in Urban Floods. Academic Press Inc.
- Petts G.E., Stanford, J.A. and Walker, K.F. (1996): Regulated Rivers: Research and Management. Wiley publishers.
- Peters, C.B. (1996). A guide to Academic writing. ACTS Publishers. Eldoret-Kenya.
- Linsley, R. K.; Kohler, M.A. and Paulhus, J.L.H. (1982): Hydrology for Engineers 3rd Edition, McGraw-Hill, Inc.
- Reliefweb (2004): Retrieved June 05, 2004, from <http://reliefweb.int/w/rwb>.
- Republic of Kenya (1982): Ministry of Water Development. Pre- Investment Study for Water Management and Development of the Nyando and Nzoia River Basins.
- Republic of Kenya (1985a): Sondu River Multipurpose Development Project Vol.II No.31 Feasibility Report on Sondu Hydropower Development Project. JICA.
- Republic of Kenya (1985b): Sondu River Multipurpose Project: Pre-Feasibility Report on Kano Plain Irrigation Project. Vol. III No. 41, JICA.
- Republic of Kenya (1985): Nutrition Aspect of Rice Cultivation in Nyanza Province. Kenya Report No. 14.
- Republic of Kenya (1986): Lake Basin River Catchment Profile, C. Lotti and Associates Studies pp.4.
- Republic of Kenya (1992): National Water Master Plan. Government Printers-Kenya

- Republic of Kenya (1994): Kisumu District Development Plan; Nairobi; Kenya.
- Republic of Kenya (1996): Kisumu District Development Plan, Nairobi; Kenya.
- Republic of Kenya (2001a): Nyando District Development Plan; Nairobi; Kenya.
- Republic of Kenya. (2001b): National Development Plan. Government printers.
- Republic of Kenya (2001c): Kisumu District Development Plan; Nairobi; Kenya.
- Republic of Kenya (2002): Nyando District Development Plan, Nairobi; Kenya.
- Republic of Kenya (2004): Strategy for Flood Management for Lake Victoria Basin, Kenya. Joint Project by WMO, MWRMD and APFM.
- Rice, R.J. (1988): Fundamentals of Geomorphology, Longman Singapore Pub. (PTE) Ltd. 2nd. ed. Pp 420.
- Rosgen, D. (1996): Applied River Morphology. 2nd Ed, Wildland Hydrology.
- Rowan, D. (2002): Kenya hit by floods. Available online:
<http://www.wsws.org/artcles/2002/may2002/Keny- m31.shtml>.
- Rowntree, K.M. and Wadeson, R.A. (1999): A hierarchical Geomorphological Model for Classification of Selected Southern African Rivers.WRC Report No. 497/1/99. Water Resource Commission.
- Sakeyo, E.K. (2008): Modelling the impact of deforestation on stream flow – A case of chalimbana river catchment chengwe, Zambia. Published M.Sc. thesis submitted at Linkoping University, Sweden.
- Semazzi HFM, Indeje M. 1999. Inter-seasonal variability of ENSO rainfall signal over Africa. Journal of the African Meteorological Society 4: 81-94.
- Senter, A. (2004): Time series analysis. Available online: Retrieved May 01, 2006, from <http://userwww.sfsu.edu/efc/classes/biol1710>.
- Schulz, E.F. (1976): Problems in Applied Hydrology. Water Resources Publication. Fourth Edition, USA.
- Shaw, E.M., (2004): Hydrology in Practice. 3rd Edition; Routledge publishers.
- Shepherd, K et.al, (2000): The rapid measurement of soil properties and erosion In the Kano Plains. In a study for Improved land management in the Lake Victoria Basin. Published under ICRAF research Series of reports.
- Sjors, A.B. (2002): Erosion History of the Ragen and Nyalunya area, Nyando

- district, Kenya. Application of Geographic Information Technology, remote sensing and radiometric quantification to monitor temporal and spatial change. Available Online: www.worldagroforestrycentre.org/.../sites/.../publications.htm
- Song, Y., Semazzi, F.H.H, Xie, L.J. (2004): A coupled regional climate model for the Lake Victoria basin of East Africa. *International Journal of Climatology*, 24 (1), 57-75: Available Online: <http://www3.interscience.wiley.com/journal>
- Soya, L.G. (1998): Flooding across Kenya has increased. Available Online: <http://www.reliefweb.int/w/rwb>.
- StatSoft (2006): Electronic Statistics Text Book: Methods and Applications. Retrieved April 26, 2006, from <http://www.statsoft.com/textbook/stathome.html>
- Strahler, A.N. (1975): *Physical Geography*. Fourth Edition. Wiley and Sons, Inc.
- Tashakori, A. and Teddlie, C. (1998): *Mixed Methodology Combining Qualitative and Quantitative Approaches*. Applied Social Research Methods Series. Vol. 46. SAGE Publications
- Timberlake, L. and Wijkman, A. (1984): *Natural disasters: Acts of God or acts of Man?* International Institute for Environment and Development (Pub) London
- Torrence, C. and Compo, G.P. (1998): A practical guide to wavelet analysis. *Bulletin of the American Meteorological Society*.
- Torrence, C. and Webster, P.J. (1999): Interdecadal changes in the ENSO-Monsoon System. *Bulletin of American Meteorological Society*.
- Trenberth, K.E., Karl, T.R. and Spence, T.W. (2002): The need for a systems approach to climate observations. *Bull. American Meteorological. Soc.*, 83: 1593-1602.
- United States Geological Society [USGS] (2006): *Water Availability and Quality*. Available Online: http://www.usgcrp.gov/usgrp/nacc/background/meetings/forum/water_summary.html.
- UNEP (2004): "Coping With Floods in Kenya: Vulnerability, Impacts and Adaptation Options for the Flood Prone Areas of Western Kenya".
- UNDP (2001): *Human Development Report 2001. Addressing Social and Economic Disparities*. KENYA.
- Varley, A., ed. (1994): *Disasters, Development and Environment*. Chichester, England: John Wiley and Sons.

Vogt, J.V., and Somma, F. (2000): Drought and Drought Mitigation in Europe. Kluwer Academic Publishers, Dordrecht. 325pp.

Vogt, J.V, Colombo, R. and Bertolo, F. (2002): Deriving drainage networks and catchment boundaries: a new methodology combining digital elevation data and environmental characteristics. Retrieved July 17, 2004 from <http://www.sciencedirect.com/geomorphology>.(2003) 281-198.

Ware, R. and Lad, F. (2003): Flood Frequency Analysis of the Waimakariri River. Retrieved from <http://www.math.canterbury.ac.nz/research>

Wang, X. and Yin, Z. (1997): An Evaluation of Using AicInfo to Extract Basin Physiographic Parameters from DEMs. Available Online: <http://www.gis.esri.com/library/userconf/proc97/proc97/to 250/pap215/p215.htm>.

Weng, H.Y. and Lau, K.M (1994): Wavelet period doubling and time frequency localization with application to satellite data analysis. Journal of Atmo.science, 51:2523-2541.

World Food Programme (2002): World Food Programme extends assistance to Kenya flood victims. Retrieved July 21, 2004, from <http://www.reliefweb.int/w/wr.../8ef961b1.d9679941852566660062aOd 1>.

World Meteorological Organization (2001): Unusual floods and droughts in East Africa. From the World Climate News. No. 19-June. Retrieved July 18, 2004, from <http://www.reliefweb.int/w/rw>.

World Meteorological Organization and UNEP (2004): “Coping with Impacts of Climate Variability and Climate Change in Water Management”, Inter Governmental Panel on Climate Change.

Zang, P., Shao, G, Zhao, G., Master Le, D.C., Parker, G.R., Dunning, J.B., and Li, Q (2000): China’s forest policy for the 21st century. Science, 288, 2135-2136.

Zeng, N. (1999): Seasonal Cycle and Interannual variability in the Amazon hydrologic Cycle. Journal of Geophysical Research, 104, 8, 909-910

Zhang, Q. ; Gemmer, M. and Chen, J. (2006): Climate changes and flood/drought risk in the Yangtze Delta, China, during past millennium. Quaternary International 176-177 (2008) 62-69. Available on-line at www.sciencedirect.com

Ziegler, A.D.; Giambelluca, T.W. (1997): Importance of rural roads as source areas for runoff in mountainous of northern Thailand. Journal of Hydrology. 196: 204-229. Available online: www.forestencyclopedia.net/c/c3523

APPENDIX 1: INDIVIDUAL QUESTIONNAIRE

TOPIC: THE IMPACT OF FLOODING CHARACTERISTICS OF THE NYANDO RIVER ON COTTON CULTIVATION IN LOWER KANO PLAINS IN NYANDO DISTRICT, WESTERN KENYA

I am Peter Omondi Ocholla, from University of Zululand. I am conducting a research on how flooding characteristics impact on cotton cultivation. This study is for the degree of Master of Science in hydrology. I have selected you to be one of the farmers/informants to interview. Any information given will be treated confidentially and will only be used for academic purposes.

[A] General Information

- i Head of Household
- ii Name of village
- iii Name of location
- iv Name of Sub-location
- v Name of division
- vi Name of block
- vii Name of household
- viii Number of children
- ix Number of adults

[B] Level of Education

- i Illiterate
- ii Primary
- iii Secondary
- iv Others (specify)

[C] The history of flooding in Kano Plains

- 1 In which months do farmers experience floods in the area?
 - i February
 - ii March – April
 - iii May
 - iv Others (specify)
- 2 Do you remember the floods of 1963/64s (Uhuru rains)?
 - i Yes
 - ii No
- 3 If yes, what happened?
- 4 Do you remember any floods event in the 1970s and 80s?
 - i Yes
 - ii No
- 5 If yes, comment.....
- 6 Did the flood of 1996/97 affect crop production?
 - i Yes
 - ii No

- 7 If yes, which crops got affected?
 - i Maize
 - ii Sorghum
 - iii Cotton
 - iv Others (specify)
- 8 What other catastrophe affected cotton cultivation other than floods?
 - i Destruction by livestock
 - ii Drought
 - iii Pests/diseases
- 9 Did farmers experience similar floods this year 2004?.....
- 10 Is it true that the problem of flooding on cotton cultivation is intensifying?
 - i True
 - ii False
- 11 If true, what are some of these problems?
 - i Increased incidences of pests
 - ii Increased number of weeds
 - iii Inaccessibility to farming grounds
 - iv Young plants are physically damaged and their roots rot
- 12 If false, what are the other key problems facing cotton cultivation?
 - i Cotton prices are low
 - ii Inadequate land
 - iii Competition with higher paying vegetables and sugarcane
 - iv Higher cost of farming inputs
 - v Low number of cotton ginneries
 - vi Others [specify].....
- 13 What exactly do you think makes this area to be prone to flooding?
- 14 How does your household avoid the problems of floods in the area?
- [D] Impact of flooding on cotton cultivation and yields
- 15 Do you grow cotton?
 - i Yes
 - ii No
- 16 If yes, which variety?
 - i UKA
 - ii MSA
- 17 If no, what stops you from growing the crop?
 - i Insufficient land
 - ii Pests and diseases
 - iii Drought
 - iv Floods
 - v Low prices

- 18 Is the variety you grow favoured by flooding conditions in the area?
- i Yes
 - ii No
- 19 If yes, how?.....
- 20 When is the cotton variety grown?
- i Jan-Feb
 - ii Mar-May
 - iii Jun-July
- 21 Where do you grow the variety?
- i Next to the riverbanks
 - ii Away from the swamps
 - iii Away from the riverbanks
 - iv Closer to the homestead
- 22 What is the average flood height in the area?
- i (0.5-1m)
 - ii (1.5-2m)
 - iii 2.5-3m)
 - iv Others (specify)
- 23 Is it true that crop production will be affected by flood height?
- i Yes
 - ii No
- 24 If yes, which is the most disastrous height on cotton plant?
- i (1-2m)
 - ii (3m and above)
- 25 What exactly happens to the cotton crop when the height is severe?
- 26 How long does flooding take to recede in the area?
- i A few hours
 - ii 2-4 days
 - iii one week
 - iv Others (specify)
- 27 Do you think the duration of flood may affect cotton cultivation?
- i Yes
 - ii No
- 28 If yes, specify?.....
- 29 How many hectares of land do the household own?
- i (1-2)ha
 - ii (3-5)ha
 - iii (6-9)ha
 - iv (10 or more)ha
- 30 How many of these hectares do the household put under cotton cultivation?...

- 31 Does any of this portions get flooded?
- i Yes
 - ii No
- 32 If yes, how many hectares?
- i 0.5 ha
 - ii 1 ha
 - iii Others (specify)
- 33 Does the portion receive silts brought in by floods?
- i Yes
 - ii No
- 34 If yes, does it get deposited in the portion put under cotton cultivation?
- i Yes
 - ii No
- 35 If yes, how have these silts influenced cotton cultivation?.....
- 36 How have these silts affected other crops?.....
- 37 Do you experience any increase in cotton yields when it is grown in areas where floods have receded?
- i Yes
 - ii No
- 38 If yes, by what quantity (kgs/bag)?
- i 2-4 bags
 - ii 5-6 bags
 - iii Others (specify)
- 39 Is silt brought in by the Nyando river favour cotton cultivation?
- i Yes
 - ii No
- 40 If yes, comment!.....
- 41 Is cotton production and yield likely to increase with flood conditions?
- i Yes
 - ii No
- 42 If yes, under what conditions?
- i When floods recede immediately
 - ii When the duration is shorter
 - iii When floods recede then followed by a little rainfall
- 43 If no, what stops the increase?
- i Waterlogging
 - ii Incidences of pests/diseases
 - iii Delay in planting

44 Do you think cotton cultivation and output may increase when there are no
floods?

i Yes

ii No

45 If yes, how?.....

46 How much did the household harvest in 1990/91?

i 3-4 bags

ii 5-6 bags

iii 7-8 bags

iv Others (specify)

48 How much did the household harvest in 1992/93?

i 4-6 bags

ii 7-8 bags

iii Others (specify).....

49 How much did the household harvest in 1994/95?

i 4-6 bags

ii 7-8 bags

iii Others (specify)

50 How many bags did the household harvest in 1996/97?

i 4-6 bags

ii 7-8 bags

iii Others (specify)

51 How much did the household harvest in 1998/99?

i 4-6 bags

ii 7-8 bags

iii Others (specify)

52 How much did the household harvest in 2000/01?

i 4 - 6 bags

ii 7 – 8 bags

iii Others (specify).....

53 Have you changed the cropping pattern?

i Yes

ii No

54 If yes, has this change been influenced by the increasing extent of flooding
conditions?

i Yes

ii No

55 If yes, what exactly is the extent of this change?.....

56 If yes, explain how in each case:.....

57 How many kgs/bags of cotton lint does the household harvest per hectare every year?

- i 3-6 bags
- ii 7-9 bags
- iii 10 bags and above

58 How many bags did the household harvest last year (1995)?

- i 4 – 6 bags
- ii 7 – 9 bags
- iii 10 bags and above
- iv Others (specify)..

59 Did the floods interfere with the yield in any way? Comment.....

60 Where do you market/ sell the cotton produce?.....

61 How much is the household paid per kg(in Kshs.)?

- i 10 Kshs. AR and Kshs.6 BR
- ii 15 Kshs.AR and Kshs.9 BR
- iii 20 Kshs. AR and Kshs.11 BR

62 How long do the buyers take to pay farmers?.....

63 How many bags/Kgs does the household harvest when there are no flooding conditions?

- i 4-6 bags
- ii 7-9 bags
- iii 10-15 bags

[C] Flooding on cotton pests and diseases

64 Which are the common pests, associated with floods on cotton plant in the area?

- i Aphids
- ii American boll worm
- iii Others (specify).....

65 Which are the common cotton plant diseases in the area?

- i Boll stainers
- ii Leaf rusts
- iii Others (specify)

66 Are you happy with cotton cultivation in the area?

- i Yes
- ii No

67 If yes, what makes you happy?.....

68 If no, what stops you from being happy?.....

69 Are you happy with staying here?

- i Yes

ii No

70 If yes, how are you happy?

i The land is fertile

ii There is adequate water

iii The household are used to flooding condition

iv No alternative place for settlement

71 If no, what stops you from being happy?.....

72 Are you the original owner of this portion of land? Comment...

73 Where was the household settled before moving here?.....

74 Why has the household moved to the present location?

i Former area covered with Nyalbiego swamp

ii Former area covered with Nyando swamp

iii Former area is under the lake water

iv Nyando river abandoned its channel (s)

75 Are you planning any further movement? Comment.....

76 In your opinion what exactly do you think has lowered the importance of Cotton cultivation in this Area?.....

Thank you for your timeDate.....

APPENDIX 2a: 31 Years time series satellite data of rainfall for the Nyando river extracted at 34°E and 35°04 E and 0' Northing												
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1970	56.82	41.189	85.084	54.817	32.29	19.119	11.018	15.496	20.121	28.578	30.337	24.285
1971	35.85	27.913	4.283	69.171	32.193	14.169	9.328	20.96	21.017	26.338	20.749	37.937
1972	20.21	48.411	37.949	35.572	15.48	33.375	9.707	14.351	28.09	51.665	52.392	24.769
1973	35.78	35.231	27.11	41.697	26.393	14.831	8.757	12.702	34.787	25.255	31.843	5.778
1974	14.99	21.361	63.017	48.168	64.224	31.312	21.4	31.675	22.197	23.055	21.402	19.542
1975	14.76	29.647	78.843	53.99	34.762	19.902	50.109	17.797	51.241	54.654	28.929	28.381
1976	4.53	56.345	42.308	66.037	51.978	38.038	47.061	41.243	34.064	52.546	63.151	30.02
1977	85.17	71.361	79.05	103.143	78.095	42.309	35.585	33.107	31.269	105.324	101.893	47.094
1978	64.83	70.769	92.347	59.028	29.646	35.897	50.141	60.689	75.416	84.954	47.338	40.686
1979	29.92	70.561	51.781	69.953	47.483	42.006	29.231	28.885	43.829	60.617	51.438	50.058
1980	46.28	22.749	44.493	58.846	58.51	44.546	19.174	29.46	46.112	66.322	71.278	21.047
1981	16.67	43.624	65.46	79.718	54.273	38.395	61.649	38.385	88.048	61.236	67.387	57.279
1982	70.37	67.249	44.981	84.778	75.551	45.599	38.474	29.286	61.26	79.129	78.28	64.671
1983	39.61	58.806	32.766	81.376	39.385	53.589	39.379	68.157	57.442	99.238	64.354	56.169
1984	44.94	19.347	39.441	73.652	11.937	11.354	36.087	25.074	41.494	69.375	37.416	39.64
1985	28.88	63.827	58.469	88.26	49.206	30.308	32.844	18.385	51.515	35.214	60.373	24.149
1986	31.43	16.771	76.809	72.239	45.96	53.847	40.79	25.125	61.406	89.156	58.975	82.461
1987	69.69	58.184	90.624	104.465	60.714	61.117	19.793	31.764	46.888	22.322	31.234	9.686
1988	38.72	7.804	55.296	55.082	39.067	14.771	21.471	22.182	57.937	64.078	45.874	31.816
1989	88.16	50.311	51.438	37.504	8.843	1.471	29.506	28.909	50.595	41.208	24.841	44.541
1990	29.17	89.617	63.556	81.304	61.097	10.467	19.337	24.787	37.666	51.397	27.648	21.25
1991	31.19	15.147	28.84	70.211	51.155	40.428	25.733	35.376	28.107	76.447	47.282	44.105
1992	11.28	31.448	48.554	46.859	35.294	24.223	23.977	16.406	17.57	51.664	17.962	36.339
1993	43.95	19.352	36.135	37.977	19.325	18.254	4.976	10.01	5.717	2.797	24.181	8.917
1994	9.497	32.532	64.453	38.72	18.997	32.382	23.921	37.997	35.862	68.617	96.654	17.289
1995	7.226	57.606	57.855	50.787	40.031	38.377	33.381	26.65	44.862	65.149	51.554	14.78
1996	18	27.651	64.488	31.166	1.345	23.566	12.279	25.271	44.203	44.352	37.698	13.99
1997	3.459	2.396	39.03	76.437	35.534	25.302	29.275	27.494	15.459	10.638	66.52	62.82

1998	69.56	47.153	31.371	24.209	17.711	11.911	6.891	28.652	34.393	53.031	33.342	12.775
1999	41.54	9.202	53.981	26.716	10.127	6.026	14.147	18.585	28.427	50.668	26.644	19.309
2000	0.904	6.645	8.173	16.932	0.931	0.696	1.178	21.71	6.711	35.393	46.539	50.197

APPENDIX 2b: MONTHLY ACTUAL RAINFALL FOR KANO PLAINS IN NYANDO RIVER BASIN IN KENYA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total	Mean
1970	221.8	101.3	160.8	198	85.6	92	79.2	127.4	35.8	35	84.2	61	1282.1	106.8417
1971	59.6	6.6	34	221	167.2	147.2	55.7	71.1	50.1	46.7	134.1	67.5	1060.8	88.4
1972	33.7	96.3	60.5	202.9	128.2	62	51.7	51.4	139	102.2	152.1	72.3	1152.3	96.025
1973	153.7	132.9	4.1	76.1	250.5	49.2	71.1	138.4	70.1	56.7	113	9.5	1125.3	93.775
1974	43.2	18.5	217.4	282.9	126.6	71.9	79.3	84.3	57.6	35.5	109.3	75.7	1202.2	100.1833
1975	9.7	78.1	178	97.6	117.1	59.5	101.9	233.1	64.8	61.1	115.25	78.5	1194.65	99.55417
1976	112	88.85	43.3	144.1	97.7	82	121.8	103.9	79.3	22.1	81.7	83.9	1060.65	88.3875
1977	86.1	123.9	117.3	230.7	120.7	103.9	58.8	68.2	39.9	127.2	157.4	21.9	1256	104.6667
1978	125.6	134.9	202.3	234.1	62.1	52.4	151.3	75.6	89.2	124.9	46.6	137.7	1436.7	119.725
1979	78.7	203.3	224.8	100.6	153.9	65.3	53.7	41.8	133.8	56.6	102.7	104.7	1319.9	109.9917
1980	72.8	30.9	96.6	179.1	102.5	92	50.4	45.9	92	25.3	67.5	119	974	81.16667
1981	7.7	30.4	222.3	167.3	155	50.5	127.7	98.3	115.4	27.6	78	79.53	1159.73	96.64417
1982	54.5	174.7	50.8	130.6	198.9	162.4	46.5	166.9	56.7	72.7	178	33.8	1326.5	110.5417
1983	32	65.6	68.6	217.1	97.3	57.8	70.3	131.9	38.6	152.7	36.8	60.6	1029.3	85.775
1984	60.1	34.3	54.2	170.2	80.2	121.2	73	66	9.9	108.5	143.7	88.7	1010	84.16667
1985	36.9	45.6	176.9	252.1	165.2	34.2	65.1	138	59.8	59.8	83.6	31	1148.2	95.68333
1986	48.3	72	151.1	255.8	139.3	74.3	83.9	26.5	98.5	118.4	104.7	136.7	1309.5	109.125
1987	57.6	64.2	144.3	203.6	143.6	159.1	33.9	76.1	41.6	68	150.7	37.9	1180.6	98.38333
1988	234.1	18	150.7	334.5	135.7	36.1	42.2	106.5	91.2	68.4	81.6	11.4	1310.4	109.2
1989	60.7	157.6	196.1	187	145.5	30.1	86.7	145.6	72.3	141.1	104.8	133.7	1461.2	121.7667
1990	82.7	151	153	181.2	174.4	60.3	81.9	77.8	116.1	96.2	26.7	59.6	1260.9	105.075

1991	124.1	21.5	138.4	128.7	222.4	103.4	75.1	36.5	38.1	165.6	70.8	42.8	1167.4	97.28333
1992	11.4	162.2	92.2	194.8	104.3	134.6	78.8	61.1	43.1	75.8	75.4	25.3	1059	88.25
1993	128.1	99.4	69.2	98	139.4	89.8	11	150.7	65.3	69	45	113	1077.9	89.825
1994	42	131.23	114.58	227.6	133.5	42.2	68.18	60.6	26.3	62.7	230.2	85.03	1224.12	102.01
1995	28.9	91.8	99.5	212.9	154.2	106.9	42.1	53.2	42.9	166.6	56	107.2	1162.2	96.85
1996	159.6	171.5	197.4	201.7	143.6	60.7	140.8	71.9	46.98	54.7	235.5	94.6	1578.98	131.5817
1997	155.5	157.2	80.4	230.4	121	82.8	96.4	81.5	27.5	159.6	220.8	79.98	1493.08	124.4233
1998	377.4	142.9	99.9	218.2	200.9	45.1	12.1	99.9	91.2	116.1	64.4	92.54	1560.64	130.0533
1999	56.1	80.95	161.1	144.8	93.7	39.8	78.8	101	186.9	116.6	122.8	105.1	1287.65	107.3042
2000	10.3	19	98.4	144.6	212.7	33.3	64	159.5	61.6	90.1	108.3	124.3	1126.1	93.84167

APPENDIX 3: 31 YEARS TIME SERIES DATA FOR FLOW OF THE NYANDO RIVER AT GAUGE STATION IGD03												
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1970	9.276021	13.05294	14.04962	40.67931	46.87624	29.13906	19.81927	53.57651	41.79206	19.15944	9.510415	6.469788
1971	6.392905	3.568701	2.865779	14.13475	30.69458	27.97789	36.08666	47.22837	42.64659	18.57799	7.37603	7.012907
1972	4.442963	5.882617	3.126776	3.741503	17.79446	20.30102	20.41402	17.53844	9.476798	25.24329	49.66399	12.33263
1973	13.77099	20.8579	8.908204	7.40071	16.92277	20.74612	11.29432	32.58029	31.97871	15.6884	9.513095	5.191898
1974	4.360933	2.923804	4.218821	56.15744	19.78896	21.62738	53.83578	23.5095	22.51957	13.07473	6.975952	3.985703
1975	2.896252	2.528523	6.402665	16.18297	12.73014	19.56775	31.15477	66.89057	80.13409	43.10409	12.71874	10.23131
1976	6.324794	4.756373	3.961036	6.66966	11.49812	12.60065	23.61122	20.25169	20.6619	5.633263	4.81961	3.774657
1977	4.732621	7.436576	4.021653	30.07415	73.94392	41.29181	50.0612	45.82134	29.30276	17.55331	79.54483	31.73359
1978	20.18692	21.94641	58.3081	51.19056	54.64368	23.15377	35.38018	43.62078	36.61045	30.00783	15.81936	17.69765
1979	10.22138	69.00087	36.56586	31.89837	32.34478	40.03771	29.13675	49.86803	20.56344	11.11589	10.85728	6.965797

1980	7.304583	4.486576	4.334537	23.27517	36.65378	21.04526	22.28828	14.2565	11.41195	4.957256	4.895949	3.538903
1981	2.576821	2.217997	6.53271	59.63576	41.07875	9.886705	22.3274	60.91568	12.36824	9.095697	6.659084	2.999483
1982	3.456388	5.151189	2.246898	5.413107	29.54	17.29535	6.478758	32.548	15.63362	12.64382	45.50415	56.60285
1983	12.12022	7.062221	4.51478	12.42623	16.50759	15.82906	16.19648	39.51722	44.98225	53.6279	23.1593	11.77159
1984	7.691672	4.55265	3.429694	9.834664	5.013014	5.822698	7.27621	12.28679	7.910105	5.54415	7.636918	4.043478
1985	1.862724	2.773671	4.00864	65.73045	70.78115	35.30737	32.86386	25.02373	18.57458	7.827936	7.7173	3.621057
1986	2.572868	2.422522	3.514442	10.53308	25.77678	14.72985	10.65085	10.25577	7.141524	3.276547	2.985347	2.461642
1987	1.833445	2.264045	8.908574	5.172114	20.37766	39.5132	8.63197	6.292097	4.042306	2.935744	13.9748	3.588278
1988	15.14648	3.093749	6.348225	75.82745	116.8868	18.36063	23.3809	100.4358	51.01218	46.50603	17.75251	9.448358
1989	7.64448	9.324853	15.2526	63.4593	52.93369	24.61711	24.08931	29.77483	32.24981	29.44136	13.04077	13.38938
1990	37.62744	20.36549	54.94326	117.8534	40.84613	24.44647	22.05549	28.13811	16.95738	9.819676	8.60941	6.20492
1991	15.08014	3.564422	4.750246	19.70256	22.49908	37.69158	31.84259	29.58084	17.98626	13.39173	9.93964	5.636639
1992	4.221169	4.023357	2.911201	8.513497	13.42241	25.83436	28.53928	47.81608	54.0514	23.50312	13.34592	8.477217
1993	10.98296	7.042662	4.537594	4.274472	27.62097	24.00656	11.65374	9.855173	8.465754	4.413066	3.301256	5.617861
1994	2.293258	1.891286	11.94933	33.21932	61.88139	37.18836	48.39421	50.53716	36.95674	12.65432	66.69962	7.524977
1995	7.524977	4.707494	7.26188	7.424029	27.91598	16.56092	34.63952	13.11318	54.52568	12.46737	10.53163	7.796928
1996	4.285739	6.431851	26.44854	22.25932	49.10373	51.27745	103.9356	113.3817	93.60881	7.37125	23.66867	19.41048
1997	6.402479	4.770827	4.520092	48.0404	54.10711	11.78684	5.954599	19.83092	7.498751	9.373823	27.28381	10.85744
1998	65.14493	33.45112	8.163278	60.22158	61.31803	13.1833	18.2787	25.7539	17.62658	9.440238	6.0013	4.725606
1999	4.135741	3.534178	6.693822	39.56275	52.05756	28.94141	14.30692	14.20205	28.63068	17.22915	3.842135	5.668389
2000	2.914582	2.309013	2.143493	5.374045	13.78671	2.201278	5.545373	4.587489	1.920893	1.905849	1.169509	0.847277

APPENDIX 4: 21 YEARS TIME SERIES DATA FOR FLOW OF THE NYANDO RIVER AT GAUGE STATION IGB03

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1968	2.47	5.56	7.74	13.64	16.03	14.03	6.01	16.16	8.67	5.46	4.84	8.07
1969	4.04	8.28	6.06	3.7	4.9	4.19	3.87	5.78	6.23	4.04	3.46	2.51
1970	4.24	2.99	5.15	10.58	11.69	8.68	6.7	12.65	12.87	6.7	4.44	3.78
1971	1.18	0.75	1.74	5.91	6.39	6.09	10.04	15.67	14.5	7.57	4.36	3.77
1972	2.94	3.55	2.33	2.16	6.8	6.66	7.3	7.43	4.71	6.66	14.1	7.11
1973	5.17	5.43	2.54	2.11	4.35	6.5	3.8	8.43	10.6	5.55	4.23	2.2
1974	1.76	1.23	1.85	9.34	3.46	3.25	14.28	6.5	7.33	4.71	2.79	1.99
1975	1.38	1.29	1.55	3.38	3.47	5.89	8.62	15.84	21.81	13.74	5.17	4.39
1976	2.17	1.79	1.53	2.5	4.66	4.09	5.4	5.36	5.5	2.21	2.15	1.62
1977	1.99	2.19	1.63	5.21	13.17	8.56	12.53	10.91	9.84	7.12	10.05	12.07
1978	8.14	7.6	11.74	11.45	13.63	8.97	9.83	10.81	13.17	10.21	7.4	6.93
1979	5.42	9.16	10.12	8.95	11.32	11.53	8.94	13.71	8.19	5.38	4.66	3.73
1980	2.65	1.9	1.94	4.18	7.06	5.54	6.04	4.53	5.92	2.72	2.54	1.09
1981	0.52	0.44	1.94	7.03	6.25	3.01	5.32	9.05	6.92	5.38	2.75	1.26
1982	0.87	1.35	0.79	2.4	5.41	3.24	2.47	5.35	3.04	2.87	5.89	7.47
1983	2.48	1.75	1.18	2.12	2.55	3.26	2.89	6.02	3.7	6.12	3.49	1.63
1984	1.58	1.01	0.81	2.07	1.2	1.29	1.5	2.48	1.96	1.29	1.23	1.39
1985	0.92	0.97	1.26	14.71	12.35	5.69	7.04	7.85	6.76	3.62	1.4	2.08
1986	1.52	1.41	1.2	1.73	3.5	2.62	5.32	3.26	2.93	1.62	1.59	1.13
1987	0.81	0.72	2.94	0.96	5.27	7.94	2.35	1.43	1.33	1.12	3.38	1.17
1988	1.51	0.89	2.33	8.61	11.42	3.12	2.87	12.05	9.18	5.99	2.69	1.19

