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DEPARTMENT OF GEOLOGY

POTENTIAL EFFECTS OF CHANGES IN CLIMATE, LAND COVER AND POPULATION ON THE QUANTITY OF WATER RESOURCES IN LAKE NAKURU AND LAKE ELMENTEITA AREAS, KENYA

BY

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A dissertation submitted towards the partial fulfillment of the award of a Master of Science degree in Hydrogeology and Groundwater Resources Management.

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Declaration

This dissertation is my original work and has not been presented for a degree in any other university or for any other award.

_______________ Date: 19/08/2011

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This work has been submitted with our approval as the university supervisors

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Abstract

This study evaluates the potential effects of changes in climate, population and land cover on the quantity of surface water and groundwater resources in Lake Nakuru and Lake Elmenteita areas. Multiple linear regression analysis of the variables was done using Statistical Package for Social Sciences (SPSS) to achieve this objective. Population grows in the area at the rate of 3.4% to 4.5% while natural vegetation cover is diminishing at 2.5% annually. There is constant rise in daily minimum temperature while there is a rise in the mean annual precipitation. The area's domestic water demand per capita is projected to rise from 50 litres per day in 1971 to 160 litres per day in 2030. This, based on the rate of population growth, will translate to a soaring total demand of 174,000,000 m^3 annually by the year 2030.

Strong positive correlation between precipitation and discharge is observed, indicating that rainfall is the main source of surface water in the area. The precipitation is thus expected to influence the occurrence of extreme events, with droughts projected for the year 2001, 2012, 2016, 2021 and 2028 while floods are projected to occur in 2006, 2009, 2018, 2024 and 2030.

To mitigate against the deteriorating surface and groundwater resources in the area, there is need to restore Mau escarpment since it is the most affected. Resettlement of the inhabitants will be key to ensuring sustainable water supply. The reforestation of Mau catchment should take into account promoting cross-breeding to produce superior tree species. These species should be fast-maturing, heat-and-drought tolerant and pest-and-disease-resistant.

Measures that are recommended to reduce green house gas emissions and vegetation loss include slowing deforestation, enhancing natural forest generation, establishing tree plantation, promoting agroforestry and altering management of agricultural soils and rangelands. Enhanced resilience to future periods of drought stress can be supported by improvements in present rain-fed farming systems, such as water harvesting systems to supplement irrigation practices in dry areas. Improved early warning systems and their application may also reduce vulnerability to future risks associated with climate variability and change. Increased investment in dams will improve harvesting of water that would cause flooding during heavy rains. This would later be used to mitigate against the effects of droughts.

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My sincere thanks for the support from my colleagues and friends, Isaac Kanda, Emily Okech, Anna Mwangi, Antony Odiwuor, Anne Wanjohi, Janet Suwai, Joseph Ndetei and John Ogalo.

Lastly, my heartfelt gratitude to my parents Mr. and Mrs Paul Adede for bringing me this far.

To God be the glory, Amen.

Dedication

For Christabel, Jerry and Barry. You give me so much reason to face each day.

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Acronyms and Abbreviations

AR–4 - Fourth Assessment Report of Intergovernmental Panel on Climate Change

BRGM - *Bureau de Recherches Geologiques et Minieres*

CIFEG – *Center International pour la Formation et les Echanges en Géosciences*

CMS - Cubic Meters per Second

GCM- General Circulation Model

IGAD - Inter-Governmental Authority on Development

IPCC - Intergovernmental Panel on Climate Change

ITCZ – Inter-tropical Convergence Zone

RCM- Regional Climate Model

TAR – Third Assessment Report of of Intergovernmental Panel on Climate Change

UNEP - United Nations Environmental Program

UN – United Nations

USGS - United States Geological Survey

CHAPTER ONE: INTRODUCTION

1.1 Background Information

The sustainability of freshwater resources is a major and growing international concern. In Africa, 60% of the rural population and 25% of the urban population do not currently have access to safe drinking water, due primarily to population growth, and these percentages are expected to increase (Beniston, 2000). Changes in the hydrological balance due to greenhouse gas-induced climate change, although still poorly constrained by predictive models, are likely to compound this dire situation. Of even greater concern, however, is the prospect of enormous and potentially catastrophic hydrological changes that will follow (Alverson & Edwards, 2003).

Temperature and precipitation are two climatic elements that have been widely studied globally to provide evidence of climate change. Estimates derived from instrumental data suggest that the northern hemisphere average temperature has increased over the past 100 years by approximately 1°C, and can be expected to rise at least another degree, perhaps as much as 5, over the next 100 years (Alverson & Edwards, 2003). In contrast, estimates based on palaeorecords suggest that the range of natural average-temperature variability in the northern hemisphere over the past millennium, which included periods such as the "Little Ice Age" and the "Medieval Warm Period," was substantially less than one degree, indicating that the ongoing anthropogenic changes are indeed substantial when compared with this longer-term record (Alverson & Edwards, 2003).

Temperature data, since 1976, from Amboseli on the northern foothills of Kilimanjaro, reveal a drastic increase of mean daily maximum temperature at a rate of over 2K per decade (Altmann et al., 2002). Increases were greatest during the hottest months, February and March. According to the climate trends in the Kilimanjaro area presented by Hay et al. (2002) for 1941–1995, temperatures rose between 1951 and 1960, and between 1981 and 1995, but were stable or decreased slightly during the remaining interval. Long-term trends from 1900 to 2005 have been observed in precipitation amount over many large regions. Significantly increased precipitation has been observed in eastern parts of North and South America, northern Europe and northern and central Asia. Drying has been observed in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Precipitation is highly variable spatially and temporally, and data are limited in some regions (IPCC, 2007).

Only a decade ago, palaeorecords such as snow accumulation rate and δ^{18}O-inferred temperature obtained from Greenland ice cores, were invoked to suggest that a relatively stable global climate existed during the Holocene as compared to the large oscillations associated with glacial periods (Dansgaard *et al.*, 1993). However, this polar-centric paradigm of Holocene stability has now been rejected in favor of a picture of large and sometimes abrupt, natural climatic oscillations during the Holocene, clearly of great relevance to modern concerns and largely based on evidence for pronounced hydrological variability at lower latitudes. Although recent attention has been focused mainly on rising global temperatures, as a monitor of anthropogenic influence, changes in regional hydrological balance have had a more substantial and direct effect on human livelihoods over the past century. In addition, the more distant past record is replete with examples of sustained hydrological variability on all timescales. On *timescales* of 100,000 years, for example, global sea level fluctuated on the order of 100m in response to the waxing and waning of large continental ice sheets (Waelbroek *et al.*, 2002). These sea-level changes, at times extremely rapid – on the order of 1m per century – reflect profound changes in the global hydrological cycle. Not surprisingly, regional water balance during glacial periods was in most cases also radically different from that of the present (Verschuren *et al.*, 2000). This is not without relevance to many of today's concerns, since many of the aquifers currently being exploited in densely populated, semiarid regions were recharged during the glacial times and have insignificantly small recharge rates under modern conditions (Verschuren *et al.*, 2000). Decadal to century-scale hydrological variability such as that manifested by the shifting level of Lake Naivasha, Kenya, has substantially influenced the history of local populations (Verschuren *et al.*, 2000).

1.2 Scope of the Research

The project aims at determining the potential effects of changes in climate, land cover and population on the quantity of surface and ground water resources in Lake Nakuru and Lake Elmenteita areas (Fig. 1.1). The study therefore focuses on the understanding of the history of surface water flow as well as groundwater recharge. Future trends are predicted using linear regression analysis. The results are used as a guide to understanding the sensitivity of regional water balance to ongoing climate, land cover and population changes. Adaptation and mitigation measures are proposed to avert future crises that are likely to arise due to scarcity of water resources.

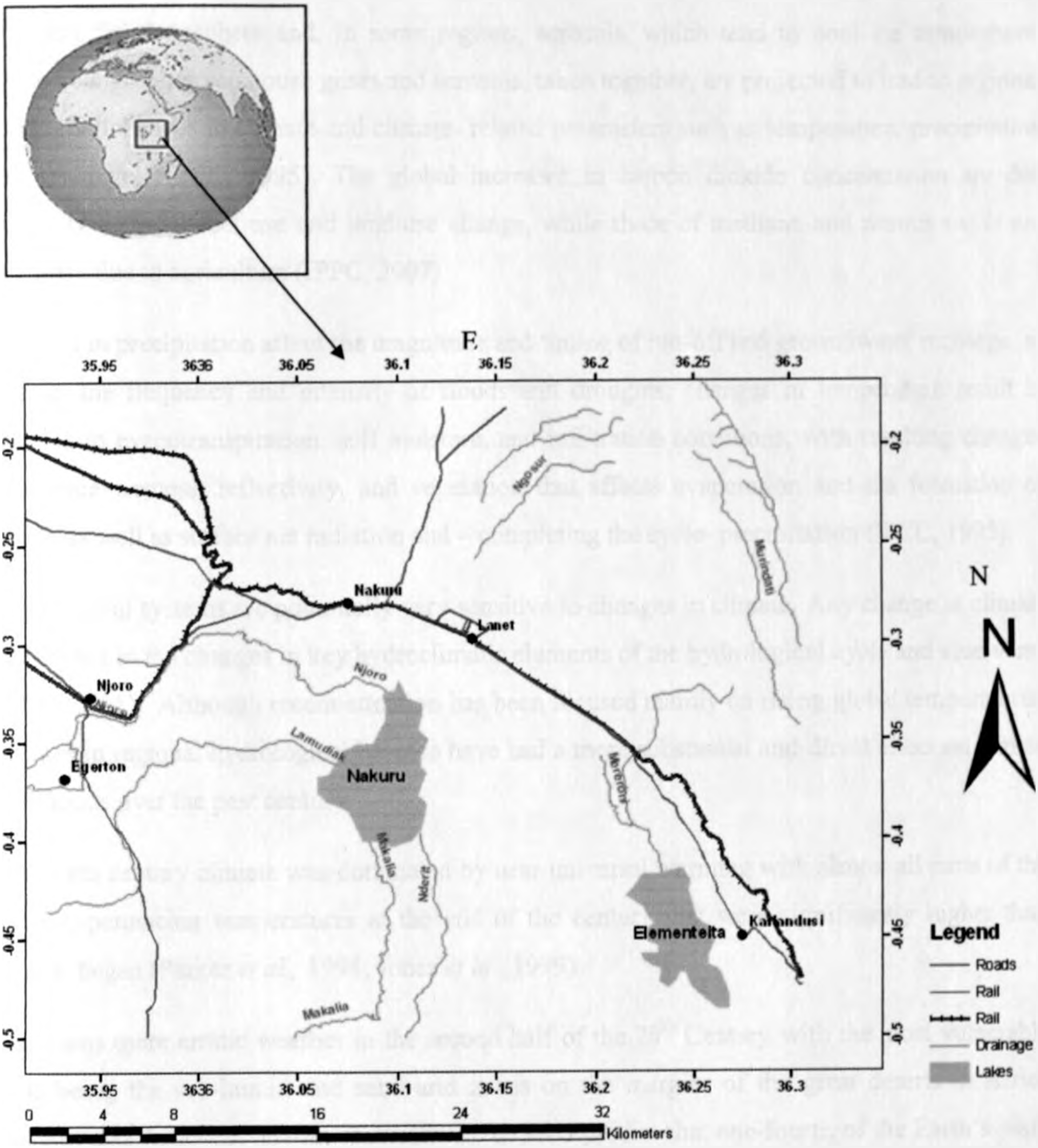


Fig. 1 Location map of the study area (adapted from McCall, 1967)

1.3 Literature Review

1.3.1 Global Changes

Human activities are increasing the atmospheric concentrations of greenhouse gases which tend to warm the atmosphere and, in some regions, aerosols, which tend to cool the atmosphere. These changes in green house gases and aerosols, taken together, are projected to lead to regional and global changes in climate and climate- related parameters such as temperature, precipitation and sea level (IPCC, 1995). The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land-use change, while those of methane and nitrous oxide are primarily due to agriculture (IPPC, 2007).

Changes in precipitation affect the magnitude and timing of run-off and groundwater recharge, as well as the frequency and intensity of floods and droughts; changes in temperature result in changes in evapotranspiration, soil moisture, and infiltration conditions, with resulting changes in surface wetness, reflectivity, and vegetation that affects evaporation and the formation of clouds as well as surface net radiation and – completing the cycle- precipitation (IPCC, 1995).

Hydrological systems are potentially very sensitive to changes in climate. Any change in climate is reflected in the changes in key hydroclimatic elements of the hydrological cycle and vice-versa (IPCC, 1995). Although recent attention has been focused mainly on rising global temperatures, changes in regional hydrological balance have had a more substantial and direct effect on human livelihoods over the past century.

Twentieth century climate was dominated by near universal warming with almost all parts of the globe experiencing temperatures at the end of the century that were significantly higher than when it began (Parker *et al.*, 1994; Jones *et al.*, 1999).

There was more erratic weather in the second half of the 20th Century with the most vulnerable areas being the sub-humid and semi-arid zones on the margins of the great deserts in Africa (Sahara) and Asia (e.g. Trauth *et al.*, 2003). Experts predict that one-fourth of the Earth's plant and animal species will be headed for extinction by 2050 if the warming trend continues at its current rate (Government of Kenya, 2010).

1.3.2 Regional Context

Africa is one of the most vulnerable continents to climate change and climate variability, a situation aggravated by the interaction of 'multiple stresses', occurring at various levels. Africa's major economic sectors are vulnerable to current climate sensitivity, with huge economic impacts, and this vulnerability is exacerbated by existing developmental challenges such as endemic poverty, poor governance and weak institutions, limited access to capital, including markets, poor infrastructure and technology, ecosystems degradation, and complex disasters and conflicts. These in turn have contributed to Africa's weak adaptive capacity, increasing the continent's vulnerability to projected climate change (IPPC, 2007).

In East Africa, most climate records document dramatic hydrological changes since the Last Glacial Maximum (LGM) (e.g. Trauth *et al.*, 2003). The change in climate is marked by high frequencies of extremes of rainfall and temperature compared with the 1900-1940 period when both temperature and rainfall were more equable in continental interiors and winds more consistent (See Table 1.1 below).

Table 1.1 Notable climate anomalies in the region between 1961 and 1998 (Ngaira, 2005).

YEAR	EVENT
1961	Extremely high equatorial rainfall in East Africa which led to East Africa lakes rising in levels above all twentieth century records
1968-73	Severe phase of drought (Sahelian drought) in Ethiopia and the Sahel region which caused several famines, animal loss, desertification, and reduced the size of Lake Chad
1977	Highest rainfall ever recorded in Kenya which caused severe gulley erosion, Lake level rise in semi-arid regions
1984	Severe droughts in Kenya led to introduction of "food queues" in supermarkets

1991-92	Severe droughts in most arid areas in Kenya led to the introduction of "food for work" programs, and reduced surface areas of the lakes in the regions
1997-98	Kenya experienced the worst floods in 36 years caused by El-nino which increased surface area of lakes in the rift valley

Loss of vegetation is also a major concern in the region. Several areas, for example, Zimbabwe, Malawi, eastern Zambia, central Mozambique as well as the Congo Basin rainforests in the Democratic Republic of Congo, are undergoing deforestation with estimates of about 0.4% per year in the 1990s (Biggs *et al.*, 2004). Further threats to Africa's forest are also posed by the high dependency on fuelwood - a major source of energy in rural areas - representing about 70% of total energy consumption in the continent (FAO, 2004). Moreover, fire incidents represent a huge threat to tropical forest in Africa. An estimated 70% of the detected fires occur in the tropics, with 50% of them in Africa. More than half of forested areas were estimated to have burned in Africa in 2000 (Kempeneers *et al.*, 2002). Bush fires are a particular threat to the woodlands, causing enormous destruction to both flora and fauna in eastern and southern Africa.

1.3.3 Local Context

Duhnforth *et al.*, (2006) noted a significance decrease in Lake Nakuru surface area and water volume in the basin since the early Holocene highstand. The size of the modern catchment is the same as that of the palaeo i.e., 2390 km^2, while lake surface area is 66 km^2 compared to the 960 km^2 palaeo value (Duhnforth *et al.*, 2006).

Due to these changes, there is much concern over the diminishing recharge zones of the basin's groundwater reserves. The effects of hydrological changes are now being felt in the basin even as high population exerts more pressure on the water resources (Odada *et al.*, 2006). Residents of the basin have now turned to groundwater as the only alternative. Issues regarding equitable access to natural resources and sustainable environmental conservation and economic development have arisen in the basin (Odada *et al.*, 2006). The ever-increasing human population, poor enforcement of environmental regulations, and unsustainable exploitation of natural resources are root causes for human-resource conflict (Odada *et al.*, 2006). Denudation and degradation of forestlands, clearing of riverbanks, lack of regulation of the mining industry, poor land use planning and urban development, the prevalence of poverty, and human-wildlife conflicts around Lake Nakuru National Park exemplify the conflict between the catchment's natural resources and human population (Odada *et al.*, 2006).

Between 1967 and 1986, more than 400 km^2 of forest and land under natural vegetation in the catchment basin were cleared for settlement. During this same period, the area of the catchment under forest and natural vegetative cover declined from 47 to 26% (Odada *et al.*, 2006). Declines also occurred in the land area under large-scale farming and ranching, with small-scale subsistence farming burgeoning from insignificant levels in 1970 to over 35% of the catchment area in 1986. Between 1994 and present, over 30,000 ha of natural and plantation forest are estimated to have been clear felled and the land put under the plough. An estimated 30,000 people migrated into the catchment during this period (Odada *et al.*, 2006). The extent of the Eastern Mau Escarpment was reduced by 28% between 1967 and 1989, largely due to excisions for human settlement. Further degazettement of about 30,000 hectares of plantation forest followed in 1994, with illegal felling and burning within the gazette reserve making further inroads into the forest thereafter (Fig. 1.2). Eburru and Dondori forests are not spared either.

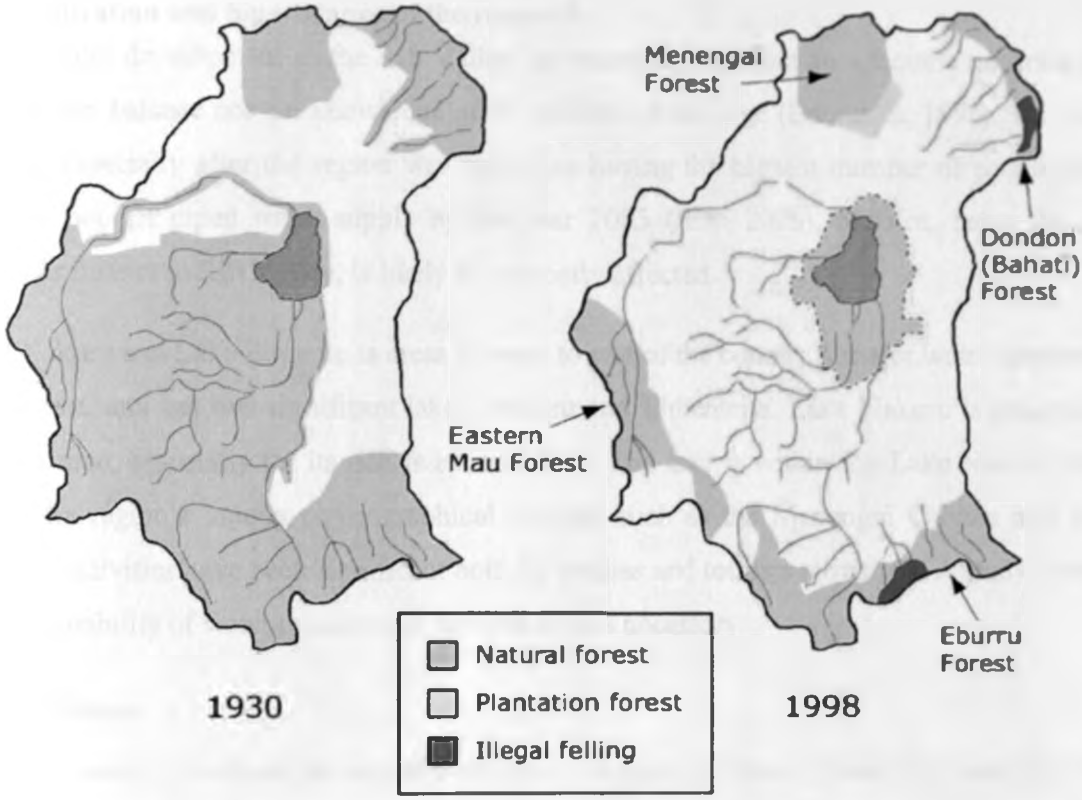


Fig.1.2 Change in forest cover in Lake Nakuru Basin between 1930 and 1998 (Modified from Odada *et al.*, 2006).

1.4 Problem Statement

Owing to multiple stresses that Lake Nakuru and Lake Elmenteita areas's water resources are subjected to, there is concern over the sustainability of the resources. Due to the growing population, Nakuru is now faced by acute water shortages. Nakuru town, with a population of nearly 700,000, has a water demand of 70 000 m^3 per day compared with the current supply of 35 000 m^3 (Olago *et al.*, 2009). Several boreholes have already dried up due to decline in recharge especially at Egerton University which is next to River Njoro. River Njoro is the main river supplying Lake Nakuru.

The forests in the basin are now threateaned by large-scale caltivation, charcoal burning and illegal logging (Odada *et al.*, 2006). As Karanja *et al.* (1995) observed, the area has attracted much settlement due to its fertility thus leading to increased deforestation.

CHAPTER TWO: THE STUDY AREA

2.1 Location

The area of study is located in Lake Nakuru and Lake Elmenteita areas, Central Kenyan Rift between 0° S 36° E and 1° S 36.5° E (Fig. 1.1). The deepest part of the area contains two lakes, Lake Nakuru (1770 m above sea level) and Lake Elmenteita (1786 m). The catchment area is about 2390 km^2 and the elevation ranges from 1760 to 3080 m. On the western side, the area is bounded by east-dipping normal faults of the Mau Escarpment (3080 m). To the east, the area is bordered by west-dipping faults that separate the intra-rift Bahati-Kinangop Plateau (2740 m) from the eastern rift shoulder and the Aberdare Ranges (3999 m). The northern boundary comprises the Menengai Caldera (2278 m). To the south, the Mt. Eburru volcano (2820 m) separates the Lake Nakuru basin from the Naivasha Basin, which contains the modern Lake Naivasha (1890 m) (Duhnforth *et al.*, 2006).

2.2 Climate

The region's climate is strongly influenced by the seasonal migration of the Intertropical Convergence Zone (ITCZ) and the coinciding precipitation pattern (Nicholson 1996; 2000). Rainfall associated with the transition of the ITCZ follows the highest sun in March and September with a lag of three to four weeks (Nicholson, 2000). Therefore, the area receives most of its precipitation during the ''long rains'' in April to May and the ''short rains'' in November. A third subordinate precipitation maximum occurs in September, when the Congo air masses transport moisture from the Congo basin to East Africa (Vincent *et al.*, 1979). Mean annual rainfall is 920 mm/yr, whereas evaporation is about 1736 mm/yr (Kenya Meteorological Department, 2000). The amount of precipitation is strongly linked to topography. Thus, the highest rates are obtained in the high elevation parts of the area in the west and east, whereas the lower areas are relatively dry.

The long term hydrologic budget of the area is primarily controlled by the spatial and temporal distribution of rainfall, superimposed on tectonically- driven influences on the drainage network and basin geometry (Strecker *et al.*, 1990). Generally, north–south trending fault blocks deflect most of the rivers draining the Aberdare Ranges and Kinangop Plateau towards the south into the Naivasha basin. Only minor rivers periodically drain into the Lake Nakuru basin.

2.3 Vegetation

The natural forest within the study area comprises indigenous hardwood trees and grasses such as bamboos. Menengai Crater, the Eburru Hills, Bahati forest and Mau Escarpment are all hosts to hardwood forest, whereas bamboo is confined to the Mau escarpment.

A savannah, woodland and shrub vegetation appears in a wide area where more grazing activities take place. In the higher areas of the catchment, different types of agriculture (normally rain fed) and forest cover appear. The wetland around the shores of the lake is dominated by *Papyrus* swamps while other parts which are a bit far from the lake are occupied by natural vegetation, mainly grassland, acacia, and shrub. The swamps are mainly used as indicators of hydrological regimes, modifiers of water quality and as habitats for numerous animals and birds.

2.4 Land Use and Land Resources

The land cover is related to the land uses in the catchments. The semi-arid climate and the topography are greatly influencing the land cover of the area.

The land cover can be broadly grouped into:

- Forest
- Bushland
- Grassland and
- Agricultural land

Irrigated agriculture is practiced on the rift valley floor. This includes irrigated crop farming and flower farming. Other crops such as vegetables, cabbages and fruits, are grown mainly for local consumption. The low lying central parts of the catchment carry natural and semi-natural vegetation that provide suitable habitat for wildlife and indigenous livestock farming. Game sanctuaries for wildlife are mainly in the west of the area.

The main farming system in this area would commonly be referred to as mixed farming. Rain fed crop production is the most important activity within the area. Slopes of the Mau Mountains are the most common farming areas. Common crops include maize, wheat, potato, beans and sunflowers.

2.5 Physiography and Drainage

Six seasonal rivers (Makalia, Nderit, Ngosur, Naishi, Njoro, and Larmudiac) drain Lake Nakuru Basin. Some of these rivers (Njoro, Ngosur and Naishi) become influent, disappearing along the fault lines to recharge deep aquifers. A study of the groundwater conditions indicates the presence of perched water tables in the vicinity of the Njoro River. This is attributed to losses down the fault zones. Lower down the Njoro River movements are still proceeding in a fault trough extending from Butleigh Stone Quarry through Glanjoro to Ronda sisal estate. The Njoro River tapers completely on reaching Lake Nakuru plains, firstly, because of these losses in the fissure zones, and secondly because its bed runs over porous pumice and lake sediments and the water sinks to join the water table which feeds Lake Nakuru (McCall, 1956). River Mereroni drains the eastern part of the area, flowing into Lake Elmenteita.

2.6 Geology and Structures

The geology of Lake Nakuru and its catchment area comprises volcanic rocks (lava flows and pyroclastics) of the Tertiary-Quaternary age, which have been affected by a series of faulting (fig. 2.3). The volcanic rocks exposed in the Mau and Bahati Escarpments are thought to be the oldest volcanic rocks exposed within the area (Odada *et al.*, 2006). At Mau, the bulk, if not all, of the volcanic rocks near the surface consist of a series of greenish-grey welded trachytic tuffs together with yellow pumice tuffs, and sedimentary intercalations, reworked tuffs and clay. At Bahati Escarpment, similar welded trachytic tuffs and yellow pumice tuff intercalations are the only formations exposed. Solai phonolites underlie the Mau and Bahati tuff formations.

Major fault structures are associated with large accumulations of pyroclastics and trachyte lavas, intercalated with tuffs and welded tuffs. The major faults in the detachment display large scale structural domains with consistent structural style, controlled by the geometry of the interaction among those fault displacements that show more than 1 km throw (Morley *et al.*, 1990). The structural pattern of Nakuru is quite unparalleled in the Rift Valley system owing to the number and variety of orientation of the faults, which is related to the junction of the Gregory and Kavirondo Rifts which are normal to one another.

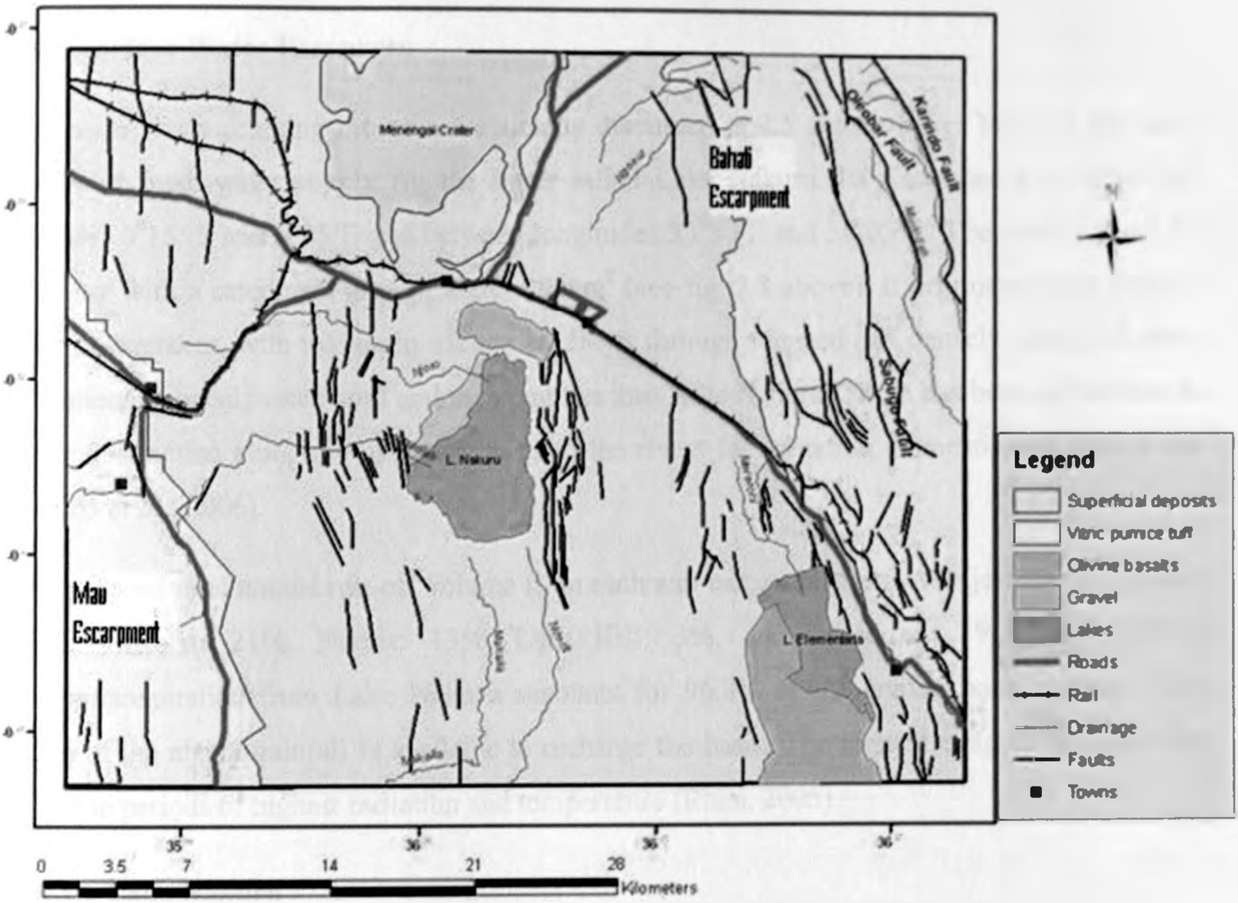


Fig 2.3 Geology of Lake Nakuru And Lake Elmenteita areas (adapted from McCall, 1967).

2.7 Soils

The soil of the study area is of volcanic origin and, due to its high porosity, permeability and loose structure, is highly susceptible to erosion, land subsidence and fractures during or after heavy rain (Odada *et al*., 2006). The soils were developed on ashes and other pyroclastic rocks of very recent volcanic activity. The regosols are excessively drained, deep, dark brown in colour but strong calcareous, stony to gravel clay loam. The andosols are well drained as they are developed on older ashes of volcanoes. On the hills and minor scarps are the cambisols. The soils are well drained too, with a few outcrops. They are mainly clay loam in texture. The andosols in this unit are mollic, a humic topsoil and gravelly loam.

2.8 Surfacewater and Groundwater Resources

2.8.1 Surface Water Resources

Six major rivers draining the area are already discussed in 2.5 above. River Njoro is the main source of fresh water supply for the hyper saline Lake Nakuru. Its watershed lies within the latitudes 0°15' S and 0°25'S and between longitudes 35°50'E and 35°05'E. The river is about 50 km long with a catchment area of about 280km^2 (see fig. 2.3 above). It originates from Eastern Mau Escarpment, with two main tributaries; flows through forested and densely populated areas and intensively cultivated land and then empties into Lake Nakuru. There has been an increase in water abstraction along the upstream parts of the rivers for irrigation, domestic and factory use (Odada *et al.*, 2006).

The proportion of annual run-off volume from each sub-basin is as follows: Njoro: 39%, Ngosur: 23%, Makalia: 21%, Nderit: 13%, Lion Hill: 3%, and Lamuriac: 1% (Raini, 2005). Evapotranspiration from Lake Nakuru accounts for 96.8% of the annual basin rainfall. Only 3.2% of the annual rainfall is available to recharge the basin. The highest evaporation coincides with the periods of highest radiation and temperature (Raini, 2005).

2.8.1.1 Lake Nakuru

Lake Nakuru is one of the highest lakes in the central Kenya dome of the Rift Valley. Its elevation of 1,759m asl has hydrological implications on the lake's water balance. Unlike other low-lying Rift Valley lakes that have conspicuous water supply through a series of hot and fresh water springs (e.g., Bogoria, Magadi), there is minimal underground flow into Lake Nakuru through the axial fault line system. The Baharini Springs, and other springs along the eastern shoreline, are perennial, contributing about 0.6 m^3/s to the lake (Odada *et al.*, 2006).

2.8.2 Groundwater Resources

Groundwater in the volcanic regions in Kenya occurs at varying depth and several aquifers may exist on top of each other (IEA, 2006). The aquifers in these areas are confined. and depths to the aquifers and piezometric levels vary widely. The average yields are about 7.5 m^3/h. The depth to the aquifer on average is 94 m (IEA. 2006). An east-west oriented geological and geo-electric profile slightly north of Lake Nakuru indicates that secondary permeability zone such as fractures (N-S oriented) control the flow and distribution of groundwater. and that the best water yielding aquifers are found in the fractured volcanics or along weathered contacts between different lithological units (Olago *et al.* 2009). The bulk of groundwater in Nakuru area flows in linear fissure zones linking gently dipping, perched water tables in an open system that extends under lake Nakuru's salt-impregnated clay pan.

Due to increasing water demand, many people have now resorted to groundwater resources. The Njoro River watershed alone has over 41 boreholes in its upper reaches. There are 156 registered boreholes in the catchment and a few unregistered. None of these are metered. Nakuru Municipality has over 55 registered boreholes, of these 35 are located in Kabatini aquifer, which recharges the Baharini Springs (Odada *et al.*, 2006).

CHAPTER THREE: METHODOLOGY

To achieve the objectives of this study, four major phases of methodology were adopted. The first one involved desk study; the second was field work; third data analysis and finally data intergration.

3.1 Desk study

3.1.1 Climate

Several studies and research was done on the current topics on climate and how it affects water resources. These involved reading of journals on climate change and IPPC publications. The most up to date reports like AR4 (Fourth Assessment Report) were studied at the initial stages of this work.

Temperature and Precipitation data was collected from Kenya Meteorological Department. The data was collected for the year 1971 to 2000. Only Nakuru Meteorological Station (9036261) (Fig. 3.1) had temperature data that covered this period, and the data was daily minimum temperature. It was therefore not possible to come up with average daily temperature.

Rainfall data was available for station 9036032 (Lanet Gate) (Fig. 3.1). The data was collected in monthly averages.

3.1.2 Land Cover

Land Cover changes were studied with the aim of identifying the gaps in knowledge. The studies included various reports, published and unpublished and maps and images. Satellite images were accessed at internet sites.

3.1.3 Population

Population study was carried out to establish the number of people in the area, the growth rate and how the population growth affects the water resources in Lake Nakuru and Lake Elmenteita areas. This study was done at the KNBS (Kenya National Bureau of Statistics) library.

3.1.4 Water Resources

Hydrological data was collected from the Ministry of Water and Irrigation. The data collected includes discharge rates from five gauging stations in the area for the period of 1971 to 2000. The stations are representative by virtue of their geographical location within the area as can be seen in fig. 3.1 below.

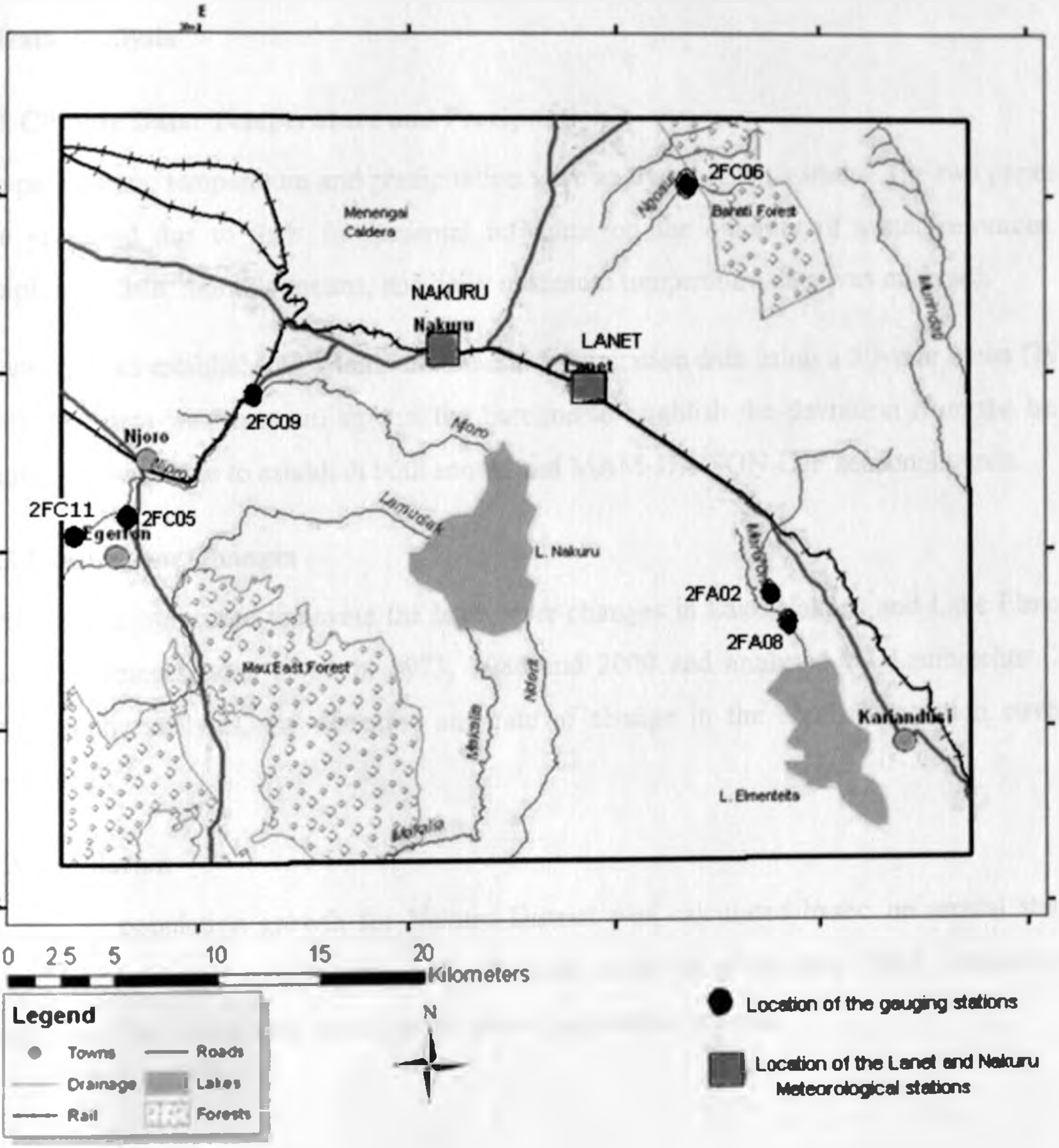


Fig. 3.1 Map of the area showing the locations of the gauging and meteorological stations used (Adapted from McCall, 1967).

3.2 Field Work

The actual fieldwork took place between 27th April, 2008 and 11th May, 2008. During this period, data was collected on boreholes; depth, water levels and yields. Confirmation of geology, structures and vegetation at the various sites was done as well. Gauging stations were visited as river courses were followed to confirm the drainage.

3.3 Data Analysis

3.3.1 Climate Data: Temperature and Precipitation

Two parameters; temperature and precipitation were analysed for this study. The two parameters were preferred due to their fundamental influence on the quantity of water resources. The precipitation data, monthly means, and daily minimum temperature data was analysed.

A baseline was established for temperature and precipitation data using a 30-year mean (1971 to 2000). The data was then run against the baseline to establish the deviation from the baseline trends. This was done to establish both annual and MAM-JJA-SON-DJF seasonal trends.

3.3.2 Land Cover Changes

Three images were used to assess the land cover changes in Lake Nakuru and Lake Elmenteita areas. The images were taken in 1973, 1986 and 2000 and analysed by Lambrechts (2002). Based on the analysis, the direction and rate of change in the area's vegetation cover was determined.

3.3.3 Population

The rate of population growth for Nakuru District was calculated based on annual statistical abstracts and decadal census data and projections made up to the year 2030. Domestic water demand was then calculated based on the rate of population growth.

3.3.4 Water Resources

3.3.4.1 Surface Water

Baseline trends were established for discharge in five gauging stations using a 30-year mean (1971 to 2000). The data was then run against the baseline to establish the deviation from the baseline trends. This was done to establish both annual and MAM-JJA-SON-DJF seasonal trends.

Gaps in the stream flow records were filled using record extension technique known as MOVE. 1 (Maintenance Of Variance-Extension, type 1) or the Line of Organic Correlation (Helsel and Hirsch, 1992). It was first used as a means of record extension by Hirsch (1982). The MOVE.1 technique produces streamflow estimates at the short-term station with a statistical distribution similar to that expected if the streamflow had actually been measured (Helsel and Hirsch, 1992, p. 277) and will thus correctly estimate the probability of extreme high or low streamflow. Simple linear regression, by comparison, will always underestimate the occurrence of extreme events.

The means $(\bar{Y}\ and\ \bar{X})$ and standard deviations $(S_y\ and\ S_x)$ of the logs of the concurrent streamflow data are calculated.

The MOVE.1 equation is then written as follows:

$$\hat{Y}_i = \bar{Y} + \frac{S_y}{S_x}(X_i - \bar{X}) \quad \text{.................. i}$$

Estimates of discharge for the short-term site are computed by entering known logarithms of the discharge at the long-term site (X_i) into the equation and then exponentiating the estimates $(\bar{Y}_i)$ from logarithms back into original units. Little Shuru station (2FC11) was used as an index station since it had the longest discharge record (August, 1966 to January, 2000). The station also had a correlation of 0.60 and above with the rest of the stations. A minimum correlation coefficient required for the MOVE.1 technique has not been developed; however, similar correlation studies have used values ranging from 0.70 (Stedinger andThomas, 1985) to 0.80 (Ries, 1994).

3.3.4.1.1 Flood Frequency Analysis

Flood frequency analyses are used to predict design floods for sites along a river. The technique involves using observed annual peak flow discharge data to calculate statistical information such as mean values, standard deviations, skewness, and recurrence intervals. These statistical data are then used to construct frequency distributions, which are graphs and tables that tell the likelihood of various discharges as a function of recurrence interval or exceedence probability. Log-Pearson Type III Distribution method was used in this study.

The Log-Pearson Type III distribution is a statistical technique for fitting frequency distribution data to predict the design flood for a river at a specific site. Once the statistical information is calculated for the river site, a frequency distribution can be constructed. The probabilities of floods of various sizes can be extracted from the curve. The advantage of this particular technique is that extrapolation can be made of the values for events with return periods well beyond the observed flood events. This technique is the standard technique used by Federal Agencies in the United States (Bedient and Huber, 2002).

The Log-Pearson Type III distribution is calculated using the general equation:

$$\log x = \overline{\log x} + K\sigma_{\log x} \quad \text{..........................ii}$$

where x is the flood discharge value of some specified probability, $\overline{\log x}$ is the average of the *log x* discharge values, *K* is a frequency factor, and σ is the standard deviation of the *log x* values. The frequency factor *K* is a function of the skewness coefficient and return period and can be found using frequency factor table. The flood magnitudes for the various return periods are found by solving the general equation. The mean, variance, and standard deviation of the data can be calculated using the two formulas below.

$$\overline{\log x} = \frac{\sum(\log x_i)}{n} \qquad \frac{\sum_{1}^{n}(\log Q - avg(\log Q))^{\wedge}2}{n-1}$$

and

$$\sigma_{\log x} = \sqrt{\frac{\sum\left(\log x - \overline{\log x}\right)^2}{n-1}} \qquad \text{Or} \quad \sigma \log Q = \sqrt{variance}$$

Next, the skewness coefficient C_s can be calculated as follows:

$$C_s = \frac{n\Sigma(\log x - \overline{\log x})^3}{(n-1)(n-2)(\sigma_{\log x})^3}$$

where n is the number of entries, x the flood of some specified probability and $\sigma_{\log x}$ is the standard deviation.

The analysis was done along the three rivers at all the five gauging stations.

3.3.4.2 Groundwater

3.3.4.2.1 Recharge Estimation

Recharge has been defined as the water added to the saturated groundwater body; in the context of river recharge, it is the water that leaves a river and crosses the water table (Beekman *et al.*,1996). Estimating recharge is often difficult, and many studies and methods find it easier to estimate transmission losses, that is, the water that leaves the river downwards. Storage in the unsaturated zone, bank storage, evapotranspiration, perched water tables and shallow lateral flow can lead to large differences between recharge and transmission losses (Beekman *et al.*.1996). Four main modes of recharge can be distinguished:

A. “Downward flow of water through the unsaturated zone reaching the water table”

B. “Lateral and/or vertical inter-aquifer flow”

C. "Induced recharge from nearby surface water bodies resulting from groundwater abstraction" and

D. "Artificial recharge such as from borehole injection or man-made infiltration ponds".

Natural recharge by downward flow of water through the unsaturated zone is generally the most important mode of recharge in arid and semiarid areas. Mechanisms of infiltration and moisture transport that are likely to occur for this mode are illustrated in Figure 3.2 below. Main sources of recharge are rainfall, surface water bodies (ephemeral or seasonal rivers, lakes, estuaries) and irrigation losses.

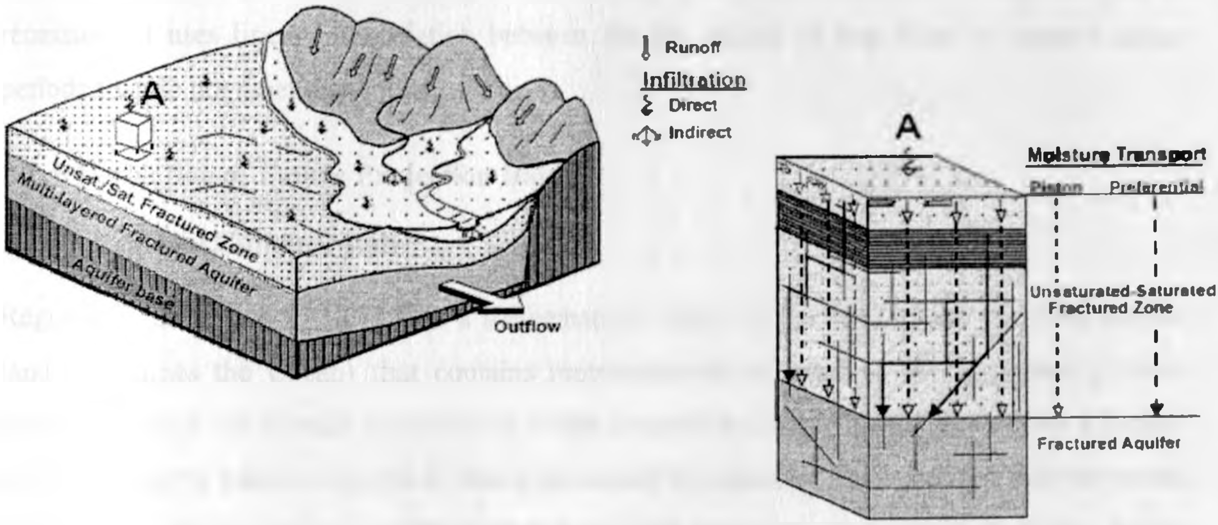


Fig. 3.2 Mechanisms of infiltration and moisture transport (Beekman *et al.*,1996).

3.3.4.2.2 Use of Hydrograph Records in Recharge Estimation

The computer program PART was used to provide estimates of base flow for selected gauged watersheds in the basin. Base flow is the part of streamflow usually attributed to ground-water discharge (U.S. Geological Survey, 1989). Although base flow is not recharge, it is sometimes used as an approximation of recharge when underflow, evapotranspiration from riparian vegetation, and other transfers of ground water to or from the watershed are minimal. If these conditions are met, base flow may provide a reasonable estimate of recharge for long time periods (1 year or more). Methods for separating streamflow hydrographs into components of base flow and surface runoff have been available for many years (Hall, 1968) and, more recently, computer programs have automated the separation procedures (e.g. Pettyjohn and Henning, 1979).

The computer program PART (Rutledge, 1998) was used for this study because it has been widely and successfully used by researchers (Rutledge and Mesko, 1996; Holtschlag, 1997; Nelms *et al.*, 1997; Bachman *et al.*, 1998) and the software is supported by the USGS. The PART program computes base flow from the stream-flow hydrograph by first identifying days of negligible surface runoff and assigning base flow equal to streamflow on those days; the program then interpolates between those days. PART locates periods of negligible surface runoff after a storm by identifying the days meeting a requirement of antecedent-recession length and rate of recession. It uses linear interpolation between the log values of base flow to connect across periods that do not meet those tests.

3.3. 5 Derivation of Future Projection Data

3.3.5.1 Regional Climate Model

Regional Climate Model (RCM) is a mathematical model of the atmosphere and land surface (and sometimes the Ocean) that contains representations of most of the important physical processes within the climate system. It is a high resolution climate model that covers a limited area of the globe based on physical laws represented by mathematical equations that are solved using a three-dimensional grid. The typical horizontal resolution of an RCM is 50 km. Hence RCMs are comprehensive physical models, usually including the atmosphere and land surface components of the climate system and containing representations of the important processes within the climate system (e.g., cloud, radiation, rainfall, soil hydrology). Many of these physical processes take place on much smaller spatial scales than the model grid and cannot be modeled and resolved explicitly. Their effects are taken into account using parametrizations by which the process is represented by relationships between the area or time averaged effect of such sub-grid scale process and the large scale flow.

The nested regional climate modeling technique consists of using initial conditions, time-dependent lateral meteorological conditions and surface boundary conditions to drive high-resolution RCMs. The driving data is derived from GCMs (or analyses of observations) and can include Green House Gases (GHG) and aerosol forcing. A variation of this technique is also used to force the large scale component of the RCM solution throughout the entire domain.

The RCM was set up for the eastern Africa domain and run to simulate the climate for the present (1961-1990) and a future period 2010-2100 using ERA-40 reanalysis, HadAM3P and ECHAM4 GCM output as initial and boundary forcing. The A2 and B2 GCM future scenarios or storylines were used. Note that, A2 scenario is based on heterogeneous world with a large gap between the rich and the poor, high rates of population growth, and slower economic development. In the A2 scenario the distribution of new technology is assumed to be slow, and energy needs are largely met through fossil resources. This scheme results in medium to high emissions, with atmospheric CO_2 concentrations reaching 715ppm and global temperatures expected to increase by around 3.3°C by the 2080s (IPCC 2007). On the other hand, the B2 storyline describes a technologically imbalanced world, a world with emphasis on local solutions for economic, social, and environmental sustainability. In some areas, technology will develop rapidly, while other areas will be forced to make do with outdated technology. It describes a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels. The accompanying emissions scenario is medium low, with CO_2 concentrations at 562ppm and global temperatures expected to increase by around 2.3°C.

3.3.5.2 PRECIS Regional Climate Projections

To generate climate change projections, two time-slice periods were used to drive the RCM. The first period is usually when there are no increases in emissions (i.e. to represent pre-industrial climate) or can be for a recent climate period. 1961-1990 is often chosen as it is the current WMO 30-year averaging period. The second period can be any period in the future, although will often be taken at the end of the century (for example, 2071-2100) when the climate change signal will be clearest against the noise of climate variability. The projected regional climate model in this study are based on the difference of two 30-year simulated climate regimes; the future climate (average for 2071 to 2100) minus the present day climate (average for 1961 to 1990).

The model simulations were performed with and without including the sulphur cycle, to understand the role of regional patterns of sulphate aerosols in climate change. However, the effect of black carbon (soot) was not included in the simulation experiments. Using the model output from these experiments, high-resolution climate change scenarios have been developed for various surface and upper air parameters of critical importance to the impact assessments for East Africa region.

An effective way of exploring a model's internal variability is to use ensembles, effectively increasing simulation length while minimising the effect of the change in external forcing due to atmospheric composition. To increase the range of climate states captured, a set of realizations of a particular climate can be produced, each using the same evolution of atmospheric composition (recent or future). The individual members of the driving model ensemble are initialized with different (but equally plausible) states. The deterministic nature of the model produces a different (but again equally plausible) representation of the subsequent climate for each initial state.

The regional climate projections were computed by weighting output of ensemble members of the two GCMs, ECHAM4 and HadAM3P, used as forcings to PRECIS RCM for a high emissions scenario (SRES A2) and also low emission scenario (SRES B2).

3.4 Data Integration

To determine the influence of changes in climate, land cover and population on the quantity of the area's water resources, multiple linear regression analyses was done using SPSS (Statistical Package for Social Sciences). The analyses described the dependence between the various variables. The model was tested with the 1971-2000 data and predictions made for the years 2010, 2020 and 2030 based on IPCC- AR4 global warming scenario.

3.4.1 Linear Regression Analysis and Prediction

Linear regression is performed either to predict the response variable based on the predictor variables, or to study the relationship between the response variable and predictor variables.

Multiple linear regression analysis performs linear regression on a selected dataset. This fits a linear model of the form

$$Y = b_0 + b_1 X_1 + b_2 X_2 + \ldots + b_k X_k + e$$

where Y is the dependent variable (response) and X_1, X_2,... ..X_k are the independent variables (predictors) and e is random error. b_0 , b_1 , b_2 , ... b_k are known as the regression coefficients, which have to be estimated from the data. The analysis was performed and predictions made on the response variables up to the year 2030.

3.5 Limitations

Based on the scope of this research, four different data sets were collected and analysed. These include temperature, precipitation, land cover changes and population. Only daily minimum temperature data for the years of interest were available.

Some of the data, especially the rate of changes in catchment area, were, however, not available on annual basis. To fill in the gaps, a simple linear trend of change was assumed. A lot of gaps were also noted in streamflow records; which were approximated and filled as explained in section 3.3.4.1 above.

The Linear Regression Models developed are limited as they only capture the parameters under the scope of this work, namely; daily minimum temperature, precipitation, land cover and population,

CHAPTER FOUR: RESULTS

4.1 Baseline Trends, 1971 – 2000

4.1.1 Temperature

Daily minimum temperature rose from 8.9 °C in 1971 to a record 12.15 °C in 1998 (Fig. 4.1). Relatively higher temperatures were observed in 1972, 1973, 1977, 1983, 1987, 1988, 1994 and 1998. The temperatures were relatively low in 1971, 1976, 1984, 1985 and 1986.

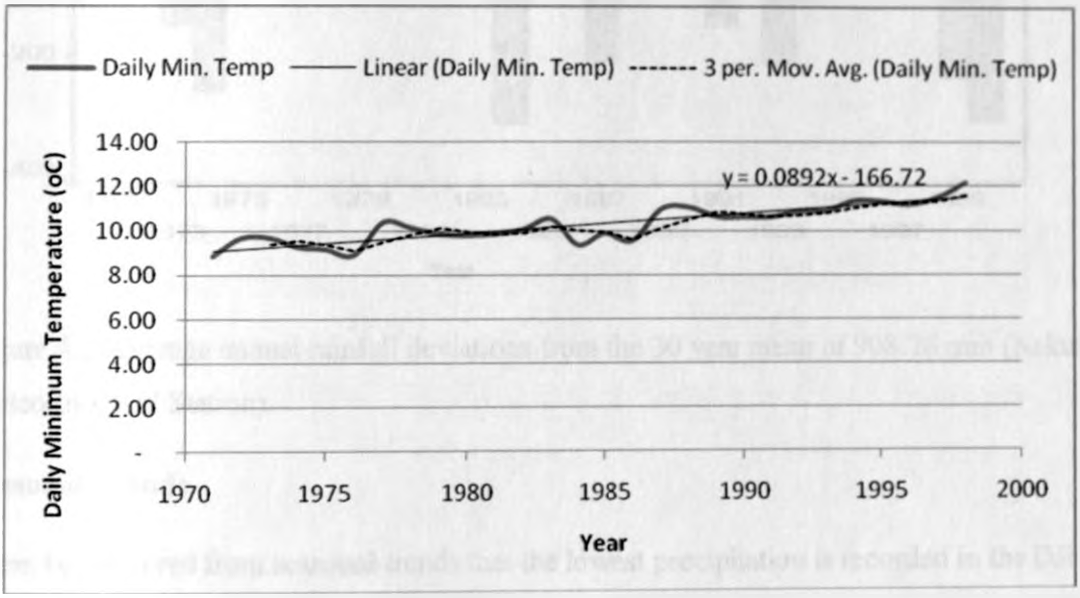


Fig. 4.1 Daily minimum temperature, 1971 – 2000.

The above temperature data indicates changing weather patterns as observed elsewhere in the rest of the world. There is a consistent increase in the daily minimum temperature as can be observed from the regression line (Fig. 4.1).

4.1.2 Precipitation

The area has experienced dry and wet years between 1971 and 2000 (Fig. 4.2). The positive values indicate years with higher precipitation than the annual mean value (908.76 mm) while negative values indicate drier years. Extremely wet periods were observed in the years 1977, 1978, 1988, 1989 and 1999.

The seasonal deviations for DJF, MAM, JJA and SON are also observed (Fig. 4.3 a-d).

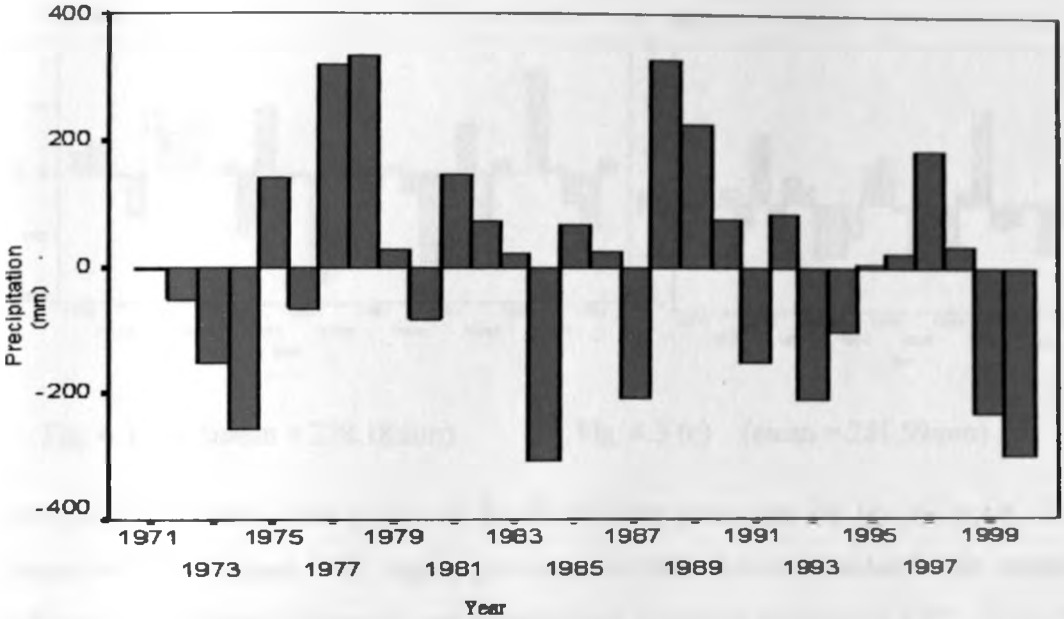


Figure 4.2 Average annual rainfall deviations from the 30 year mean of 908.76 mm (Nakuru Meteorological Station).

Seasonal Trends

It can be observed from seasonal trends that the lowest precipitation is recorded in the DJF while the highest precipitation is recorded in MAM season. Slightly higher precipitation was recorded in JJA than in SON season.

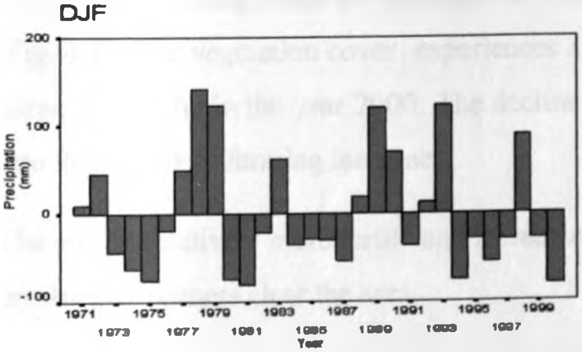


Fig. 4.3 (a) (mean = 104.38mm)

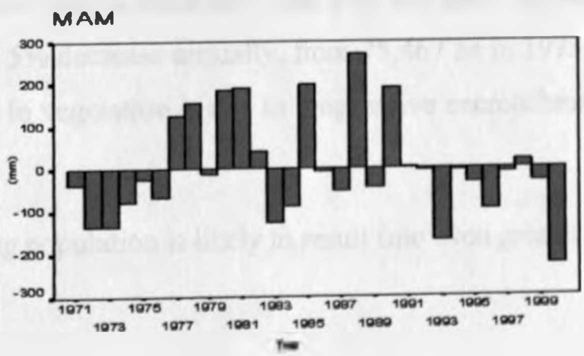
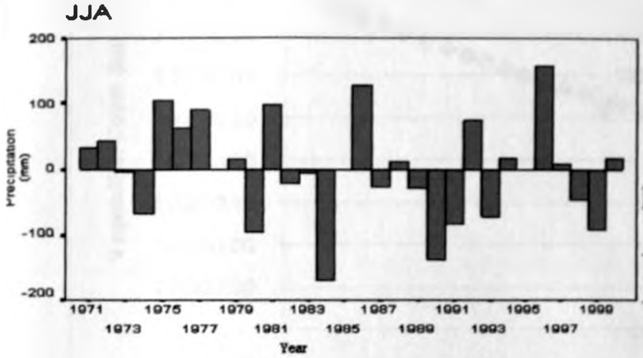


Fig. 4.3 (b) (mean = 294.61mm)



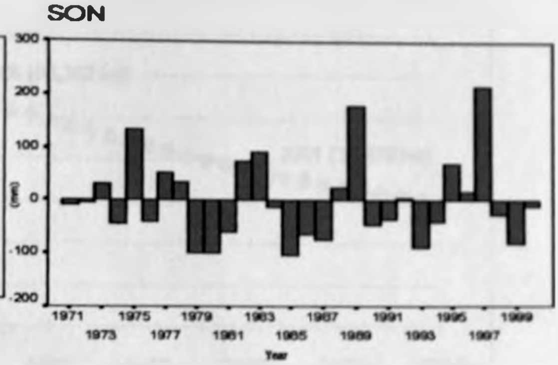


Fig. 4.3 (d) (mean = 228.18mm) Fig. 4.3 (c) (mean = 281.59mm)

Precipitation records show cycles of floods and droughts over the last 30 years. The positive values indicate seasons with higher precipitation than the mean value while negative values indicate drier seasons. Extremely wet periods were observed in the years 1977, 1978, 1988, 1989 and 1999. These correspond to el-Niño rains. Extremely dry periods were observed in the years 1974, 1984, 1984, 1987, 1993, 1999 and 2000 which also corresponds to droughts. Highest precipitation is observed in MAM season (Fig. 4.3b). This is because long rains occur between March and April while short rains occur in August and September. The dry season of DJF recorded the least amount of precipitation (Fig. 4.3a).

4.1.3 Land Cover Change

There is a declining trend of vegetation in Lake Nakuru catchment area over the past 30 years (Fig. 4.4). The vegetation cover experiences 2.5% decrease annually, from 75,467 ha in 1973 to about 40,000 ha in the year 2000. The decline in vegetation is due to progressive encroachment into the forests as farming increases.

The area is relatively more fertile and increasing population is likely to result into even greater pressure as farmers clear the area.

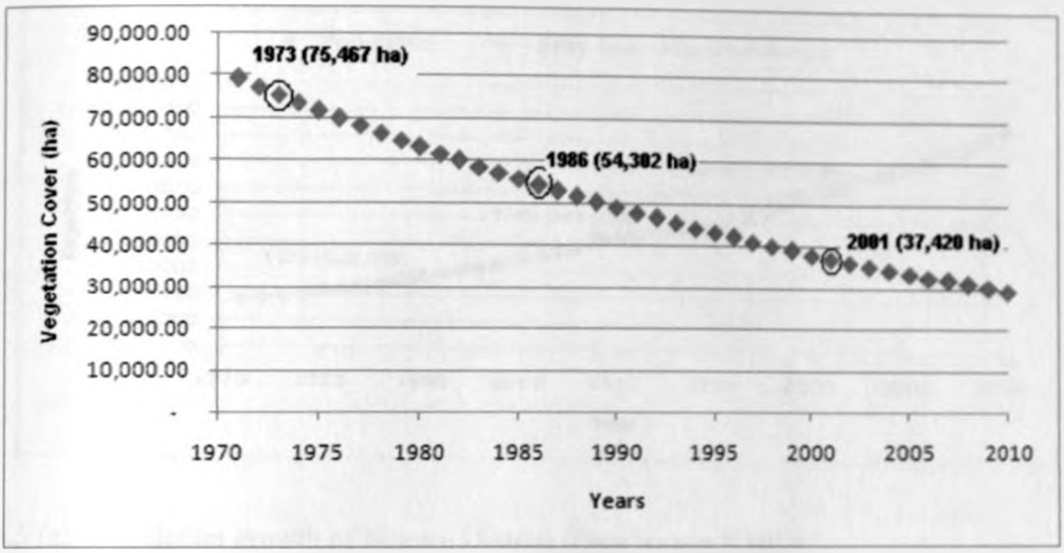


Fig. 4.4 Land cover changes in the Lake Nakuru catchment area (Adapted after Lambrechts, 2002).

4.1.4 Population

The population grows at between 3.5% to 4.5% in Nakuru. The population stood at 523,000 in 1979, 849,000 in 1989 and 1,187,000 in 1999 (4.5a). The increase in population is exerting more pressure particularly on the water and land resources.

4.1.5 Domestic Water Demand

The domestic water demand in the area has been on a steady increase following increasing population as discussed in section 4.1.4 above (Fig. 4.5b). The annual demand per person is estimated to risen from 18 m^3 in 1971 to 32 m^3 in 2000. This translates to approximately 2% annual increase of demand per capita.

The increasing demand per capita makes the rate of increase of total domestic water demand to be higher than the rate at which the population is growing. This is because the total domestic water demand is a product of the demand per capita and the population. The rate of increase in total water demand is approximately 7% annually. See also figure 4.15 in section 4.3.4.

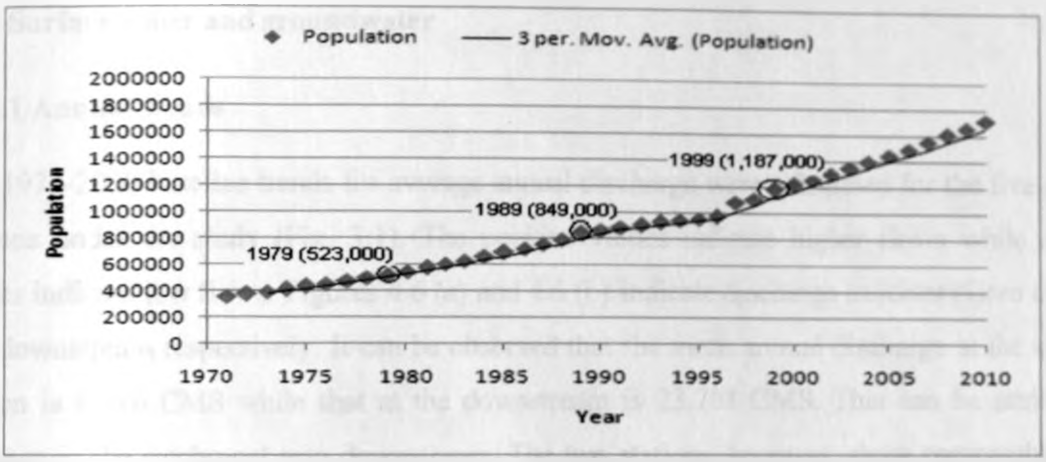


Fig.4.5 (a) Population growth of Nakuru District (Data source KNBS).

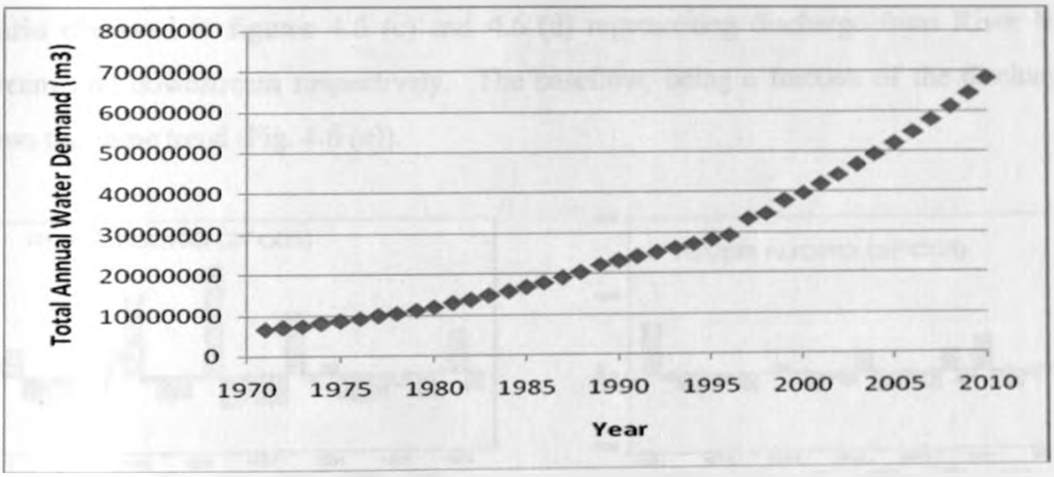


Fig. 4.5 (b)Total Annual domestic water demand in Nakuru District between 1971 and 2010.

4.1.6 Surface water and groundwater

4.1.6.1 Annual trends

The 1971-2000 baseline trends for average annual discharge were calculated for the five gauging stations under the study (Fig. 3.1). The positive values indicate higher flows while negative values indicate low flows. Figures 4.6 (a) and 4.6 (b) indicate discharge in River Njoro upstream and downstream respectively. It can be observed that the mean annual discharge at the upstream station is 8.716 CMS while that at the downstream is 23.703 CMS. This can be attributed to increase in the catchment area downstream. The two stations, however, show comparable trends of high and low flows, with low flows observed between 1973 – 1975, 1980 – 1983, 1985 – 1988 where as high flows were observed in 1971, 1979, 1984, 1989 and 1999. This is the same scenario observed in figures 4.6 (c) and 4.6 (d) representing discharge from River Mereroni upstream and downstream respectively. The baseflow, being a fraction of the discharge, also follows the same trend (Fig. 4.6 (e)).

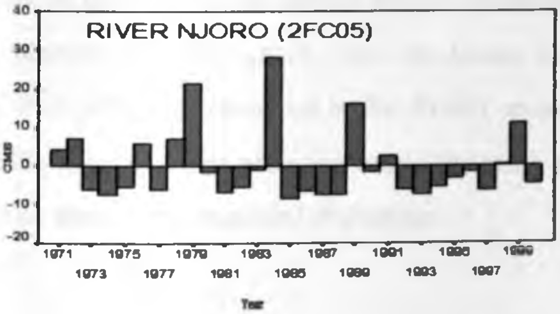


Fig. 4.6 (a) (mean = 8.716 CMS)

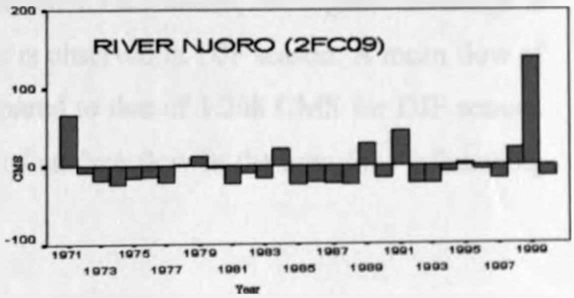


Fig. 4.6 (b) (mean = 23.703 CMS)

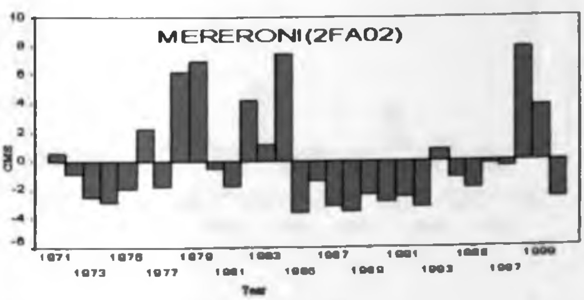


Fig. 4.6(c) (mean = 3.645 CMS)

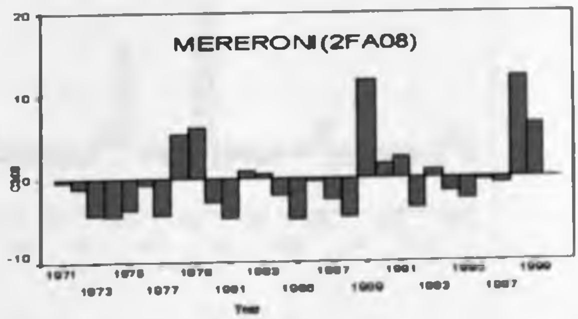


Fig. 4.6 (d) (mean = 4.831 CMS)

The figures 4.6 (a-d) above show annual deviations from the baseline for various rivers in the basin.

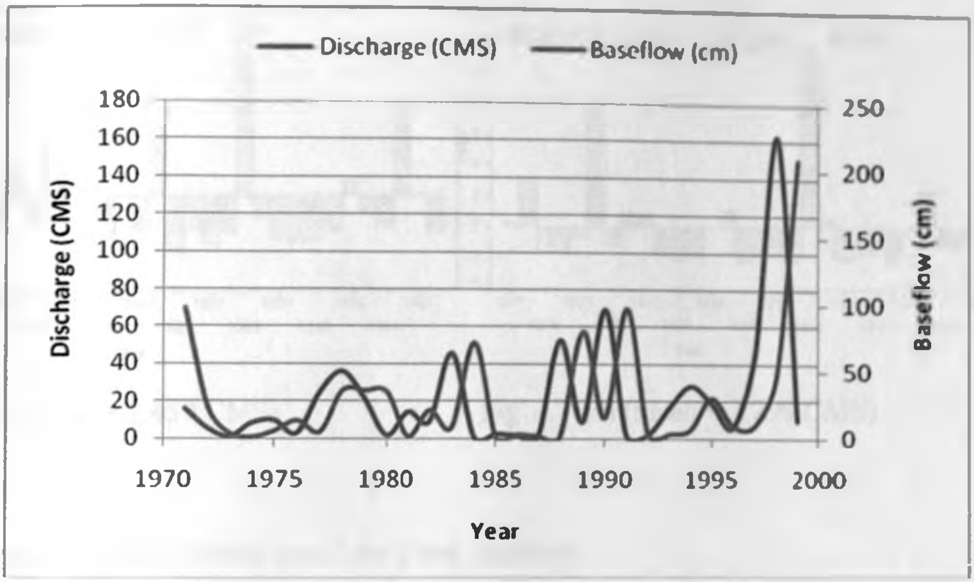


Fig. 4.6 (e) Discharge and baseflow for station 2FC09 along River Njoro.

4.1.6.2 Seasonal Trends

Figures 4.7a-d below show the seasonal discharge for station 2FC05 along River Njoro. And just like in the case of the annual trends discussed in section 4.1.6.1 above, the highest discharge is observed in MAM season while the lowest discharge is observed in DJF season. A mean flow of 2.751 CMS was observed in the MAM season compared to that of 1.208 CMS for DJF season. This indicates that precipitation is the main source of surface flow in the area thus influencing both annual and seasonal discharge.

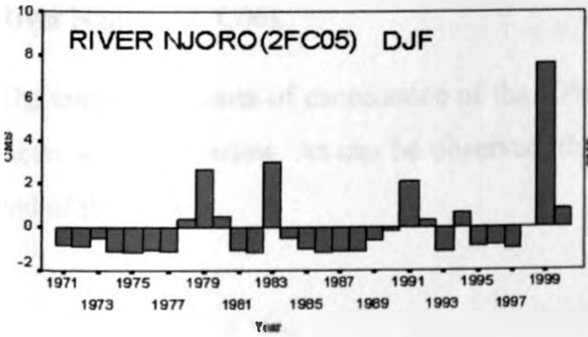


Fig. 4.7 (a) (mean = 1.208 CMS)

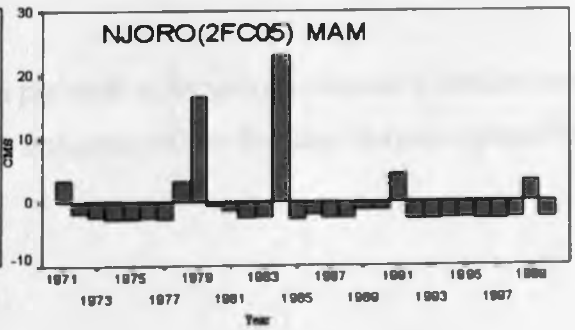


Fig. 4.7 (b) (mean = 2.751 CMS)

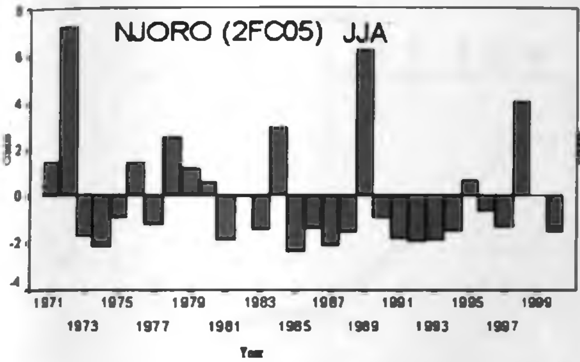


Fig. 4.7(c) (mean = 2.459 CMS)

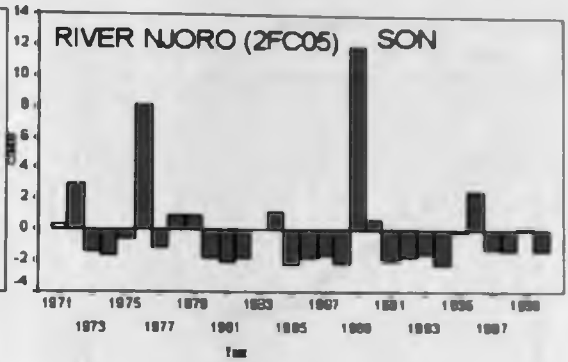


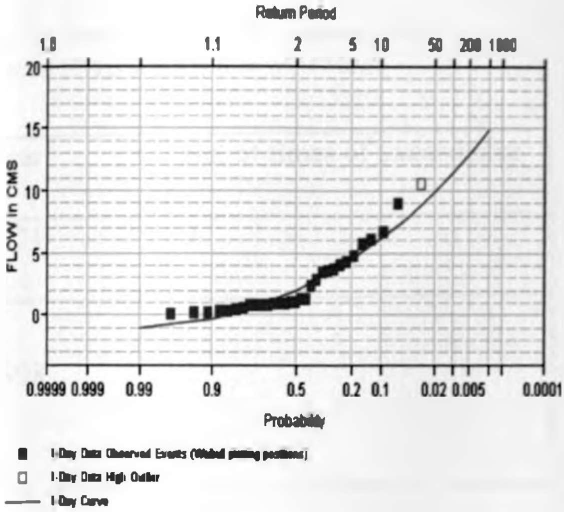
Fig. 4.7 (d) (mean = 2.299 CMS)

4.1.7 Extreme Events: Floods and Low Flow Analysis

The graphs below (Fig. 4.8 (a) - (d)) show the flood frequency analysis for four stations. The graphs show the likelihood of various discharges as a function of recurrence intervals. This makes it possible to extract probabilities of floods of various sizes. Tables 4.1 – 4.4 below show the number of times of exceedence of 10% probability of flow (10-year-return period) for the various stations. The 10-year-return period flow for various gauging stations has been increasingly exceeded by peak flows towards the end of the series.

The highest 10% chance of flow is recorded for River Njoro (2FC09) at 147 cms. This flow was exceeded 7 times in 1971, once in 1998 and 12 times in 1999. The ten year return period for River Njoro (2FC05) is 21 cms, and was exceeded only four times in 1978. Other 10% chance flow are 10 cms for River Mereroni (2FA08), 6 cms for River Mereroni (2FA02) and 6 cms for River Ngosur (2FC06).

The number of times of exceedence of the 10% probability for various stations is detailed in the tables 4.1 – 4.4 below. As can be observed, the frequency of the flooding increases towards the end of the series.



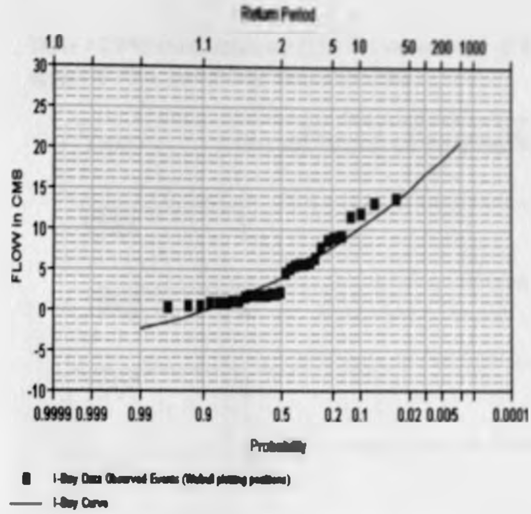
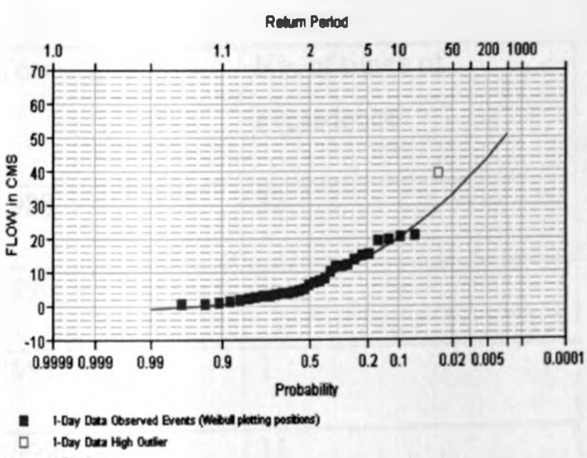


Fig. 4.8 (a)

Fig. 4.8 (b)

Volume-Duration Frequency Analytical plot for Station 2FA02 (Fig. 4.8 a) and 2FA08 (Fig. 4.8 b) along River Mereroni upstream and down stream respectively.



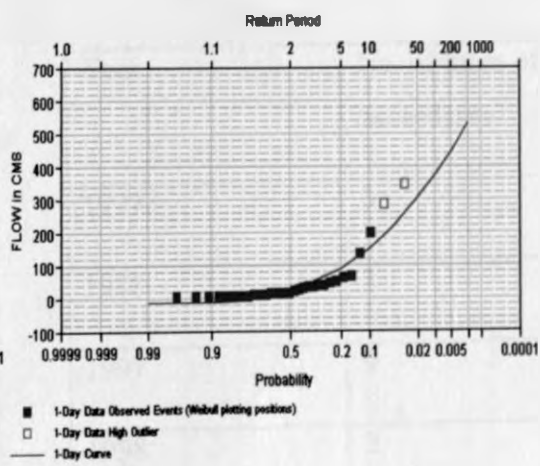


Fig. 4.8 (c)

Fig. 4.8 (d)

Volume-Duration Frequency Analytical plot for Station 2FC05 (Fig. 4.8 c) and 2FC09 (Fig. 4.8 d) along River Njoro upstream and downstream respectively.

Table 4.1 River Njoro (2FC09) exceedence of the expected 10% probability flow of 147 CMS

Year	No. of times of exceedence
1971	7
1998	1
1999	12

Table 4.2 Mereroni upstream (2FA02) exceedence of the expected 10% probability flow of 6 CMS

Year	No. of times of exceedence
1981	1
1982	2
1993	1
1997	22
1998	5

Table 4. 3 R. Ngosur (2FC06) exceedence of the expected 10% probability of 6 CMS

Year	No. of times of exceedence
1988	32
1996	3
1997	1
1999	11

Table 4.4 R. Mereroni (2FA08) exceedence of the 10% probability of 10 CMS flow

Year	No. of times of exceedence
1977	3
1988	3
1997	9
1998	2

CHAPTER FIVE: DISCUSSION

5.1 Influences on Water Quantity, 1971 – 2000

5.1.1 Relationship between temperature and water quantity

A positive correlation is observed between temperature and the total amount of discharge in the area (Fig. 5.1). This is because the discharge is majorly influenced by precipitation, which is also positively correlated with the daily minimum temperature. It can be observed that a slight increase in temperature drives a more vigorous hydrological cycle. A correlation coefficient of 0.6 was observed.

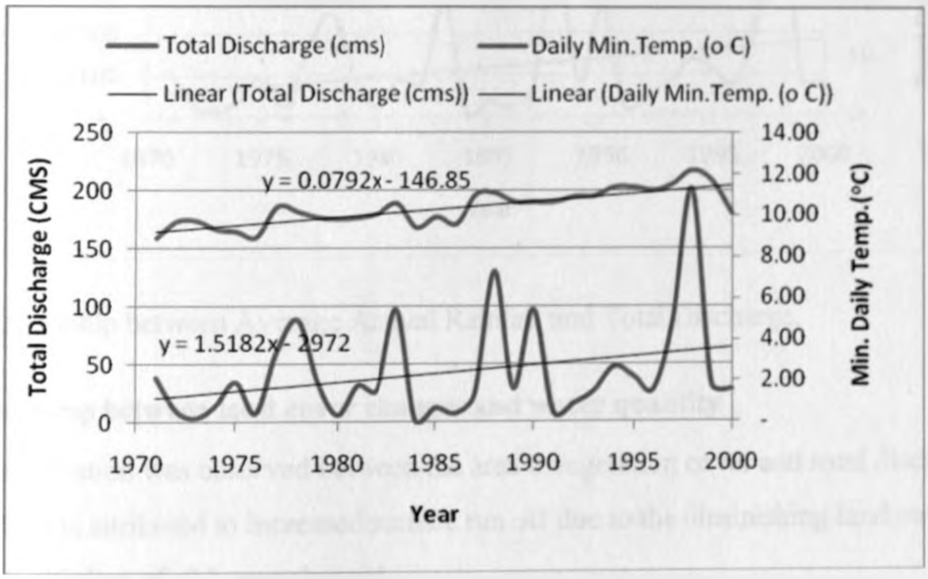


Fig. 5.1 Relationship between total amount of discharge and Minimum Daily Temperature.

5.1.2 Relationship between precipitation and water quantity

As observed in section 4.1.6.1 and 4.1.6.2 above, the rate of discharge as well as that of baseflow (Fig. 4.6) is highly correlated with the amount of rainfall in the Lake Nakuru And Lake Elmenteita areas. This is evident from high flows observed during rainy periods, both seasonally and annually. High peak flows are observed during MAM and SON which are seasons of long and short rains respectively while low flows are observed in DJF and JJA which are relatively dry seasons.

Increasing precipitation has resulted in an increase in discharge over the last thirty years as can be observed in figure 5.2 below. A correlation coefficient of 0.5 was observed.

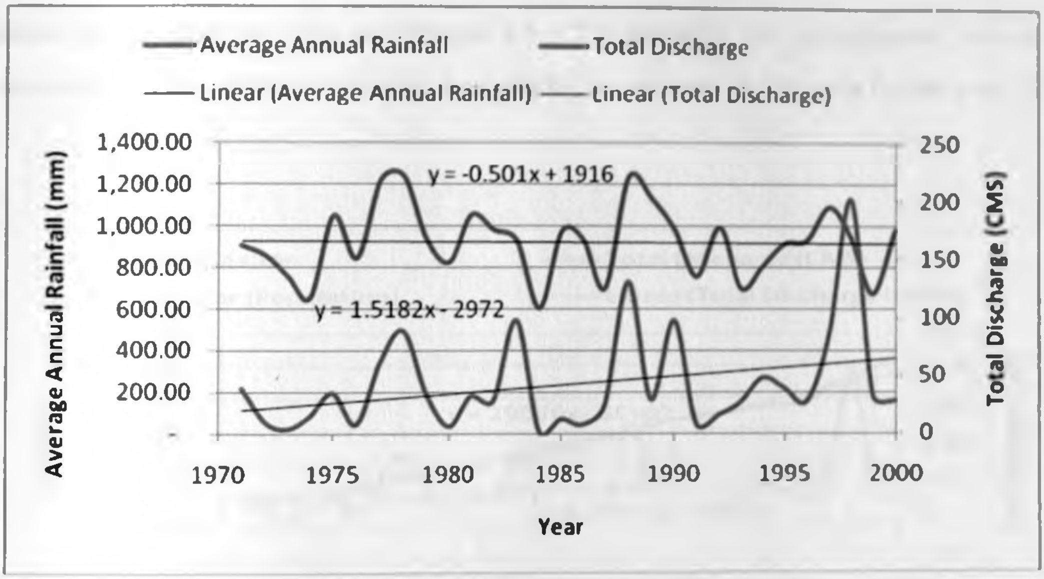


Fig. 5.2 Relationship between Average Annual Rainfall and Total Discharge.

5.1.3 Relationship between land cover changes and water quantity

A negative correlation was observed between the area's vegetation cover and total discharge (Fig. 5.3). This is attributed to increased surface run off due to the diminishing land cover. A correlation coefficient of -0.3 was oberved.

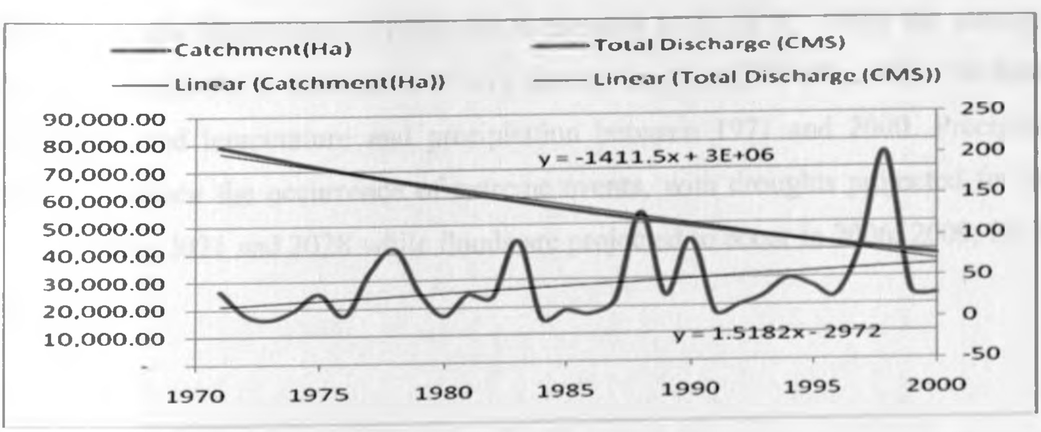


Fig. 5.3 Relationship between Catchment Area and Total Discharge.

5.1.4 Relationship between population growth and water quantity

There appears to be a positive corellation between population and total amount of discharge in the area (Fig. 5.4). However, this scenario does not signify a sustainable water supply since the rate of increase in population is higher than the rate of increase in the precipitation. Whereas the population is projected to grow at between 3.5-4.5% annually, the precipitation, which is the main source of surface water in the area, is projected to increase by 9% only by the year 2030.

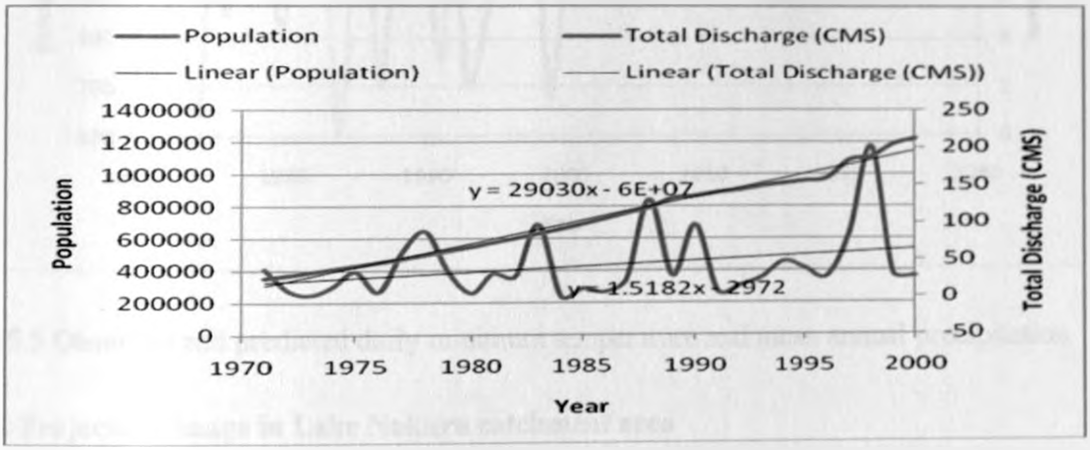


Fig. 5.4 Relationship between Population and total discharge in the area

5.2 Projections, 2001 to 2030

5.2.1 Projection of Temperature and Precipitation for Lake Nakuru Area

The daily minimum temperature is projected to increase to 13.26 °C while the average mean precipitation is projected to increase to 974.13 mm by the year 2030 (Fig. 5.5). The figure also shows the observed temperature and precipitation between 1971 and 2000. Precipitation is expected to influence the occurrence of extreme events, with droughts projected for the year 2001, 2012, 2016, 2021 and 2028 while floods are projected to occur in 2006, 2009, 2018, 2024 and 2030

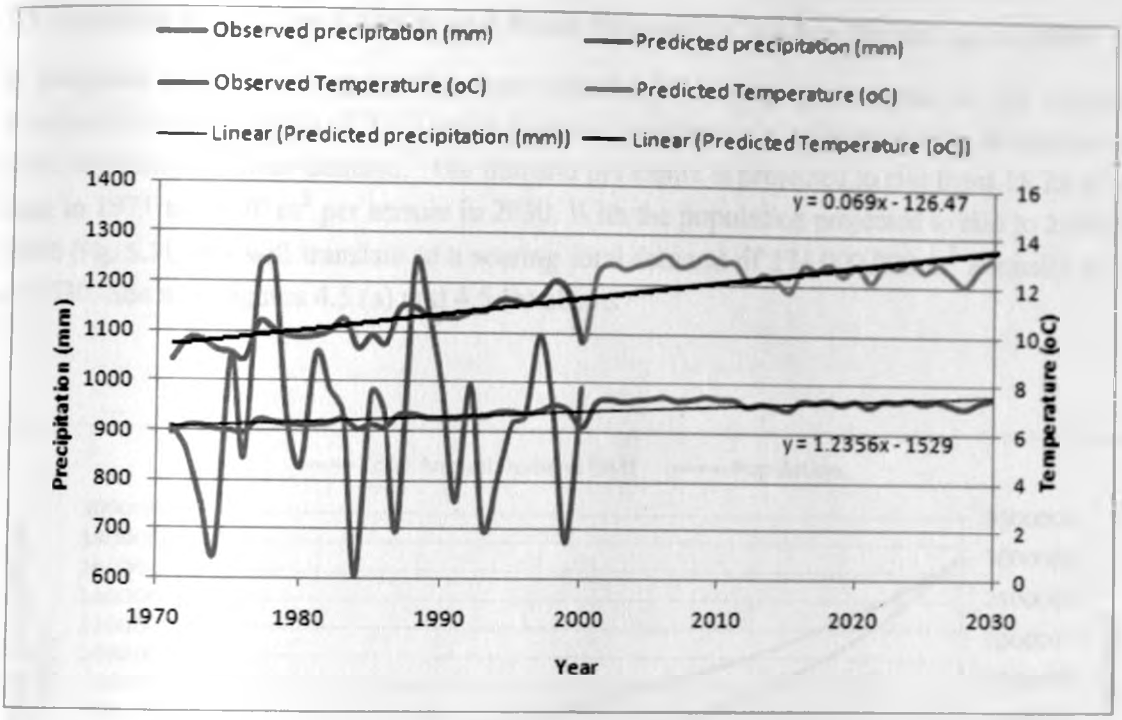


Fig. 5.5 Observed and predicted daily minimum temperature and mean annual precipitation

5.2.2 Projected change in Lake Nakuru catchment area

The area's catchment area is projected to diminish from 137,144 Ha to 17,825 Ha between 2001 and 2030 (Fig. 5.6). This is based on a constant diminishing rate of 2.5% annually. See also figure 4.4 above.

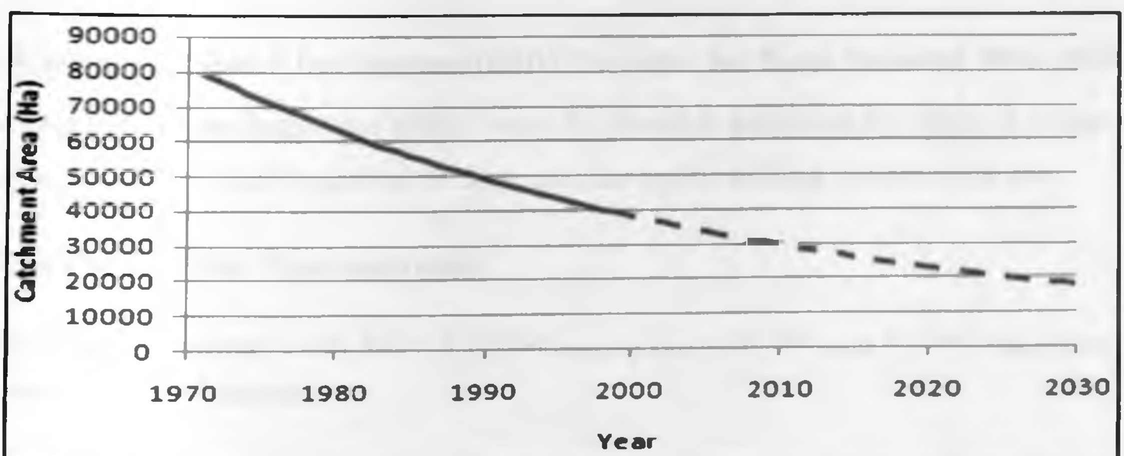


Fig. 5.6 Projected catchment area upto the year 2030

5.2.3 Projected Population Growth and Water Demand in Nakuru District up to 2030

The projected total annual domestic water demand is directly proportional to the projected population in the area (Fig. 5.7). This is because population is a factor which determines the amount of domestic water demand. The demand per capita is projected to rise from 18.25 m^3 per annum in 1971 to 58.70 m^3 per annum in 2030. With the population projected to rise to 2,967,595 by 2030 (Fig. 5.7), this will translate to a soaring total demand of 174,000,000 m^3 annually by the year 2030. See also figures 4.5 (a) and 4.5 (b) above.

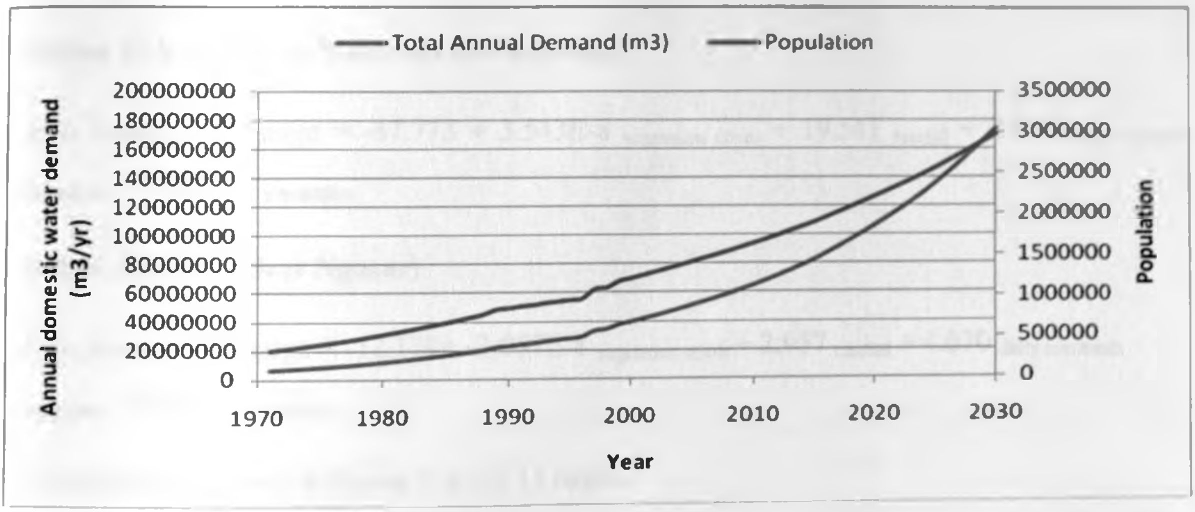


Fig. 5.7 Projected population growth and domestic water demand in Nakuru District.

5.2.4 Intergrated Model Development (IMD) Projection for Water Quantity; 2001- 2030

The following Linear Regression Models were developed to determine the effect of changes of Climate, Land cover and Population on the stream flow at the selected stations in the area:

Station 2FC 05 (River Njoro upstream)

Mean Annual Discharge = $-101.583 + 5.127E\text{-}8_{\text{vegetation cover}} + 28.108_{\text{rainfall}} + 4.661_{\text{daily minimum temperature}} + 1.001E\text{-}5_{\text{population}}$

Station 2FC 09 (River Njoro downstream)

Mean Annual Discharge = $-534.793 + 2.889E\text{-}7_{\text{vegetation cover}} + 44.855_{\text{rainfall}} + 26.295_{\text{daily minimum temperature}} + 11E\text{-}5_{\text{population}}$

Station 2FA 02 (River Mereroni upstream)

Mean Annual Discharge = $-32.408 + 1.612E\text{-}8_{\text{vegetation cover}} + 11.526_{\text{rainfall}} + 1.249_{\text{daily minimum temperature}} + 4.811E\text{-}6_{\text{population}}$

Station 2FA 08 (River Mereroni downstream)

Mean Annual Discharge = $-67.773 + 3.543E\text{-}8_{\text{vegetation cover}} + 19.541_{\text{rainfall}} + 2.088_{\text{daily minimum temperature}} + 1.810E\text{-}5_{\text{population}}$

Station 2FC 06 (River Ngosur)

Mean Annual Discharge = $-12.174 + -3.057E\text{-}8_{\text{vegetation cover}} + 2.957_{\text{rainfall}} + 4.070_{\text{daily minimum temperature}} -1.508E\text{-}5_{\text{population}}$

The models are shown in figures 5.8 to5.11 below.

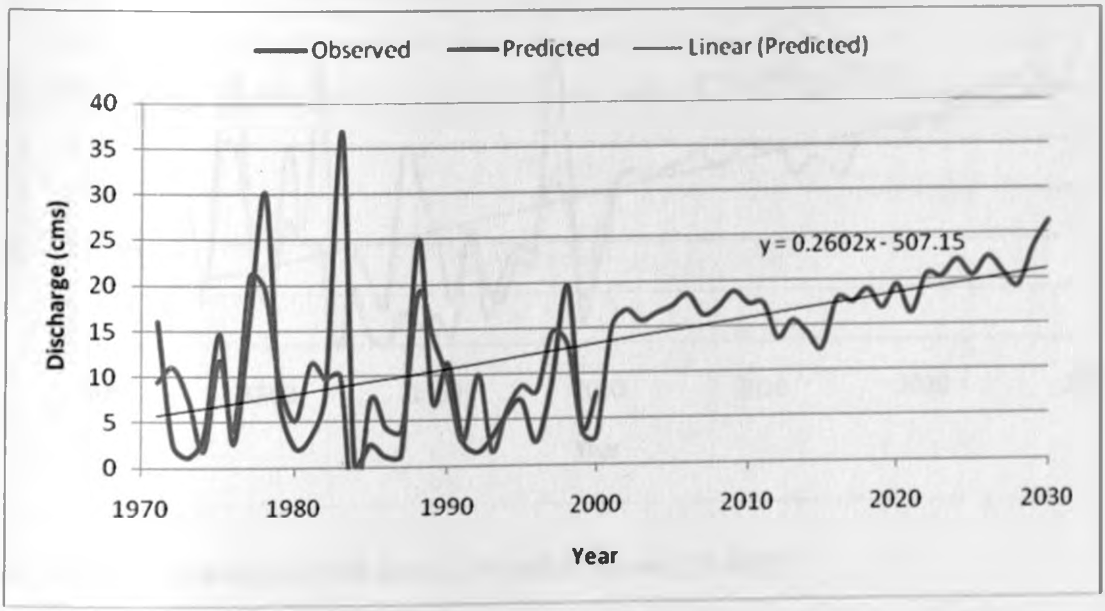


Fig. 5.8 Observed and predicted flow for RiverNjoro (2FC05).

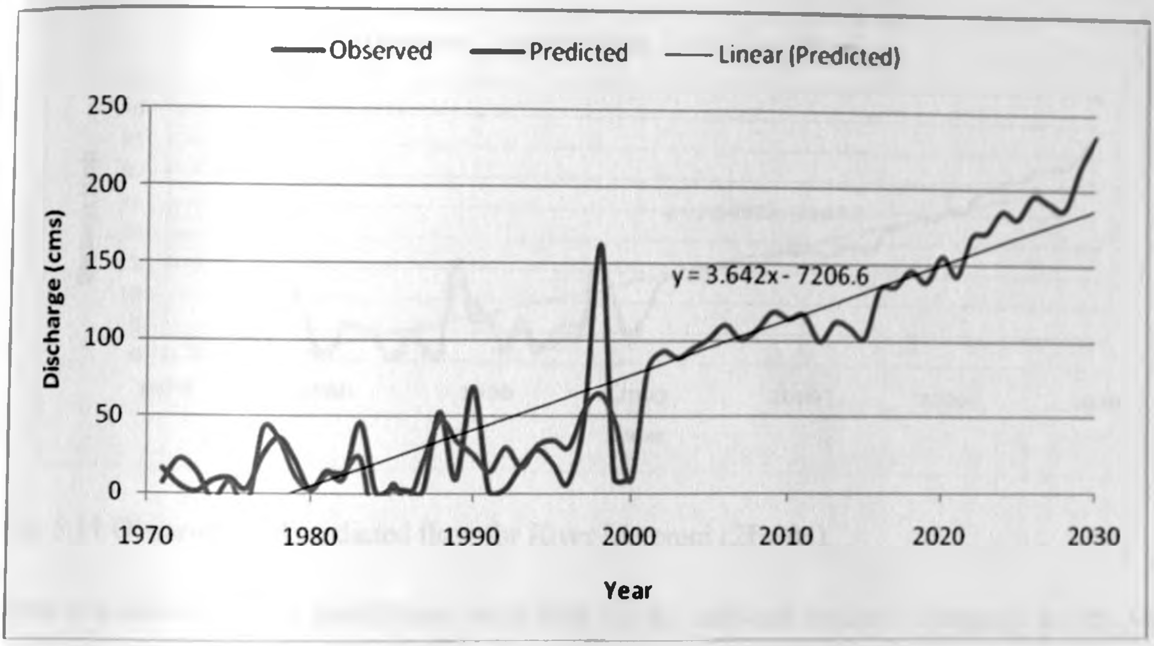


Fig. 5.9 Observed and predicted flow for RiverNjoro (2FC09).

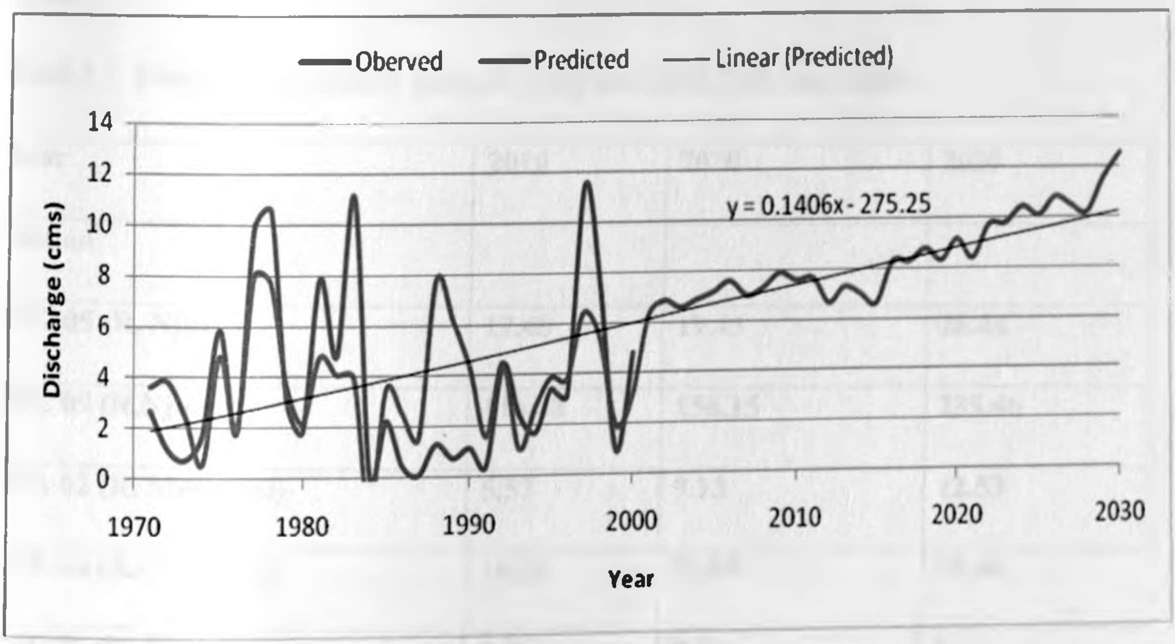


Fig. 5.10 Observed and predicted flow for River Mereroni (2FA02).

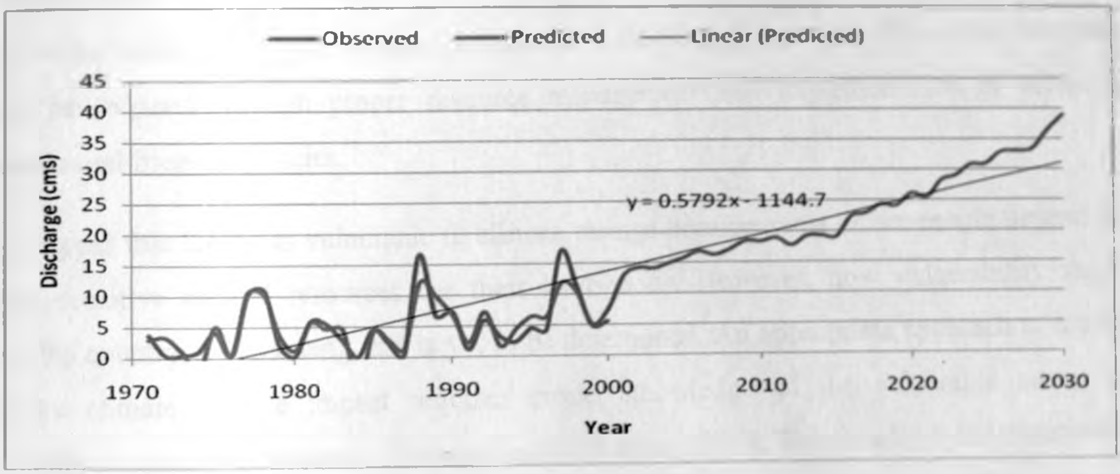


Fig. 5.11 Observed and predicted flow for River Mereroni (2FA08).

From the above models, predictions were done for the indivual stations' discharge for the year 2010, 2020 and 2030. All stations, except 2FC06, are expected to have increase in discharge. The increase is consistent with the predicted rise in pecipitation, which is the main source of discharge in the area. The total flow in the rivers was then computed as detailed in the table 5.1 below.

Table 5.1 Predicted streamflow (cms) for the years 2010, 2020 and 2030.

Year	**2010**	**2020**	**2030**
Station			
2FC 05 (R. Njoro)	**17.48**	**19.45**	**26.44**
2FC 09 (R.Njoro)	**114.68**	**156.15**	**235.46**
2FA 02 (R. Mereroni)	**5.57**	**9.13**	**12.53**
2FA 08 (R. Mereroni)	**18.35**	**26.09**	**38.98**
2FC 06 (R. Ngosur)	**9.47**	**2.73**	**0**
TOTAL STREAM FLOW (cms)	**165.55**	**213.55**	**313.41**

5.3 Management and Policy Implications

Deteriorating surface and ground water resources in Lake Nakuru and Lake Elmenteita areas can greatly be reduced through proper resource management and implementation of effective environmental friendly policies.

It is accepted that Kenya is vulnerable to climate change because most of her people depend on climate sensitive natural resources for their livelihoods. However, how vulnerability varies across the country is something that is yet to be determined. An appropriate approach to coping with the climate change impact requires proper knowledge of the vulnerable nature of communities, groups and sectors (Government of Kenya, 2010). This is why it is important to have a regional vulnerability assessment in order to come up with mitigations and adaptations measures unique to a particular basin. This will then inform the measures that need to be taken in order to minimize the negative impacts of climate change, and exploit the beneficial ones. Vulnerability assessments can address these needs and should therefore be carried out. This will involve assessing past and projected climate change evidence and impact in the country and identifying sectors as well as regions that are most vulnerable, and therefore in high need of remedial interventions (Government of Kenya, 2010).

For the Lake Nakuru basin, clearing of vegetation for settlement and farming is a major threat to water resources. Mau escarpment is the most affected and the resettlement of the inhabitants is key to ensuring sustainable water resources management.

Adaptation and mitigation measures should be enforced even as more changes are expected in the coming years. Institutions and their effective functioning play a critical role in successful adaptation. Institutions at more local scales, both formal and informal institutions should be used as a tool to reach people and educate them on other alternatives to ensure sustainable natural resource management.

It is also important to emphasize the use of participatory natural resources management skills, political good will to enforce the 10% tree cover on individual land holdings, and sensitization on tree planting focusing mainly on ground cover trees. Land fragmentation due to increased population should be abolished since it is easier to enforce these policies on larger pieces of land.

Other opportunities for adaptation that can be created include many links to technology. The role of seasonal forecasts, their production, dissemination, uptake and integration in model-based decision-making support systems has been fairly extensively examined in several African contexts (*e.g.* O'Brien and Vogel, 2003).

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Availability of surface and groundwater in Lake Nakuru and Lake Elmenteita areas is under severe threat due to changes in climate, population and land cover. Population grows in the area at the rate of 3.4% to 4.5% while natural vegetation cover is diminishing at 2.5% annually. There is constant rise in daily minimum temperature while there is a rise in the mean annual precipitation. The area's domestic water demand per capita is projected to rise from 50 litres per day in 1971 to 160 litres per day in 2030. This, based on the rate of population growth, will translate to a soaring total demand of 174,000,000 m^3 annually by the year 2030.

Strong positive correlation between precipitation and discharge is observed, indicating that rainfall is the main source of surface water in the basin. The precipitation is thus expected to influence the occurrence of extreme events, with droughts projected for the year 2001, 2012, 2016, 2021 and 2028 while floods are projected to occur in 2006, 2009, 2018, 2024 and 2030.

The effects from these changes can be prevented through concerted efforts by local, national and international institutions to enforce proper mitigations and adaptations. Necessary precautionary measures should be put in place to counter the expected droughts and floods in the coming years.

6.2 Recommendations

Emission of green house gases into the atmosphere is the main concern in global warming. Management of agricultural lands, rangelands, and forests can play an important role in reducing the current emissions and/or enhancing the sinks of CO_2, CH_4 and N_2O.

Measures that are recommended to reduce green house gas emissions and vegetation loss include slowing deforestation, enhancing natural forest generation, establishing tree plantation, promoting agroforestry and altering management of agricultural soils and rangelands. These recommendations are consistent with other objectives of land management such as sustainable development, industrial wood and fuel production, traditional forest uses, protection of other natural resources (e.g., biodiversity, soil, and water), recreation, and increasing agricultural productivity.

Enhanced resilience to future periods of drought stress can be supported by improvements in present rain-fed farming systems, such as water harvesting systems to supplement irrigation practices in dry areas ('more crop per drop strategies') (Rockstrom. 2003).

The reforestation of Mau catchment should take into account promoting cross-breeding to produce superior tree species. These species should be fast-maturing. heat-and-drought tolerant and pest-and-disease-resistant. The areas that have been cleared due for settlement. farming and charcoal burning should be rehabilitated as well.

Improved early warning systems and their application may also reduce vulnerability to future risks associated with climate variability and change. Increased investment in dams will improve harvesting of water that would cause flooding during heavy rains. This would later be used to mitigate against the effects of droughts.

There is also need to create awareness on family planning to control the soaring population. This will be crucial in ensuring the adequacy of the available resources.

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APPENDICES

Appendix I: Flood frequency analysis at River Mereroni (2FA02)

```
---------------------------
Volume-Duration Analysis
  03 Oct 2008   12:02 AM
---------------------------


--- Input Data ---

Analysis Name: MERERONI US
Description:

Data Set Name: MERERONI US
DSS File Name: C:\Documents and Settings\acer\Desktop\TEST2\TEST2.dss
DSS Pathname: /LAKE NAKURU/MERERONO/FLOW/01JAN1970/1DAY/OBSERVED/

Project Path: C:\Documents and Settings\acer\Desktop\TEST2
Report File Name: C:\Documents and
Settings\acer\Desktop\TEST2\VolumeFrequencyAnalysisResults\MERERONI_US\MERERO
NI_US.rpt
Result File Name: C:\Documents and
Settings\acer\Desktop\TEST2\VolumeFrequencyAnalysisResults\MERERONI_US\MERERO
NI_US.xml

Analyze Maximums

Analysis Year: Calendar Year

Record Start Date: 01 Jan 1970
Record End Date:   31 Jan 2000


User-Specified Durations
   Duration:   1 day

Plotting Position Type: Weibull

Probability Distribution Type: Pearson Type III
Compute Expected Probability Curve

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95

Use Default Frequencies

Skew Option: Use Station Skew
Regional Skew: ---
Regional Skew MSE: ---

Display ordinate values using 0 digits in fraction part of value

--- End of Input Data ---
```

Statistical Analysis of 1-day Maximum values

--- Preliminary Results ---

<< Plotting Positions >>
MERERONI US (1-day Max)

Events Analyzed				Ordered Events			
Day	Mon	Year	FLOW cfs	Rank	Calendar Year	FLOW cfs	Weibull Plot Pos
29	Aug	1970	1	1	1997	10*	3.12
01	Sep	1971	1	2	1998	9	6.25
16	Feb	1972	0	3	1982	7	9.38
19	Jun	1973	1	4	1981	6	12.50
03	Sep	1974	1	5	1983	6	15.62
09	Sep	1975	3	6	1993	5	18.75
07	Sep	1976	1	7	1977	4	21.88
03	May	1977	4	8	1996	4	25.00
17	May	1978	3	9	1995	4	28.12
16	May	1979	1	10	1975	3	31.25
10	Sep	1980	1	11	1992	3	34.38
15	Aug	1981	6	12	1978	3	37.50
02	Dec	1982	7	13	1985	2	40.62
01	May	1983	6	14	1974	1	43.75
02	Jan	1984	0	15	1994	1	46.88
22	Apr	1985	2	16	1976	1	50.00
10	Jul	1986	0	17	1990	1	53.12
11	Jun	1987	0	18	1979	1	56.25
28	Sep	1988	1	19	1970	1	59.38
20	May	1989	1	20	1973	1	62.50
17	Apr	1990	1	21	1999	1	65.62
03	Sep	1991	0	22	1988	1	68.75
04	Jul	1992	3	23	1980	1	71.88
10	Feb	1993	5	24	1971	1	75.00
22	Aug	1994	1	25	1989	1	78.12
22	Nov	1995	4	26	1986	0	81.25
02	Sep	1996	4	27	1972	0	84.38
18	Nov	1997	10	28	2000	0	87.50
07	May	1998	9	29	1991	0	90.62
03	Dec	1999	1	30	1987	0	93.75
02	Jan	2000	0	31	1984	0	96.88

* Outlier

<< Skew Weighting >>

Based on 31 events, mean-square error of station skew = 0.424
Mean-square error of regional skew is undefined.

<< Frequency Curve >>
MERERONI US (1-day Max)

Computed Curve FLOW, CMS	Expected Probability FLOW, CMS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CMS	Confidence Limits 0.95 FLOW, CMS
15	17	0.2	18	13
13	14	0.5	16	11
11	12	1.0	14	10
10	11	2.0	12	8
8	8	5.0	9	7
6	6	10.0	7	5
4	5	20.0	5	4
2	2	50.0	3	1
0	0	80.0	1	-1
-0	-0	90.0	1	-1
-1	-1	95.0	0	-2
-1	-1	99.0	-0	-2

<< Systematic Statistics >>
MERERONI US (1-day Max)

FLOW, CMS		Number of Events	
Mean	2.5148	Historic Events	0
Standard Dev	2.6997	High Outliers	0
Station Skew	1.4236	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	1.4236	Systematic Events	31

--- End of Preliminary Results ---

<< High Outlier Test >>

Based on 31 events, 10 percent outlier test value K(N) = 2.577

1 high outlier(s) identified above test value of 9.47

* Note - Collection of historical information and *
* comparisons with similar data should be explored, *
* if not incorporated in this analysis. *

<< Low Outlier Test >>

Based on 31 events, 10 percent outlier test value K(N) = 2.577

0 low outlier(s) identified below test value of -4.44

--- Final Results ---

<< Plotting Positions >>
MERERONI US (1-day Max)

Events Analyzed					Ordered Events			
			FLOW		Calendar	FLOW	Weibull
Day	Mon	Year	cfs	Rank	Year	cfs	Plot Pos
29	Aug	1970	1	1	1997	10*	3.12
01	Sep	1971	1	2	1998	9	6.25
16	Feb	1972	0	3	1982	7	9.38
19	Jun	1973	1	4	1981	6	12.50
03	Sep	1974	1	5	1983	6	15.62
09	Sep	1975	3	6	1993	5	18.75
07	Sep	1976	1	7	1977	4	21.88
03	May	1977	4	8	1996	4	25.00
17	May	1978	3	9	1995	4	28.12
16	May	1979	1	10	1975	3	31.25
10	Sep	1980	1	11	1992	3	34.38
15	Aug	1981	6	12	1978	3	37.50
02	Dec	1982	7	13	1985	2	40.62
01	May	1983	6	14	1974	1	43.75
02	Jan	1984	0	15	1994	1	46.88
22	Apr	1985	2	16	1976	1	50.00
10	Jul	1986	0	17	1990	1	53.12
11	Jun	1987	0	18	1979	1	56.25
28	Sep	1988	1	19	1970	1	59.38
20	May	1989	1	20	1973	1	62.50
17	Apr	1990	1	21	1999	1	65.62
03	Sep	1991	0	22	1988	1	68.75
04	Jul	1992	3	23	1980	1	71.88
10	Feb	1993	5	24	1971	1	75.00
22	Aug	1994	1	25	1989	1	78.12
22	Nov	1995	4	26	1986	0	81.25
02	Sep	1996	4	27	1972	0	84.38
18	Nov	1997	10	28	2000	0	87.50
07	May	1998	9	29	1991	0	90.62
03	Dec	1999	1	30	1987	0	93.75
02	Jan	2000	0	31	1984	0	96.88

* Outlier

<< Skew Weighting >>

Based on 31 events, mean-square error of station skew = 0.424

Mean-square error of regional skew is undefined.

<< Frequency Curve >>
MERERONI US (1-day Max)

Computed Curve FLOW, CMS	Expected Probability FLOW, CMS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CMS	Confidence Limits 0.95 FLOW, CMS
15	17	0.2	18	13
13	14	0.5	16	11
11	12	1.0	14	10
10	11	2.0	12	8
8	8	5.0	9	7
6	6	10.0	7	5
4	5	20.0	5	4
2	2	50.0	3	1
0	0	80.0	1	-1
-0	-0	90.0	1	-1
-1	-1	95.0	0	-2
-1	-1	99.0	-0	-2

<< Systematic Statistics >>
MERERONI US (1-day Max)

FLOW, CMS		Number of Events	
Mean	2.5148	Historic Events	0
Standard Dev	2.6997	High Outliers	1
Station Skew	1.4236	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	1.4236	Systematic Events	31

Warning: No ordinates specified for graphical frequency curve

---

Volume-Duration Analysis
03 Oct 2008 12:16 AM

--- Input Data ---

Appendix II: Flood frequency analysis at River Mereroni (2FA08)

```
Analysis Name: MERERONI DS
Description:

Data Set Name: LAKE NAKURU-SHUKU-FLOW5
DSS File Name: C:\Documents and Settings\acer\Desktop\TEST2\TEST2.dss
DSS Pathname: /LAKE NAKURU/MERERONI DS/FLOW/01JAN1970/1DAY/OBSERVED/

Project Path: C:\Documents and Settings\acer\Desktop\TEST2
Report File Name: C:\Documents and
Settings\acer\Desktop\TEST2\VolumeFrequencyAnalysisResults\MERERONI_DS\MERERO
NI_DS.rpt
Result File Name: C:\Documents and
Settings\acer\Desktop\TEST2\VolumeFrequencyAnalysisResults\MERERONI_DS\MERERO
NI_DS.xml

Analyze Maximums

Analysis Year: Calendar Year

Record Start Date: 01 Jan 1970
Record End Date:   31 Jan 2000


User-Specified Durations
   Duration:   1 day

Plotting Position Type: Weibull

Probability Distribution Type: Pearson Type III
Compute Expected Probability Curve

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95

Use Default Frequencies

Skew Option: Use Station Skew
Regional Skew: ---
Regional Skew MSE: ---

Display ordinate values using 0 digits in fraction part of value

--- End of Input Data ---



=====================================================================
Statistical Analysis of 1-day Maximum values
=====================================================================


-----------------------
<< High Outlier Test >>
```

Based on 31 events, 10 percent outlier test value K(N) = 2.577

0 high outlier(s) identified above test value of 15.19

<< Low Outlier Test >>

Based on 31 events, 10 percent outlier test value K(N) = 2.577

0 low outlier(s) identified below test value of -6.3

--- Final Results ---

<< Plotting Positions >>
LAKE NAKURU-SHUKU-FLOW5 (1-day Max)

Events Analyzed		Ordered Events			
Day Mon Year	FLOW cfs	Rank	Calendar Year	FLOW cfs	Weibull Plot Pos
30 Apr 1970	2	1	1997	14	3.12
01 Sep 1971	2	2	1977	13	6.25
24 Aug 1972	0	3	1998	12	9.38
30 Sep 1973	1	4	1988	11	12.50
03 Sep 1974	2	5	1981	9	15.62
07 Oct 1975	2	6	1982	9	18.75
05 Sep 1976	1	7	1990	8	21.88
18 May 1977	13	8	1978	8	25.00
05 Nov 1978	8	9	1993	6	28.12
05 Jul 1979	1	10	1989	6	31.25
02 Jun 1980	0	11	1985	5	34.38
17 Aug 1981	9	12	1999	5	37.50
02 Dec 1982	9	13	1996	5	40.62
13 Sep 1983	2	14	1995	5	43.75
02 Jan 1984	0	15	1992	4	46.88
02 Aug 1985	5	16	1974	2	50.00
15 May 1986	1	17	1971	2	53.12
11 Jun 1987	1	18	2000	2	56.25
27 Aug 1988	11	19	1994	2	59.38
20 May 1989	6	20	1983	2	62.50
07 Apr 1990	8	21	1975	2	65.62
03 Sep 1991	1	22	1970	2	68.75
04 Jul 1992	4	23	1986	1	71.88
10 Feb 1993	6	24	1979	1	75.00
22 Aug 1994	2	25	1991	1	78.12
22 Nov 1995	5	26	1976	1	81.25
02 Sep 1996	5	27	1973	1	84.38
18 Nov 1997	14	28	1987	1	87.50
07 May 1998	12	29	1972	0	90.62
22 Dec 1999	5	30	1980	0	93.75
02 Jan 2000	2	31	1984	0	96.88

```
<< Skew Weighting >>
---------------------------------------------------------------
Based on 31 events, mean-square error of station skew =   0.244
Mean-square error of regional skew is undefined.
---------------------------------------------------------------
```

```
<< Frequency Curve >>
LAKE NAKURU-SHUKU-FLOW5 (1-day Max)
```

Computed Curve FLOW, CMS	Expected Probability FLOW, CMS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CMS	Confidence Limits 0.95 FLOW, CMS
21	23	0.2	25	18
18	20	0.5	23	16
17	18	1.0	20	14
15	16	2.0	18	13
12	13	5.0	15	10
10	10	10.0	12	9
8	8	20.0	9	6
4	4	50.0	5	3
1	1	80.0	2	-1
-0	-0	90.0	1	-2
-1	-1	95.0	0	-3
-3	-3	99.0	-1	-5

```
<< Systematic Statistics >>
LAKE NAKURU-SHUKU-FLOW5 (1-day Max)
```

FLOW, CMS		Number of Events	
Mean	4.4417	Historic Events	0
Standard Dev	4.1692	High Outliers	0
Station Skew	0.8657	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	0.8657	Systematic Events	31

```
Warning: No ordinates specified for graphical frequency curve

--------------------------
Volume-Duration Analysis
  02 Oct 2008   10:48 PM
--------------------------
```

Appendix III: Flood frequency analysis at River Njoro (2FC09)

```
--- Input Data ---

Analysis Name: NJORO DS
Description:

Data Set Name: NJORO DS
DSS File Name: C:\Documents and Settings\acer\Desktop\TEST2\TEST2.dss
DSS Pathname: /LAKE NAKURU/NJORO DS/FLOW/01JAN1970/1DAY/OBSERVED/

Project Path: C:\Documents and Settings\acer\Desktop\TEST2
Report File Name: C:\Documents and
Settings\acer\Desktop\TEST2\VolumeFrequencyAnalysisResults\NJORO_DS\NJORO_DS.
rpt
Result File Name: C:\Documents and
Settings\acer\Desktop\TEST2\VolumeFrequencyAnalysisResults\NJORO_DS\NJORO_DS.
xml

Analyze Maximums

Analysis Year: Water Year

Record Start Date: 01 Jan 1970
Record End Date:   31 Jan 2000


User-Specified Durations
   Duration:   1 day

Plotting Position Type: Weibull

Probability Distribution Type: Pearson Type III
Compute Expected Probability Curve

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95

Use Default Frequencies

Skew Option: Use Station Skew
Regional Skew: ---
Regional Skew MSE: ---

Display ordinate values using 0 digits in fraction part of value

--- End of Input Data ---


=================================================================
Statistical Analysis of 1-day Maximum values
=================================================================
```

-- Preliminary Results ---

< Plotting Positions >>
JORO DS (1-day Max)

Events Analyzed			FLOW	Ordered Events			
Day	Mon	Year	FLOW cfs	Rank	Water Year	FLOW cfs	Weibull Plot Pos
30	Apr	1970	283	1	1998	341*	3.12
25	Aug	1971	29	2	1970	283*	6.25
31	Aug	1972	9	3	1998	195	9.38
09	Sep	1973	2	4	1990	131	12.50
11	Jul	1974	34	5	1996	62	15.62
30	Aug	1975	10	6	1994	56	18.75
02	Sep	1976	3	7	1993	47	21.88
07	Aug	1977	28	8	1978	43	25.00
09	Sep	1978	43	9	1989	35	28.12
08	Jul	1979	9	10	1974	34	31.25
15	May	1980	7	11	1971	29	34.38
29	Sep	1981	8	12	1983	28	37.50
04	Dec	1982	28	13	1977	28	40.62
01	May	1983	22	14	1983	22	43.75
09	Jan	1984	0	15	2000	16	46.88
21	Jun	1985	3	16	1996	10	50.00
09	Aug	1986	6	17	1975	10	53.12
11	Jun	1987	1	18	1979	9	56.25
04	Oct	1988	35	19	1972	9	59.38
31	Dec	1989	5	20	1981	8	62.50
11	Apr	1990	131	21	1980	7	65.62
03	Sep	1991	1	22	1986	6	68.75
08	Sep	1992	1	23	1990	5	71.88
11	Feb	1993	47	24	1976	3	75.00
13	Aug	1994	56	25	1985	3	78.12
26	Oct	1995	62	26	2000	3	81.25
02	Sep	1996	10	27	1973	2	84.38
08	Dec	1997	195	28	1987	1	87.50
18	Jan	1998	341	29	1992	1	90.62
03	Dec	1999	16	30	1991	1	93.75
02	Jan	2000	3	31	1984	0	96.88

* Outlier

<< Skew Weighting >>

Based on 31 events, mean-square error of station skew = 1.027
Mean-square error of regional skew is undefined.

<< Frequency Curve >>
NJORO DS (1-day Max)

Computed Curve FLOW, CMS	Expected Probability FLOW, CMS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CMS	Confidence Limits 0.95 FLOW, CMS
531	630	0.2	665	444
438	506	0.5	548	366
369	416	1.0	460	308
300	332	2.0	374	250
212	228	5.0	264	175
147	156	10.0	185	118
86	90	20.0	114	61
15	15	50.0	40	-12
-10	-10	80.0	15	-41
-14	-14	90.0	11	-45
-15	-15	95.0	10	-46
-15	-15	99.0	10	-47

<< Systematic Statistics >>
NJORO DS (1-day Max)

FLOW, CMS		Number of Events	
Mean	46.1117	Historic Events	0
Standard Dev	82.2961	High Outliers	0
Station Skew	2.6731	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	2.6731	Systematic Events	31

--- End of Preliminary Results ---

<< High Outlier Test >>

Based on 31 events, 10 percent outlier test value K(N) = 2.577

2 high outlier(s) identified above test value of 258.19

* Note - Collection of historical information and *
* comparisons with similar data should be explored, *
* if not incorporated in this analysis. *

<< Low Outlier Test >>

Based on 31 events, 10 percent outlier test value K(N) = 2.577

0 low outlier(s) identified below test value of -165.97

--- Final Results ---

<< Plotting Positions >>
NJORO DS (1-day Max)

Events Analyzed				Ordered Events			
			FLOW		Water	FLOW	Weibull
Day	Mon	Year	cfs	Rank	Year	cfs	Plot Pos
30	Apr	1970	283	1	1998	341*	3.12
25	Aug	1971	29	2	1970	283*	6.25
31	Aug	1972	9	3	1998	195	9.38
09	Sep	1973	2	4	1990	131	12.50
11	Jul	1974	34	5	1996	62	15.62
30	Aug	1975	10	6	1994	56	18.75
02	Sep	1976	3	7	1993	47	21.88
07	Aug	1977	28	8	1978	43	25.00
09	Sep	1978	43	9	1989	35	28.12
08	Jul	1979	9	10	1974	34	31.25
15	May	1980	7	11	1971	29	34.38
29	Sep	1981	8	12	1983	28	37.50
04	Dec	1982	28	13	1977	28	40.62
01	May	1983	22	14	1983	22	43.75
09	Jan	1984	0	15	2000	16	46.88
21	Jun	1985	3	16	1996	10	50.00
09	Aug	1986	6	17	1975	10	53.12
11	Jun	1987	1	18	1979	9	56.25
04	Oct	1988	35	19	1972	9	59.38
31	Dec	1989	5	20	1981	8	62.50
11	Apr	1990	131	21	1980	7	65.62
03	Sep	1991	1	22	1986	6	68.75
08	Sep	1992	1	23	1990	5	71.88
11	Feb	1993	47	24	1976	3	75.00
13	Aug	1994	56	25	1985	3	78.12
26	Oct	1995	62	26	2000	3	81.25
02	Sep	1996	10	27	1973	2	84.38
08	Dec	1997	195	28	1987	1	87.50
18	Jan	1998	341	29	1992	1	90.62
03	Dec	1999	16	30	1991	1	93.75
02	Jan	2000	3	31	1984	0	96.88

* Outlier

<< Skew Weighting >>

Based on 31 events, mean-square error of station skew = 1.027
Mean-square error of regional skew is undefined.

<< Frequency Curve >>
NJORO DS (1-day Max)

Computed Curve FLOW, CMS	Expected Probability FLOW, CMS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CMS	Confidence Limits 0.95 FLOW, CMS
531	630	0.2	665	444
438	506	0.5	548	366
369	416	1.0	460	308
300	332	2.0	374	250
212	228	5.0	264	175
147	156	10.0	185	118
86	90	20.0	114	61
15	15	50.0	40	-12
-10	-10	80.0	15	-41
-14	-14	90.0	11	-45
-15	-15	95.0	10	-46
-15	-15	99.0	10	-47

<< Systematic Statistics >>
NJORO DS (1-day Max)

FLOW, CMS		Number of Events	
Mean	46.1117	Historic Events	0
Standard Dev	82.2961	High Outliers	2
Station Skew	2.6731	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	2.6731	Systematic Events	31

Warning: No ordinates specified for graphical frequency curve

Volume-Duration Analysis
03 Oct 2008 12:25 AM

Appndix IV: Flood frequency analysis at River Ngosur (2FC06)

```
--- Input Data ---

Analysis Name: NGOSUR
Description:

Data Set Name: NGOSUR
DSS File Name: C:\Documents and Settings\acer\Desktop\TEST2\TEST2.dss
DSS Pathname: /LAKE NAKURU/NGOSUR/FLOW/01JAN1970/1DAY/OBSERVED/

Project Path: C:\Documents and Settings\acer\Desktop\TEST2
Report File Name: C:\Documents and
Settings\acer\Desktop\TEST2\VolumeFrequencyAnalysisResults\NGOSUR\NGOSUR.rpt
Result File Name: C:\Documents and
Settings\acer\Desktop\TEST2\VolumeFrequencyAnalysisResults\NGOSUR\NGOSUR.xml

Analyze Maximums

Analysis Year: Calendar Year

Record Start Date: 01 Jan 1970
Record End Date:   31 Jan 2000


User-Specified Durations
   Duration:   1 day

Plotting Position Type: Weibull

Probability Distribution Type: Pearson Type III
Compute Expected Probability Curve

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95

Use Default Frequencies

Skew Option: Use Station Skew
Regional Skew: ---
Regional Skew MSE: ---

Display ordinate values using 0 digits in fraction part of value

--- End of Input Data ---



==================================================================
Statistical Analysis of 1-day Maximum values
==================================================================


--- Preliminary Results ---
```

<< Plotting Positions >>
NGOSUR (1-day Max)

Events Analyzed				Ordered Events			
Day	Mon	Year	FLOW cfs	Rank	Calendar Year	FLOW cfs	Weibull Plot Pos
02	Apr	1970	1	1	1988	15*	3.12
19	Jan	1971	0	2	1999	8	6.25
02	Jan	1972	0	3	1996	7	9.38
28	Sep	1973	0	4	1997	7	12.50
05	Apr	1974	0	5	1987	5	15.62
29	Aug	1975	0	6	2000	4	18.75
31	Aug	1976	0	7	1994	4	21.88
25	Nov	1977	0	8	1995	3	25.00
21	Nov	1978	0	9	1984	2	28.12
02	Jan	1979	0	10	1989	2	31.25
09	Oct	1980	0	11	1990	1	34.38
30	Aug	1981	0	12	1982	1	37.50
07	Dec	1982	1	13	1970	1	40.62
26	Oct	1983	0	14	1993	1	43.75
27	Dec	1984	2	15	1991	1	46.88
08	Oct	1985	0	16	1992	1	50.00
02	Jul	1986	0	17	1981	0	53.12
24	Apr	1987	5	18	1973	0	56.25
20	Apr	1988	15	19	1986	0	59.38
02	Jan	1989	2	20	1985	0	62.50
18	Aug	1990	1	21	1977	0	65.62
02	Jan	1991	1	22	1983	0	68.75
03	May	1992	1	23	1974	0	71.88
10	Feb	1993	1	24	1978	0	75.00
22	Aug	1994	4	25	1979	0	78.12
18	Jul	1995	3	26	1975	0	81.25
03	Sep	1996	7	27	1971	0	84.38
08	May	1997	7	28	1980	0	87.50
02	Jul	1998	0	29	1976	0	90.62
22	Dec	1999	8	30	1998	0	93.75
02	Jan	2000	4	31	1972	0	96.88

* Outlier

<< Skew Weighting >>

Based on 31 events, mean-square error of station skew = 0.888
Mean-square error of regional skew is undefined.

```
<< Frequency Curve >>
NGOSUR (1-day Max)
```

Computed Curve FLOW, CMS	Expected Probability FLOW, CMS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CMS	Confidence Limits 0.95 FLOW, CMS
21	25	0.2	26	18
17	20	0.5	22	15
15	17	1.0	18	12
12	13	2.0	15	10
9	9	5.0	11	7
6	7	10.0	8	5
4	4	20.0	5	3
1	1	50.0	2	-0
-0	-0	80.0	1	-2
-1	-1	90.0	1	-2
-1	-1	95.0	0	-2
-1	-1	99.0	0	-2

```
<< Systematic Statistics >>
NGOSUR (1-day Max)
```

FLOW, CMS		Number of Events	
Mean	2.0838	Historic Events	0
Standard Dev	3.3244	High Outliers	0
Station Skew	2.4626	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	2.4626	Systematic Events	31

```
--- End of Preliminary Results ---


-----------------------
<< High Outlier Test >>
-----------------------
 Based on 31 events, 10 percent outlier test value K(N) = 2.577

        1 high outlier(s) identified above test value of 10.65

 * Note - Collection of historical information and          *
 *        comparisons with similar data should be explored, *
 *        if not incorporated in this analysis.             *


----------------------
<< Low Outlier Test >>
----------------------
 Based on 31 events, 10 percent outlier test value K(N) = 2.577
```

0 low outlier(s) identified below test value of -6.48

--- Final Results ---

<< Plotting Positions >>
NGOSUR (1-day Max)

Events Analyzed					Ordered Events			
Day	Mon	Year	FLOW cfs	Rank	Calendar Year	FLOW cfs	Weibull Plot Pos
02	Apr	1970	1	1	1988	15*	3.12
19	Jan	1971	0	2	1999	8	6.25
02	Jan	1972	0	3	1996	7	9.38
28	Sep	1973	0	4	1997	7	12.50
05	Apr	1974	0	5	1987	5	15.62
29	Aug	1975	0	6	2000	4	18.75
31	Aug	1976	0	7	1994	4	21.88
25	Nov	1977	0	8	1995	3	25.00
21	Nov	1978	0	9	1984	2	28.12
02	Jan	1979	0	10	1989	2	31.25
09	Oct	1980	0	11	1990	1	34.38
30	Aug	1981	0	12	1982	1	37.50
07	Dec	1982	1	13	1970	1	40.62
26	Oct	1983	0	14	1993	1	43.75
27	Dec	1984	2	15	1991	1	46.88
08	Oct	1985	0	16	1992	1	50.00
02	Jul	1986	0	17	1981	0	53.12
24	Apr	1987	5	18	1973	0	56.25
20	Apr	1988	15	19	1986	0	59.38
02	Jan	1989	2	20	1985	0	62.50
18	Aug	1990	1	21	1977	0	65.62
02	Jan	1991	1	22	1983	0	68.75
03	May	1992	1	23	1974	0	71.88
10	Feb	1993	1	24	1978	0	75.00
22	Aug	1994	4	25	1979	0	78.12
18	Jul	1995	3	26	1975	0	81.25
03	Sep	1996	7	27	1971	0	84.38
08	May	1997	7	28	1980	0	87.50
02	Jul	1998	0	29	1976	0	90.62
22	Dec	1999	8	30	1998	0	93.75
02	Jan	2000	4	31	1972	0	96.88

* Outlier

<< Skew Weighting >>

Based on 31 events, mean-square error of station skew = 0.888
Mean-square error of regional skew is undefined.

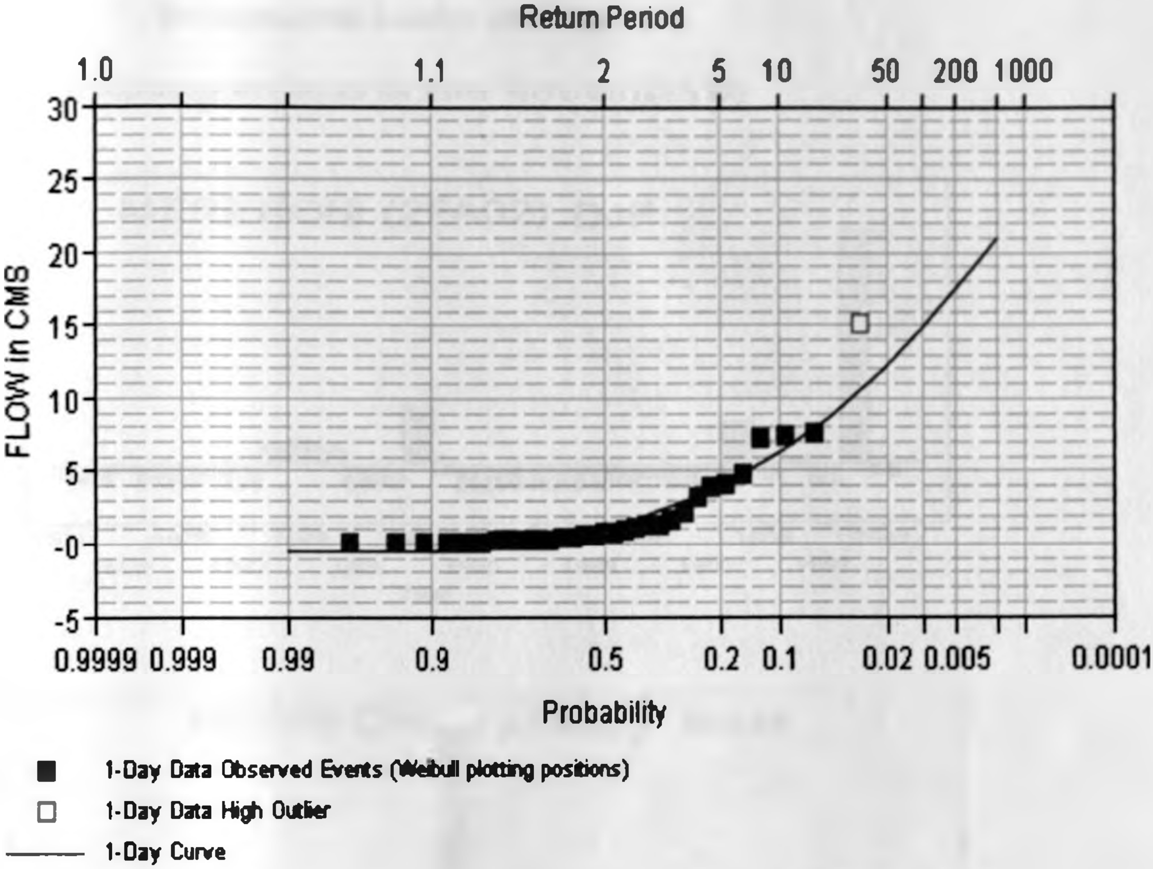
<< Frequency Curve >>
NGOSUR (1-day Max)

Computed Curve FLOW, CMS	Expected Probability FLOW, CMS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CMS	Confidence Limits 0.95 FLOW, CMS
21	25	0.2	26	18
17	20	0.5	22	15
15	17	1.0	18	12
12	13	2.0	15	10
9	9	5.0	11	7
6	7	10.0	8	5
4	4	20.0	5	3
1	1	50.0	2	-0
-0	-0	80.0	1	-2
-1	-1	90.0	1	-2
-1	-1	95.0	0	-2
-1	-1	99.0	0	-2

<< Systematic Statistics >>
NGOSUR (1-day Max)

FLOW, CMS		Number of Events	
Mean	2.0838	Historic Events	0
Standard Dev	3.3244	High Outliers	1
Station Skew	2.4626	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	2.4626	Systematic Events	31

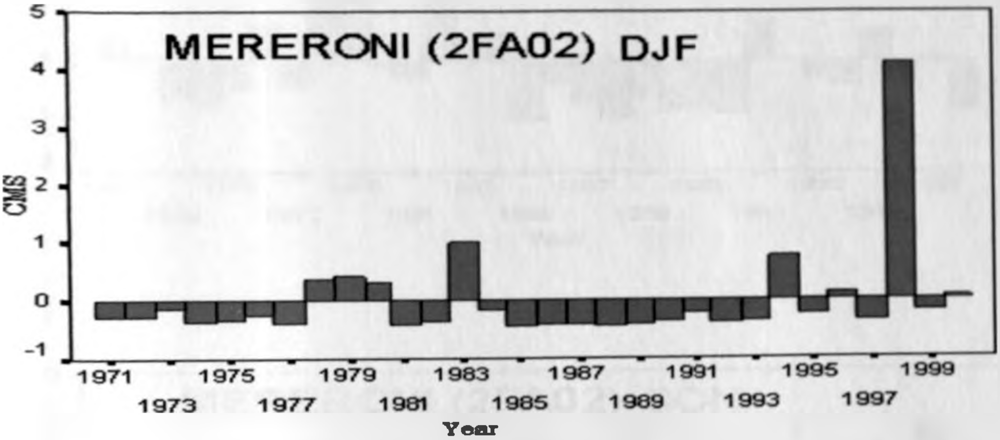
Warning: No ordinates specified for graphical frequency curve

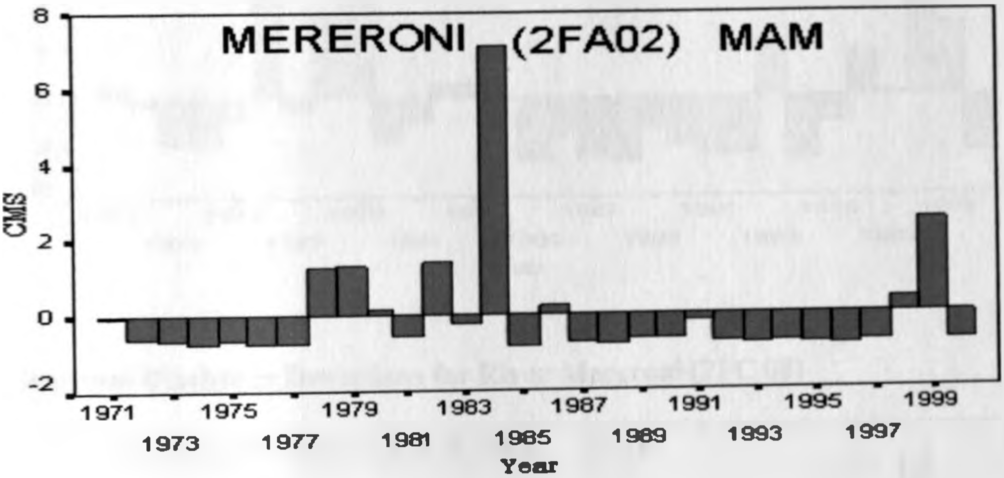


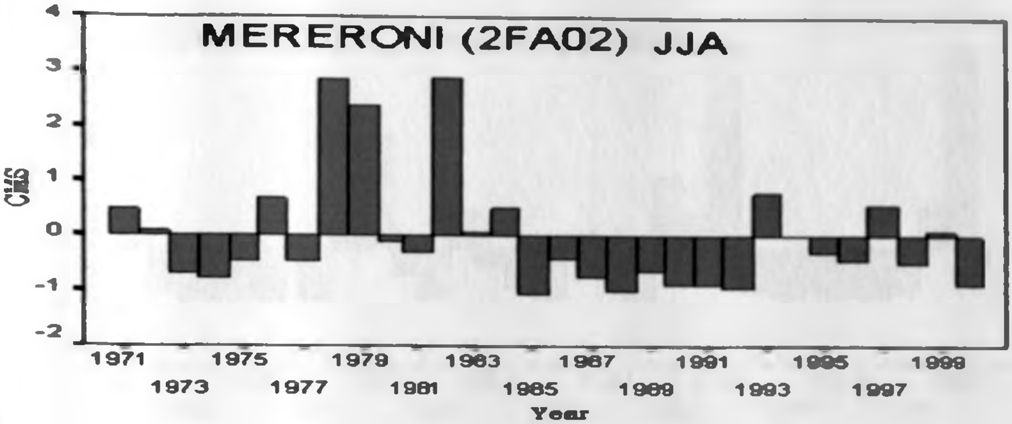
. Volume-Duration Frequency Analytical plot, Station 2FC06 along River Ngosur

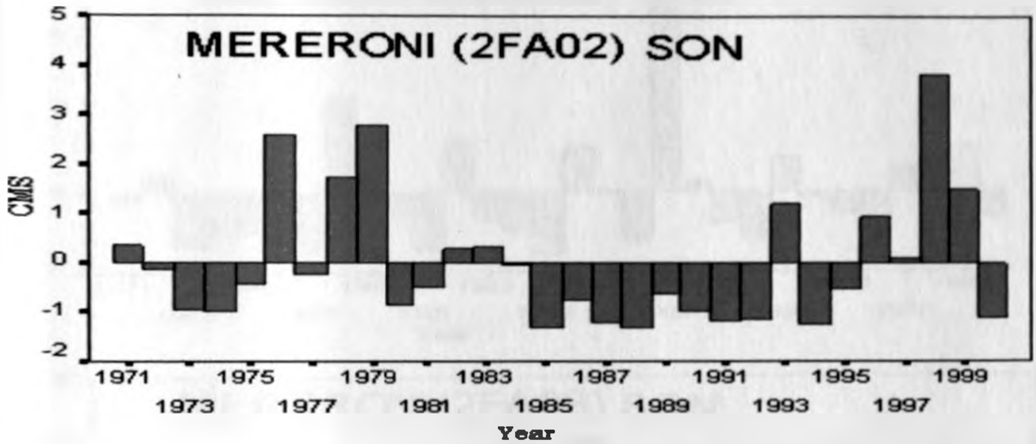
Appendix V: Deviations from baseline Discharge

Seasonal Discharge deviations for River Mereroni (2FA 02)

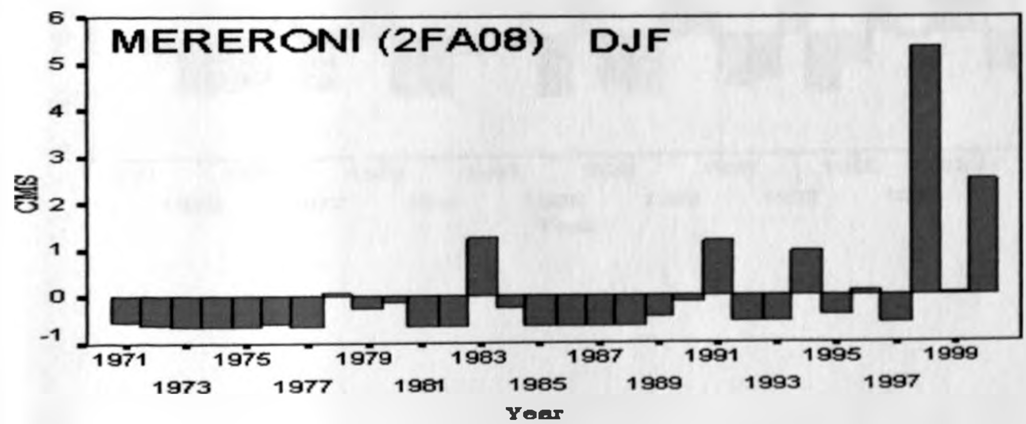


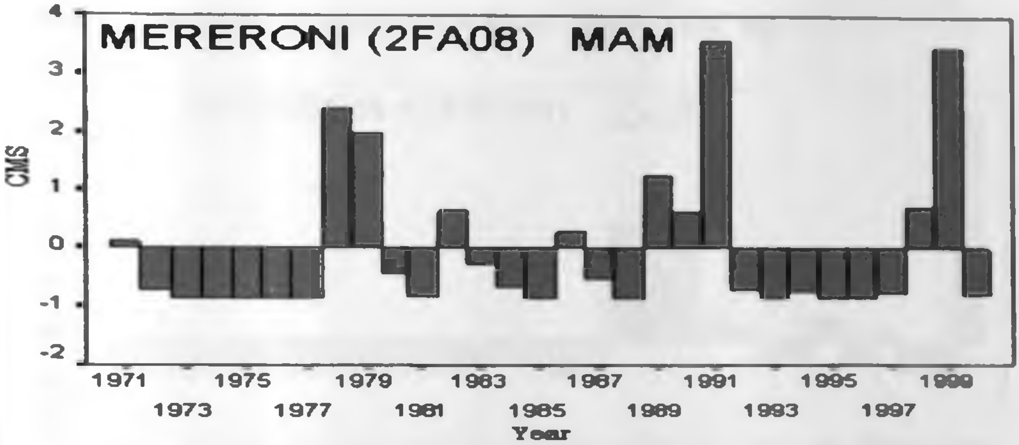






Seasonal Discharge Deviations for River Mereroni (2FC 08)

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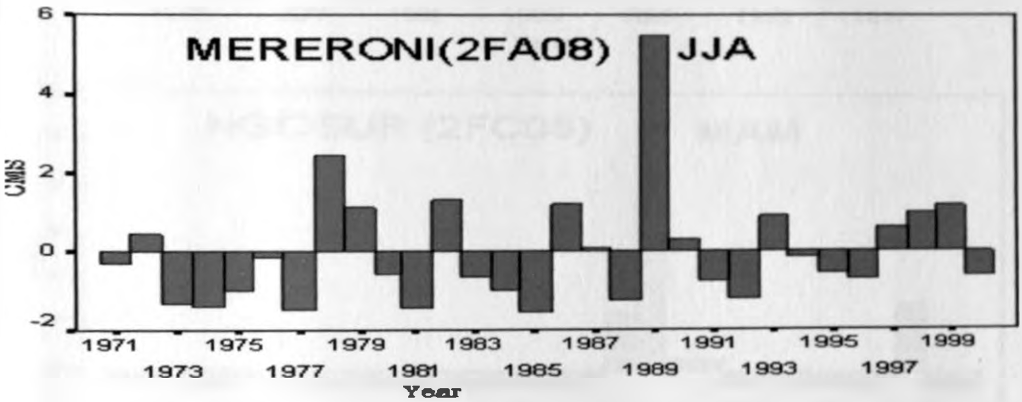
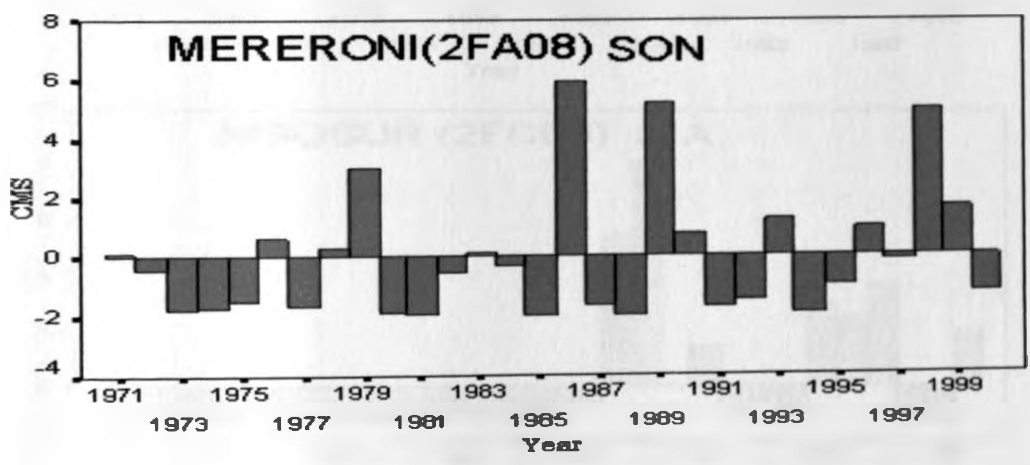
4
3
2
1
0
-1
-2
CMS
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
Year


MERERONI(2FA08) JJA
6
4
2
0
-2
CMS
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
Year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8
6
4
2
0
-2
-4
CMS
1971
1973
1975
1977
1979
1981
1983
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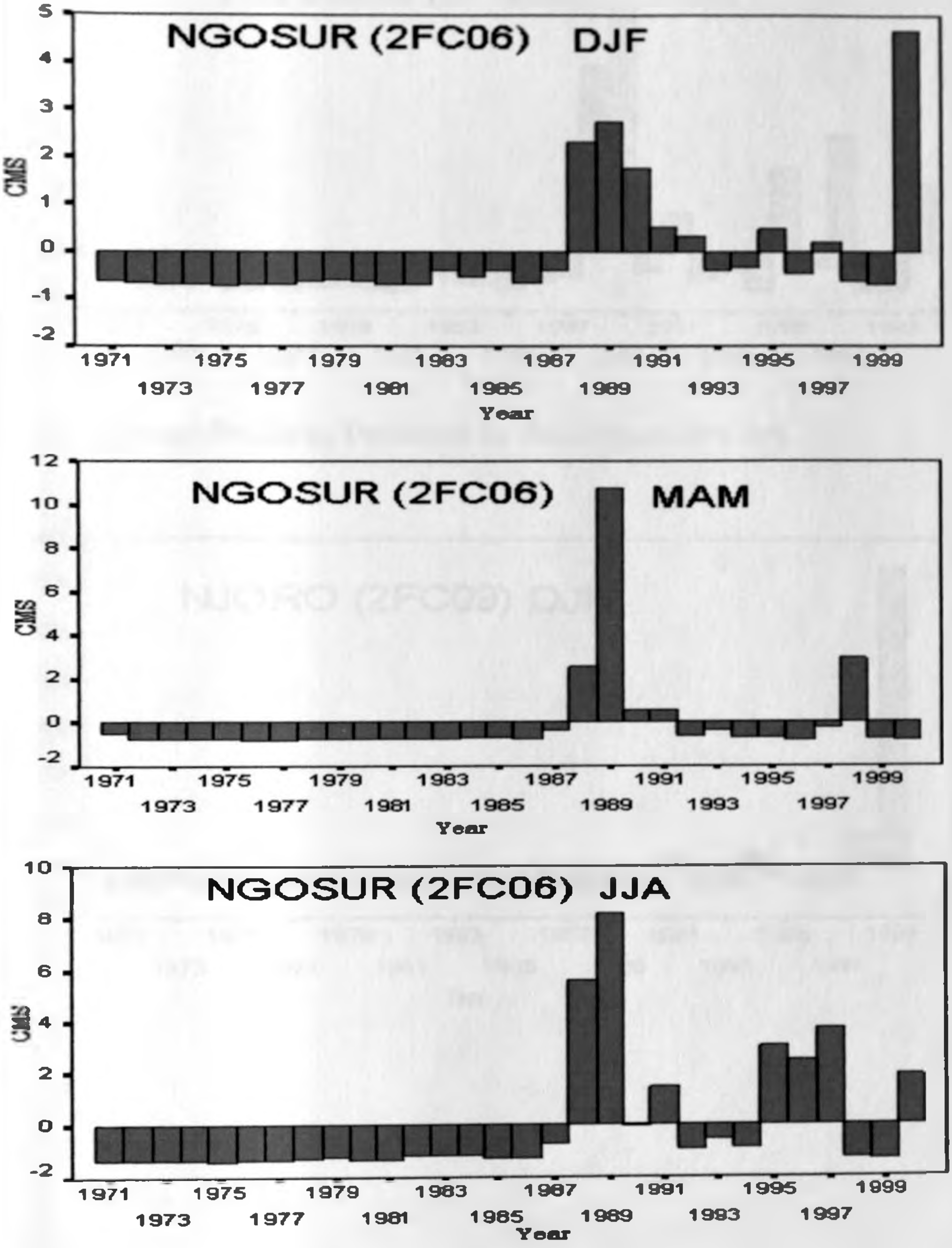
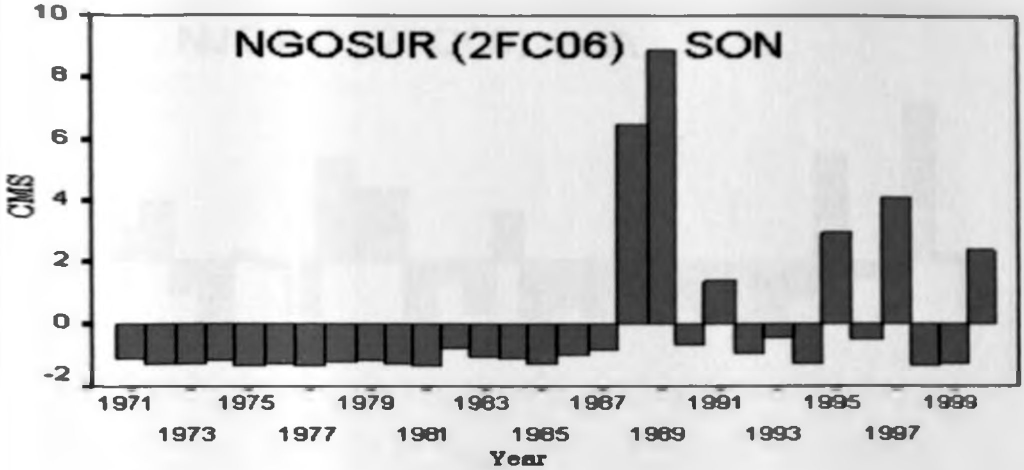
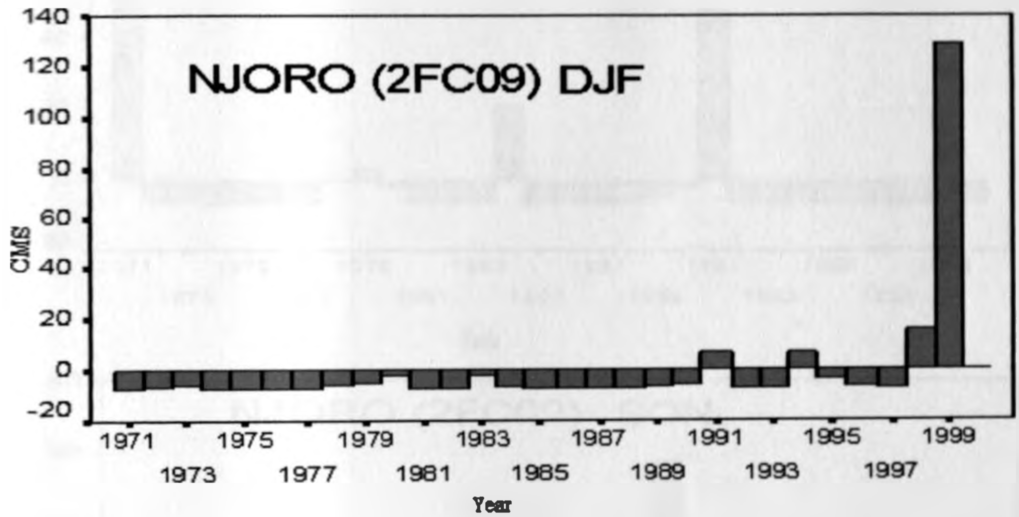
1989
1991
1993
1995
1997
1999
Year

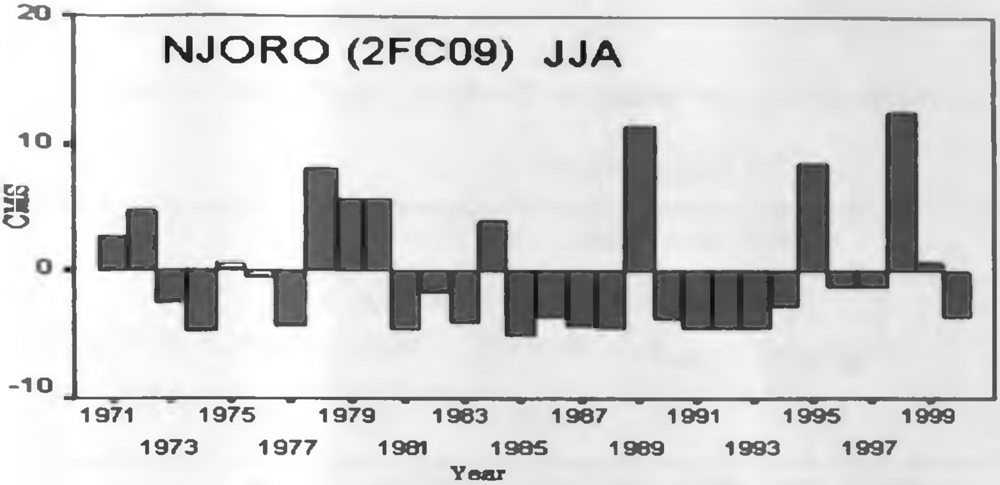
Seasonal Discharge Deviations for River Ngosur (2FC 06)

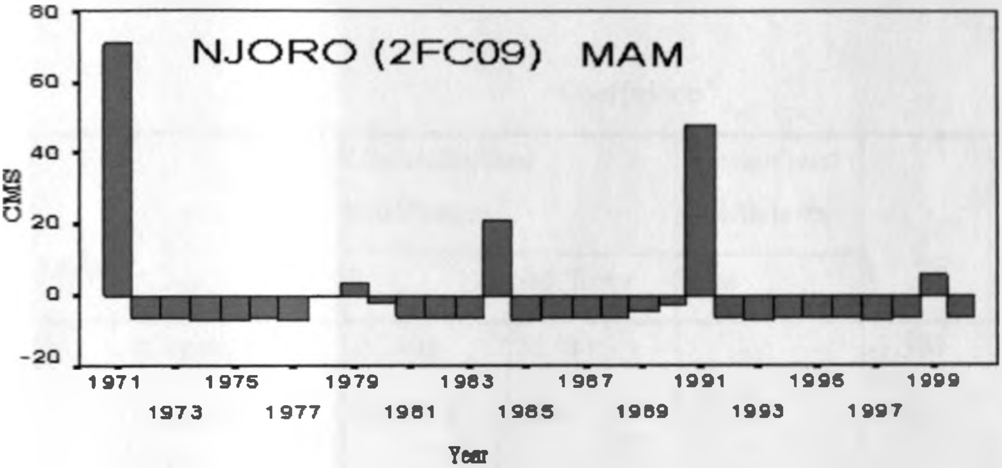


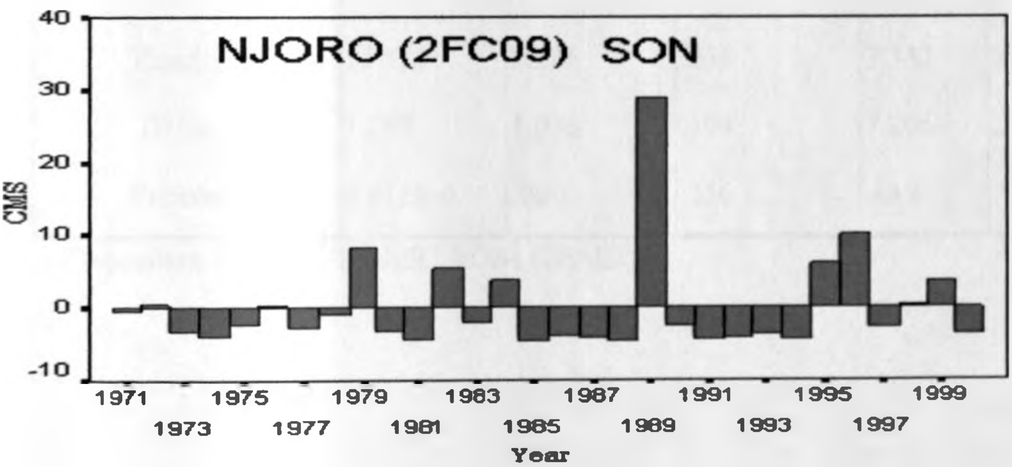


8.3.4 Seasonal Discharge Deviations for River Njoro (2FC 09)




NJORO (2FC09) JJA
CMS
Year
1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999


NJORO (2FC09) MAM
CMS
Year
1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999


NJORO (2FC09) SON
CMS
Year
1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999

Appendix VI: Model Summary

Regression of River Mereroni (2FA02) vs population, rainfall, temperature and vegetation cover

Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. Change
1	.622[a]	.387	.288	2.932189	.387	3.939	4	25	.013

a. Predictors: (Constant), Population, Rainfall (m), DMin.Temp . vegetation cover

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-32.408	24.811		-1.306	.203
	vegetation cover	1.612E-8	.000	.579	.705	.487
	Rainfall (m)	11.526	3.245	.566	3.552	.002
	DMin.Temp	1.249	1.036	.309	1.206	.239
	Population	4.811E-6	.000	.356	.449	.657

a. Dependent Variable: R.MERERONI (2FA02)

Regression of River Mereroni (2FA08) vs population, rainfall, temperature and vegetation cover

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.883[a]	.781	.745	2.282644	.781	22.232	4	25	.000

a. Predictors: (Constant), Population, Rainfall (m), DMin.Temp , vegetation cover

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-67.773	19.315		-3.509	.002
	vegetation cover	3.543E-8	.000	.978	1.990	.058
	Rainfall (m)	19.541	2.526	.738	7.736	.000
	DMin.Temp	2.088	.806	.397	2.590	.016
	Population	1.810E-5	.000	1.030	2.173	.039

a. Dependent Variable: R.MERERONI (2FA08)

Regression of River Njoro (2FC05) vs population, rainfall, temperature and vegetation cover

Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.628[a]	.395	.298	7.676238	.395	4.080	4	25	.011

a. Predictors: (Constant), Population, Rainfall (m), DMin.Temp , vegetation cover

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig
		B	Std. Error	Beta		
1	(Constant)	-101.583	64.953		-1 564	130
	vegetation cover	5.127E-8	.000	699	856	400
	Rainfall (m)	28.108	8.495	.524	3 309	003
	DMin.Temp	4.661	2.711	.437	1.719	098
	Population	1.001E-5	.000	.281	.357	.724

a. Dependent Variable: R.NJORO (2FC05)

Regression of River Njoro (2FC09) vs population, rainfall, temperature and vegetation cover

Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.622[a]	.386	.288	27.034422	.386	3.935	4	25	.013

a. Predictors: (Constant), Population, Rainfall (m), DMin.Temp , vegetation cover

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-534.793	228.755		-2.338	.028
	vegetation cover	2.889E-7	.000	1.126	1.370	.183
	Rainfall (m)	44.855	29.917	.239	1.499	.146
	DMin.Temp	26.295	9.549	.705	2.754	.011
	Population	11E-5	.000	.891	1.124	.272

a. Dependent Variable: R.NJORO (2FC09)

Regression of River Ngosur (2FC06) vs population, rainfall, temperature and vegetation cover

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.486[a]	.237	.114	7.155421	.237	1.936	4	25	.136

a. Predictors: (Constant), Population, Rainfall (m), DMin.Temp , vegetation cover

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-12.174	60.546		-.201	.842
	vegetation cover	-3.057E-8	.000	-.502	-.548	.589
	Rainfall (m)	2.957	7.918	.066	.373	.712
	DMin.Temp	4.070	2.527	.460	1.611	.120
	Population	-1.508E-5	.000	-.511	-.577	.569

a. Dependent Variable: R.NGOSUR (2FC06)