UNIVERSITY OF NAIROBI

FACULTY OF ENGINEERING
DEPARTMENT OF ENVIRONMENTAL AND BIOSYSTEMS ENGINEERING
2022/2023 ACADEMIC YEAR

THESIS

ANALYSIS OF THE IMPACT OF CLIMATE CHANGE ON RIVER FLOWS AND RISING WATER LEVELS OF LAKE NAKURU

SUBMITTED BY:

NAME: ONZERE MAXWELL AMBANI
REG NO: F56/37186/2020
PROJECT SUPERVISORS: 1. PROF. ELIJAH K. BIAMAH
2.DR. JOHN PAUL OBIERO

AUGUST, 2023

Dissertation submitted in partial fulfillment of the requirements of the Degree of
Master of Science in Environmental and Biosystems Engineering of
UNIVERSITY OF NAIROBI

DECLARATION

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

ONZERE MAXWELL AMBANI

Signature: Date: 28th August 2023

This thesis has been submitted for examination with our approval as university supervisors:

1) **PROF. ELIJAH K. BIAMAH**

Department of Environmental and Biosystems Engineering,

University of Nairobi

Signature: Date: 29th August 2023

2) **DR. JOHN P. OBIERO**

Department of Environmental and Biosystems Engineering,

University of Nairobi

Signature: Date: 29th August 2023

DEDICATION

This dissertation is dedicated to the memory of my late mother Janet Semo Ambani. I hope the achievement shall complete the dream that she had for me those many years when she made a decision to give me the best education. Although in her absence, I will always love her.

ACKNOWLEDGEMENT

I give appreciation to God almighty for his protection, mercy and love that he has shown me up to this level of my life. My sincere thanks to my project supervisors, Prof. Elijah K. Biamah and Dr. John P. Obiero for their great support, sacrifice, continued guidance and advice they offered me during this study. They were always available for consultation when needed. Their guidance was always motivational, technical and professional. They gave me the zeal to go on with the study and make sure it came to a conclusion with a great outcome. Great appreciation goes to Dr. Christian Thine Omuto, whose input into the work was immense. I am greatly indebted to the entire staff of the Department of Environmental and Biosystems Engineering under the leadership of Prof. Duncan Mbuge, who have played an important role in equipping me with the relevant skills and knowledge during my term at the University of Nairobi. Great appreciation to the Kenya Meteorological Department, Water Resources Authority and Kenya Water Towers Agency whose support and cooperation played a key role during the data collection phase for this research. Finally, my sincere gratitude to my father, Mr. Seth A. Ambale, who kept me on track to ensure I achieve the dream that my late mother had for me. I am forever grateful.

ABSTRACT

Lake Nakuru has experienced flooding occasioned by climate change and catchment areas degradation. The increasing water levels to a record of 8.5m reported in April 2020 have been a great threat to livelihoods and flora and fauna, to the extent of the lake experiencing flamingoes' migration. There have been attempts to establish the causes of flooding, with some scientists attributing the phenomenon to tectonic movements and geothermal power plant activities. This research aimed at studying the impact of climate change on the rising water levels of the lake. The objective of this study was to assess the impact of climate change in river flows and rising water levels of Lake Nakuru. Rainfall and temperature data, lake's water level, River Njoro flows and Mau encroachment data were collected from the Kenya Meteorological Department, GIS applications, Water Resources Authority and Kenya Water Towers Agency, respectively. Statistical analysis was done using Microsoft Excel 2013 and R software and the relationship amongst various variables was determined. The statistical analysis involved a polynomial regression model equation, $w= 40.90233 - 1.87230r + 0.54709r^2 - 0.487155r^3 - 0.65802f - 0.17135f^2 -6.3386f^3 + 43.23665y + 17.88745y^2 - 0.06695y^3$, with an R^2 and Nash and Sutcliffe values of 0.9343 and 0.934, respectively. The findings shows that climate change has taken places because of changes in rainfall amounts, River Njoro flows and temperature, especially in the 2010-2019 decade. It is concluded that climate change is a major contributing factor to the rising water levels of the lake. The study recommends continued monitoring of meteorological parameters, watershed management and development of a lake balance model.

Keywords: Climate change, flooding, rainfall, River Njoro flows, model

TABLE OF CONTENTS

List of tables

List of figures

Acronyms and Abbreviations

HEC-HMS	Hydrologic Engineering Center-Hydrologic Modelling System
IPCC	Intergovernmental Panel on Climate Change
KCIC	Kenya Climate Innovation Center
KEFRI	Kenya Forestry Research Institute
KMD	Kenya Meteorological Department
NEMA	National Environment Management Authority
NWHSA	National Water Harvesting and Storage Authority
NSE	Nash and Sutcliffe Efficiency
UN	United Nations
UNFCC	United Nations Framework Convention on Climate Change
RMSE	Root Mean Square Error
SDGs	Sustainable Development Goals
SWAT	Soil and Water Assessment Tool
WHO	World Health Organization
WMO	World Meteorological Organization
WRA	Water Resources Authority
WASREB	Water Services Regulatory Board

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

Every natural and man-made system is susceptible to climate change impacts (Nathan et al., 2019). The world is characterized by its efforts towards minimizing climate change impacts. However, enough measures are yet to be taken to ensure that future generations get a chance of enjoying the existing hydrological systems just like the current generation (Grafton et al., 2013). Great attention has been paid to the rise in temperature levels of the world, a scenario commonly referred to as global warming (Choi et al., 2020). Any effect on hydrological systems leads to a direct effect on the ecosystem and more so, the livelihoods of people.

The hydrological systems referred to in this study are Lake Nakuru and River Njoro, which is the major feeder river into the lake. Other minor feeder rivers include River Enderit and River Makalia. The water levels of the lake have been on the rise since 2012 (Iradukunda and Nyadawa, 2021; Herrnegger et al., 2021; Onyango, 2020). It was the first lake to experience flooding among Rift Valley lakes. The rising water levels in different reservoirs may be caused by lots of factors like increase in the amount of rainfall, sedimentation, tectonic movements, among others (Cooke et al. 2016). However, a major cause of the lake's flooding is climate change which is differentiated from climate variability on the timescale perspective. Climate variability is the variation in the climate of a place that last longer than the normal weather events while climate change indicates the variations which persist for a long time which is typically a decade or more. The lake's flooding is also attributed to land use practice changes that have increased the amount of surface runoff causing large water volumes to get directly into the lake (Hongo and Mulaku, 2021). Increased inflow has led to changes in the lake's salinity and ecology, which is exhibited by migration of flamingoes from the lake (Chrisphine et al., 2016). Figure 1 shows the effect of the lake's flooding on Lake Nakuru National Park.

(a) Closed park (b) Open gate

Figure 1: Gate to Lake Nakuru national park

Source: https://tv47.co.ke/2020/09/26/lake-nakuru-national-park-main-gate-closed-due-toflooding/ (Accessed on 2020/09/26)

The rise in water levels of rift valley lakes has been attributed to the development of geothermal plants and other factors stated above. The sedimentation aspect raises the bed level of the lake which leads to a rise in water levels (Schleiss et al. 2016). According to Iradukunda et al. (2020), the lake contains a sediment thickness layer varying from 0-0.7m with a 24,191,688.67m^3 sediment storage capacity. The findings indicate that sediments occupy approximately 8.37% of the total capacity of the lake. Therefore, the capacity of the reservoirs becomes unable to hold the increasing water levels, leading to the increase in the water levels (Schleiss et al., 2016).

The hydrologic cycle is a good tool that can help explain the phenomenon. It helps in describing water movement both on earth's surface and below the ground (Koutsoyiannis, 2020). The water mass remains constant as it moves from one reservoir to another, like from the rivers to the lake, or from the lake to the atmosphere (Koutsoyiannis, 2020). All physical processes such as surface runoff, infiltration, precipitation, condensation and evaporation are key towards understanding the cycle (Raudkivi et al. 2013), which help in explaining the increase in rainfall amounts that cause increased water levels in Lake Nakuru.

The first cause of climate change is greenhouse gases emissions to atmospheric layers by human activities (Kweku et al., 2017). Fossil fuels like oil, coal and gas are used for different activities like generation of electricity and running of engines both in the transport and processing industries (Nyashina et al., 2019). The gases are known to have health effects because of their contribution to respiratory diseases (Kweku et al., 2017). They trap heat to cause global warming. Water vapor is another greenhouse gas, which is not tracked down precisely like the other gases because human beings do not emit it directly (Colman and Soden, 2021). Its effects are also not well-known. Tropospheric ozone come from complex reactions of pollutants in the atmosphere, which makes it get less attention compared to other gases (Colman and Soden, 2021).

Another cause is deforestation, which involves cutting down trees known to absorb and store carbon dioxide (Zepettello et al., 2020). Increased CO_2 concentrations in the atmosphere have caused periodic warming of the Earth in the past years. One of the characteristics of Mau Forest is its reduced coverage because of human inhabitance. People cut down trees to get land for settling and cultivation, an aspect that has scaled up the level of concern in Kenya. It is for this reason that there have been intensified government measures to evict people from the forest (Moinani and

Barasa, 2021). Apart from reducing the number of trees meant to absorb and store carbon, the activities also exposed the area to increased soil erosion because the vegetative cover that holds soil together was reduced.

A third factor contributing towards climate change is increased intensive agriculture in most parts of the continent, and more so in Kenya. Agriculture has a direct contribution towards the production of greenhouse gases. It is estimated that it generates between 19-29% of the total greenhouse production (Tongwane and Moeletsi, 2018). When no action is taken on the agricultural emissions, the percentage shall rise despite other sectors striving towards the reduction of their emissions. About a third of the total food produced gets wasted or lost. Therefore, there needs to be attention paid to food loss and waste to help reduce environmental stress and help meet the climate goals.

The variation of water in rivers and lakes is affected by climate change. Increased precipitation levels increase water levels in rivers, which in turn increase water levels in lakes (Isupova, 2019). When there is increased runoff that leads to the increase in the amount of water that gets to the hydrological bodies like lakes. In the case of Lake Nakuru, there has been increased deforestation leading to climate change, which has reduced the vegetative cover that has increased the amount of erosion in the area (Chaudhry, 2019). The result is inclusion of soil and rock sediments into River Njoro that get deposited into Lake Nakuru. The 0-0.7m sediment layer thickness in the lake accounts for 8.37% of the lake's capacity (Iradukunda et al., 2020). This indicates that an increase in the sediment levels in the lake due to land use changes in the catchment area has a direct impact on the lake's volume, hence contributing to its flooding.

1.2 Statement of the Problem

The decade of 2010-2019 is considered to be the warmest decade in history. The effects of climate change continue to be felt all over the world, and Kenya as a country is not an exception. Since 2012, there have been rising water levels in Lake Nakuru. The water levels are reported to have hit the highest level of 8.5 meters in April 2020. Normally, it rises to an average of three meters. The area covered by the lake increased from 43 km^2 in 2012 to approximately 70 km^2 by April 2020. The roads, main gates and normal operations of the national park around the lake have been affected causing a direct effect on the local and national economies because of reduced tourism levels. In the quest to present the causes of the lake's flooding, there is a lack of attribution of changing rainfall amounts, temperature levels and River Njoro flows as contribution factors to the scenario. This study assessed the three meteorological aspects and established an increase in mean annual rainfall amounts from 73.7mm to 86.6mm for the 1990-1999 and 2010-2019 decades, respectively. The mean annual maximum temperature levels increased from 25.6^{o}C for 1990-1999 to 26.0^{o}C for 2010-2019 decade. There was an increase in mean annual River Njoro flows from 0.461341m^3/s in 1990-1999 to 0.886744m^3/s in 2010-2019 decade. The shift in the weather conditions of the place for over 30 years indicate climate change.

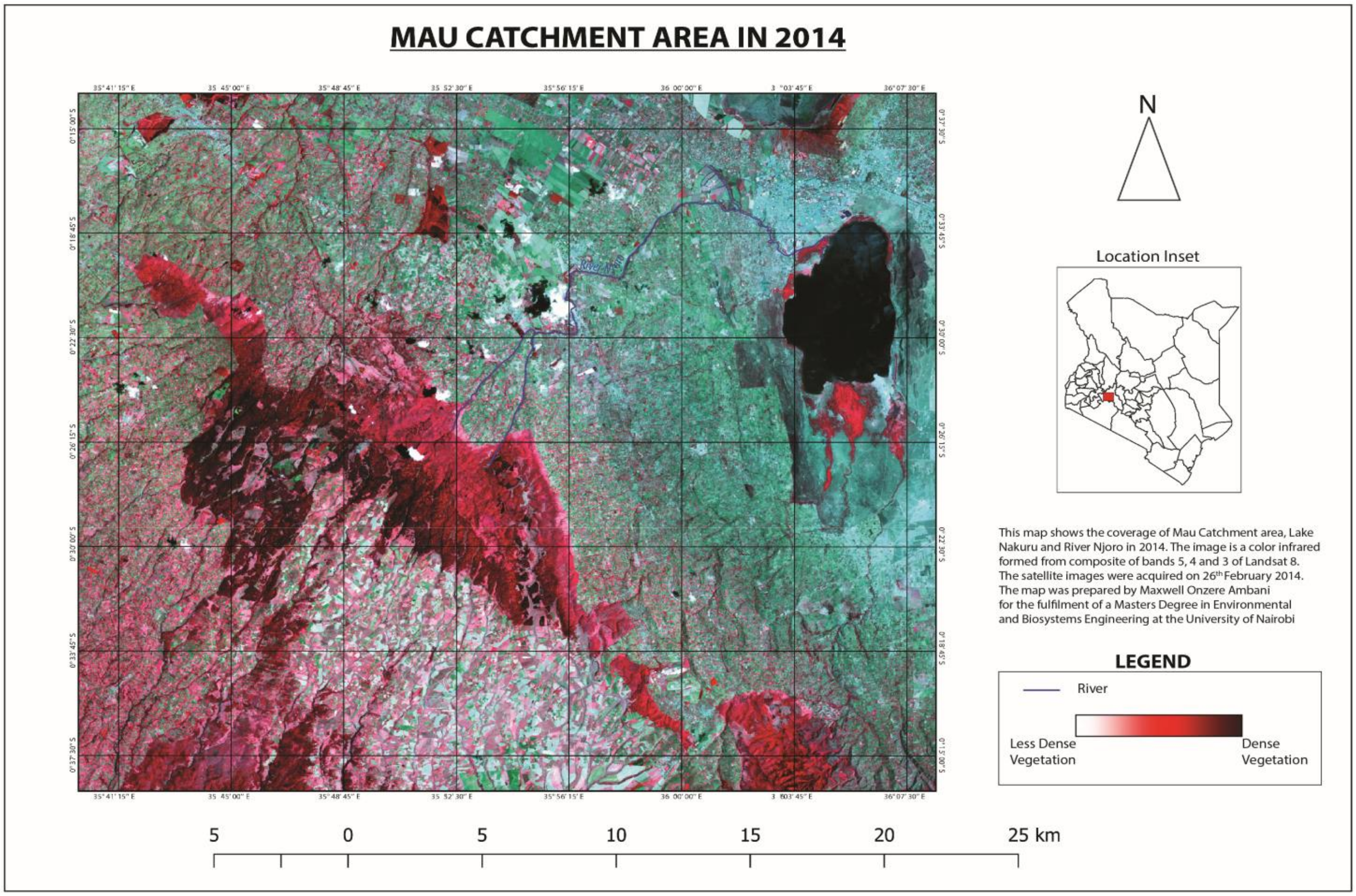
1.3 Justification

The flooding of Lake Nakuru has caused problems both at the local and national level. The local area has suffered from displacement with more than 700 families getting displaced as at 2022. There has been destruction and loss of property and spread of water-borne diseases (Keli, 2022). The migration of flamingoes', which is the main tourist attraction point has led to reduced the tourism levels in the area. Tourism contributes to 8.8% of Kenya's GDP and its reduced level results in a negative impact to the country's economy. The study aimed at establishing climate change as a contributing factor to the flooding. A benefit of the findings includes helping policy makers to make informed decisions to save the lake, people's property and the country's economy. Finally, the importance of the study is inclined towards two specific Sustainable Development Goals. The first one is about ***Climate Action,*** which represents Goal 13. The second one is about ***Life on Land,*** which represents Goal 15. SDG 13 involves taking an urgent action aimed at eradicating climate change together with the effects that come from it through regulating emissions and promoting the adaptation of renewable energy (Louman et al., 2019). Goal 15 is about the life on land and its aims at protecting, restoring, and promoting the terrestrial ecosystems use, combating desertification, sustainable management of the forests and stopping or reversing biodiversity loss and land degradation (Sayer et al., 2019). Therefore, the research has key contribution to the attainment of the stated SDGs.

1.4 Site Analysis and Inventory

1.4.1 Lake Nakuru

Lake Nakuru is located in Nakuru County in Kenya. It is one of the lakes in the rift valley. The lake has an elevation of 1,759 m and is protected by Lake Nakuru National Park (Iradukunda et al., 2020). Algae growth at the shows of the lake is a source of food for the thousands of flamingoes around it (Onyango, 2020). However, the rising water levels has affected the lake's ecology thereby interfering with algae growth. It has led to migration of the flamingoes to other lakes like Lake Bogoria. Normally, the lake covers approximately 45 km^2. Satellite images indicate that the surface area has increased due to flooding to about 64km^2, which is a 15% increase.


MAU CATCHMENT AREA IN 2014

This map shows the coverage of Mau Catchment area, Lake Nakuru and River Njoro in 2014. The image is a color infrared formed from composite of bands 5, 4 and 3 of Landsat 8. The satellite images were acquired on 26th February 2014. The map was prepared by Maxwell Onzere Ambani for the fulfilment of a Masters Degree in Environmental and Biosystems Engineering at the University of Nairobi

Figure 2: Lake Nakuru location and East Mau (River Njoro catchment)

Figure 2 shows the connection between Lake Nakuru and Mau Forest, which is its catchment area. River Njoro, which is the main feeder river to Lake Nakuru can be seen to originate from East Mau. The catchment area of the lake is about 1800 km^2 (Onyango, 2020). It is a saline lake like most of the lakes in the rift valley. Its main inflow is from River Njoro. The annual rainfall of the area ranges between 800mm and 1500mm. It is a soda-lake that has a 10.5 pH value with the main ions being bicarbonate-carbonate and sodium (Kulkarni et al., 2019). Its main use include livestock rearing, tourism and agriculture.

1.4.2 Mau Forest

Mau forest is located about 170km north-west of Nairobi. It covers around 400,000 ha and it makes up the largest water tower in the country. It borders Bomet County to the south-west, Nakuru to the North, Narok to the South and Kericho County to the west. Mau Forest complex represents the biggest water tower in the country (Onyango, 2020). It is a catchment for 12 rivers that drain into different Rift Valley lakes including Lake Natron, Lake Turkana, Lake Nakuru and Lake Baringo (Jebiwott et al., 2021). Others drain into Lake Victoria, which is a transboundary lake shared by Kenya, Uganda and Tanzania. The eastern part of Mau Forest is the source of the headwaters for rivers Njoro, Enderit and Makalia which empties directly into Lake Nakuru (Chemoiwa et al., 2015).

Continued deforestation of the largest canopy forest in the country has resulted into downstream loosing and conversion of perennial rivers into seasonal ones. These impacts have been felt by different entities including the rift valley lakes, the national parks and reserves around them and some geothermal plants that depend on the water from the forest, an example being Sondu Miriu power plant. The encroachment also affects biodiversity and causes conflicts between human beings and wild animals.

1.5 Objectives

1.5.1 Overall Objective

To analyze the impact of climate change on river flows and rising water levels of Lake Nakuru

1.5.2 Specific Objectives

1. To assess the long-term change on rainfall amounts in the contributing catchment area around Lake Nakuru
2. To assess the long-term changes in River Njoro flows into Lake Nakuru
3. To evaluate 1 and 2 above as indicators of climate change
4. To develop a model to predict the surface area variations due to changes in rainfall amounts and river flows into Lake Nakuru

1.6 Research questions

The study was based on the following research questions:

1. Is there a long-term change in the rainfall amounts in the contributing catchment area around Lake Nakuru?
2. Is there a long-term change in River Njoro flows into Lake Nakuru?
3. Are the changes in 1 and 2 indicators of climate change?
4. What model can be used to predict the surface area variations of Lake Nakuru?

1.7 Theoretical framework

Climate change can be studied under different frameworks that have been developed. For this research, the framework is represented in the flow diagram below:

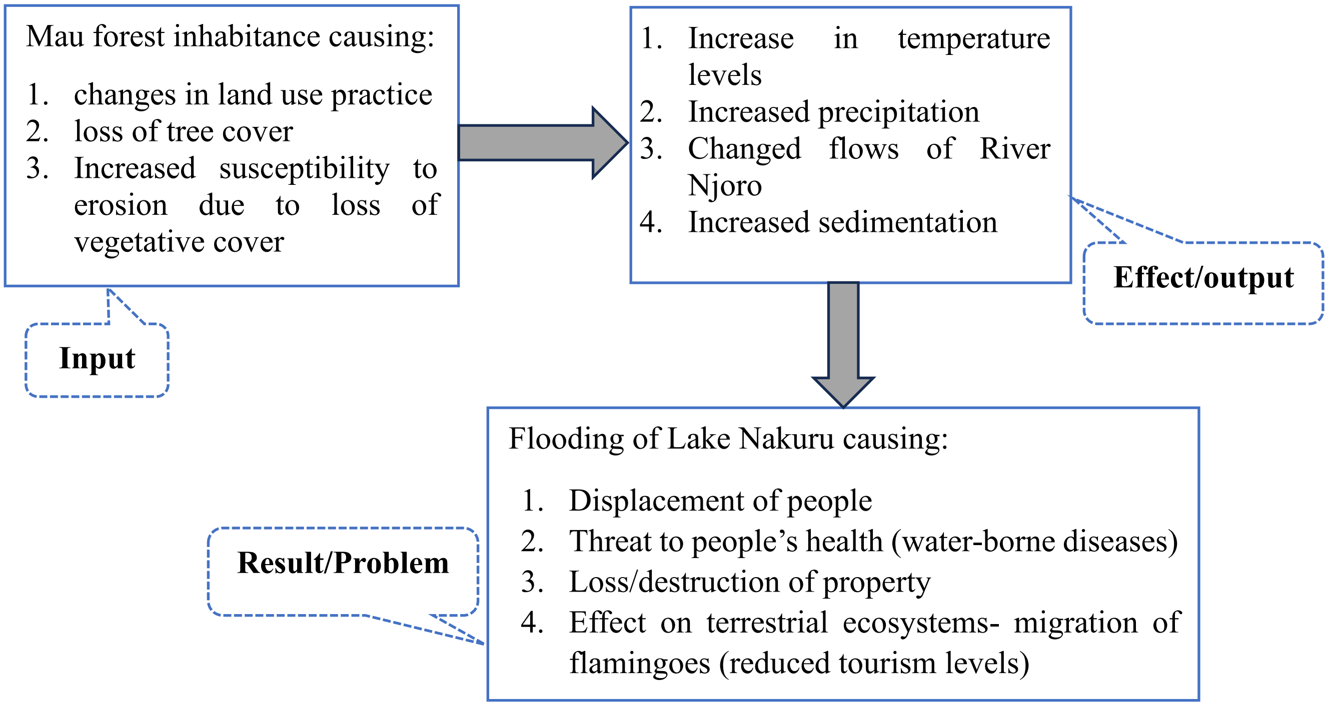


Figure 3: Theoretical framework for Lake Nakuru flooding

From Figure 3, deforestation of Mau Forest in search for land for cultivation, settling and source of fuel has contributed to a change in the climatic conditions experienced at Lake Nakuru. Forest inhabitance has led to changes in land use practice, loss of tree cover and increased susceptibility of land to erosion because of loss of vegetative cover. The effects are increased precipitation, changes in evaporation rates because of increase in temperature levels and changed flows in River Njoro, as indicated in Figure 3. The changes in climatic conditions of the place for more than 3 decades signify climate change. Another effect is increased sedimentation into Lake Nakuru, because of the increase in sedimentation and water levels of River Njoro. The result is increased flooding of Lake Nakuru leading to loss of property, displacement of people and migration of flamingoes, which are the main tourist attraction for the area. For this research, there was identification of important variables to help inform the problem. The variables include:

1) The water levels of the lake over time in km^2
2) Minimum and maximum temperature of Lake Nakuru station since 1990.
3) Tree cover loss in East Mau Forest (In km^2)
4) Monthly rainfall data on Lake Nakuru meteorological centre (In mm)
5) River flows for River Njoro

The tree cover loss data is essential because human populations are the major causes of the misfortune. The Mau settlement led to the cutting down of trees meant to absorb CO_2 in the atmosphere and curb soil erosion by providing vegetative cover. They also intensified agricultural activities that exposed the area to increased soil erosion. This may be the same cause to the riparian area of Lake Nakuru where people engaged in activities that increased sedimentation of the lake over time. The area of the forest cover and the changes that have been witnessed over time can be obtained from Landsat images over chosen years in combination with QGIS software. It is a geographical information software that uses earth's coordinates to explain environmental scenarios over time. The same software can indicate the expanded area of Lake Nakuru over time.

1.8 Scope of Study

The research focused on analyzing the impact that climate change has had on the river flows and rising water levels of Lake Nakuru. There was a focus on analyzing the rainfall and temperature amounts in the area. A relationship between the rainfall amounts and changes in River Njoro flows and Lake Nakuru rising water levels. An establishment of the Mau Forest cover loss and increase in cultivation and settling area was done. A prediction model for the water levels of the lake was developed. Other contributing causes for the scenario suggested by other scientists like tectonic movements, sedimentation and geothermal power generation were not part of the specific focus for this study.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Climate Change from the International Perspective

Climate change has various impacts on different hydrological bodies and weather patterns of places across the globe (Di Virgilio et al., 2019; Kimaru et al., 2019). The impacts may be categorized as either positive or negative. However, the negative impacts have been established to outweigh the positive impacts. It has caused the world to focus on minimizing causes of climate change that have developed gradually under human existence (Choi et al., 2020). Aspects such as long droughts, increased flooding, pests and diseases and wildfires are examples of negative impacts of climate change.

According to Lindsey and Dahlman (2020), the temperature of the earth has been rising at an average of 0.08°C per decade since 1880. The warming rate since then has doubled to 0.18°C per decade. The scenario is an indication of climate change because of the abnormal double shift in temperature levels. The 2022 year is the sixth-warmest year in history with 0.86°C temperature warmer compared to the 13.9°C average of the 20th century (Lindsey and Dahlman, 2020). The researchers also observed that the 10 warmest years in history have taken place since 2010. The observation is in agreement with the findings of this research which establishes the 2010-2019 decade to be the warmest when compared to the 1990-1999 and 2000-2009 decade.

High temperatures continue to cause severe storms and unimaginable extreme events in the world such as flooding and expansion of deserts. There have been reported wildfires in the different parts of the world because of the increase in global temperature (Di Virgilio et al., 2019, Xu et al., 2020). According to Cahill et al. (2013), there are cases where different species migrate because of destruction of their natural habitat which makes some of them become extinct (Cahill et al., 2013). The best example is the migration of flamingoes from Lake Nakuru because of the destruction of the lake's ecology by flooding. Any threat to such a terrestrial ecosystem forces them to migrate in search of better habitats.

Human life is also threatened by climate change because of the effects that it presents. Examples of such effects include water scarcity, increased diseases, economic losses, lack of food, among others. It is no surprise that the WHO considers the change in climate to be the biggest threat to the health of people in the current century (WHO, 2016). Despite efforts being put in to ensure that there is minimized change of climate, the impacts may continue to be felt by many generations to come. In such a case, the current generation won't be observing the intergenerational equity principle.

According to the Paris Agreement that was made in 2015, every nation was to play its part in ensuring that global warming does not exceed 2°C (Dimitrov, 2016). Five major goals were developed as shown in Figure 4. Despite the agreement, global warming is estimated to hit high figures of 2.7°C by the end of the current century. Scientists argue that to achieve the agreed level, the world needs to half its emissions by 2030 and having zero emissions by 2050 (Dimitrov, 2016). These goals are shown in the figure 4 below:

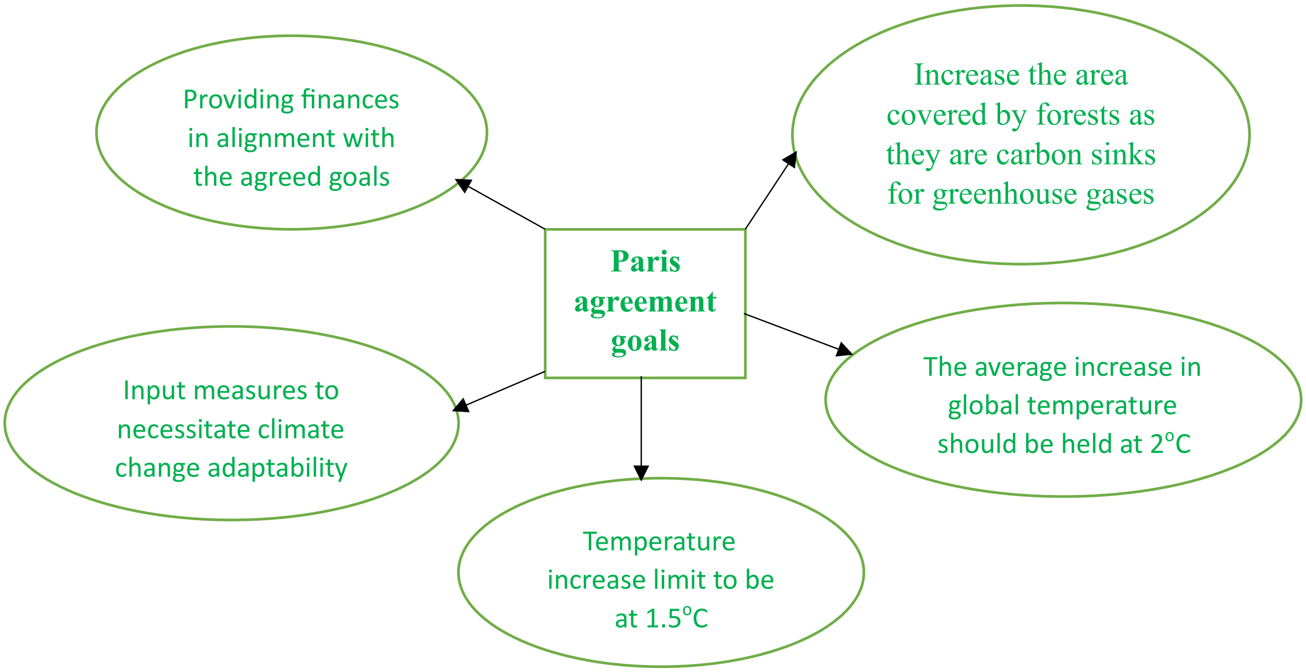


Figure 4: Paris agreement goals

Some scientists argue that a reduction in the emissions can be achieved by shying away from using fossil fuels and appreciating the low-carbon sources that produce electricity (Kweku et al., 2017; Choi et al., 2020). Examples include using solar and wind power, including heat pumps in buildings construction, shifting to electric cars and coming up with mechanisms of energy conservation. According to Federici et al. (2015), trees are net carbon sinks evidenced by net removal of $-2.2GtCO_2yr^{-1}$ and $-2.1GtCO_2yr^{-1}$ for 2001-2010 and 2011-2015, respectively. FAO (2010), 264 hectares of forest are estimated to absorb 1.5 gigatonnes of carbon from the atmosphere annually. Therefore, increasing forest cover in the world will help increase carbon removal rates from the atmosphere to help reduce the impact of climate change.

According to the United Nations (UN), the climate action plan develop ed is aimed at reducing greenhouse gas emissions by 45% and getting 80% of the world electricity from renewable energy (Nerini et al., 2019). Different countries have developed policies and measures that are in line with the United Nations objectives to ensure that there is a combined effort towards minimizing climate change to help save natural resources and human existence in particular.

There are other international agencies that act under the directives of the United Nations. The Intergovernmental Panel on Climate Change (IPCC) was established under the World Meteorological Organization (WMO) and the UNEP to provide give scientific knowledge to people on the climate change state together with the possible socioeconomic and environmental effects (Porter et al., 2019). The UNFCC Secretariat has the responsibility of providing technical expertise and support to any of its negotiations and necessitate the implementation of the Paris agreement and the Kyoto Protocol (Kolleck et al., 2017). The Green Climate Fund is tasked with the responsibility of channeling financial support to the second and third-world countries to implement the adaptation and mitigation measures on climate change. Kenya is among the developing countries that benefits from the entity (Bowman and Minas, 2019). UNEP plays the role of facilitating, catalyzing, educating and advocating for the sustainable use and development of the global environment. World Meteorological Organization (WMO) coordinates all international monitoring regarding meteorological patterns that indicate climate change (Qui, 2018). The UN Office for Disaster Risk Reduction (UNISDR) is responsible for coordinating and supporting all the UN system efforts for disaster preparation and mitigation. All these international agencies have a common goal of mitigating climate change because of the detrimental aspects it presents.

Finally, there are lakes across the world that have felt the climate change impact. This scenario has either been by flooding or reducing its water levels. Examples of the world’s known lakes referred to here are the great lakes made of Lake Erie, Lake Michigan, Lake Superior and Lake Ontario.

One lake in Africa that continue to feel the impact include Lake Chad, which has shrunk by more than 90% since 1960 in 40 years (Gao et al., 2011). It covered 22,000km^2 in 1960 compared to 2000km^2 in 2000. Others include Lake Victoria, Lake Tanganyika and Lake Turkana and some of the rift valley lakes. Figure 5 shows the variation in water levels of Lake Victoria, which is located in the East African region.

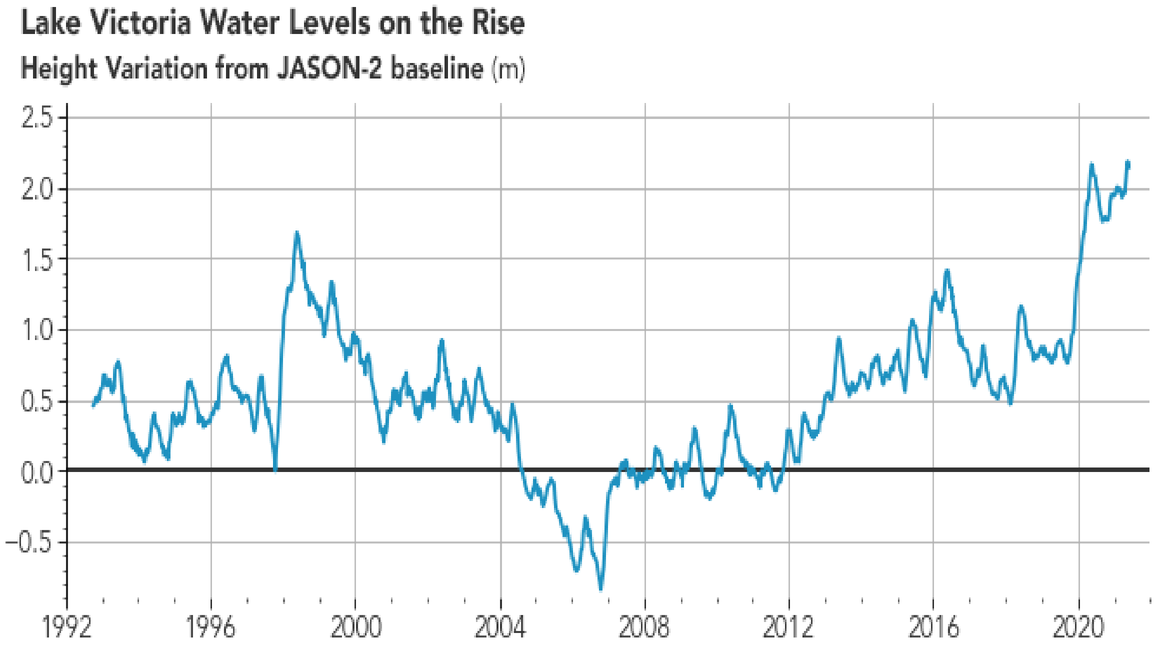


Figure 5: Variation of water levels in Lake Victoria

Voiland and Stevens (2021)

From Figure 5, it is noticeable that the water levels in the lake hit a record height of 2.2m in 2020. The highest level of water experienced by the lake before 2020 was in 1998. During that year, the water levels rose to 1.6m. The scenario is not different from Lake Nakuru which had the highest water levels in 2020 at 8.5m. Therefore, climate change has impacted the shift in water levels experienced by lakes both at the global, regional and local stages.

2.2 Climate Change from the Kenya Perspective

Kenya is a country that is vulnerable to climate change. The aspect continues to impact the Kenyan lives and the environment. There have been extreme weather events in the country including droughts that have lasted longer than expected, unpredictable and irregular rainfall, increasing temperature and flooding (Herrnergerr et al., 2021). The climatic challenges posed by the changing weather conditions have created difficulties in the existing problems of food security, water security and the economic growth of the country (Kogo et al., 2021). The agricultural production has fallen down despite the sector being a major contributor to the nation's GDP (Kogo et al., 2021). The rainfall variability in the arid areas, increased temperatures and strong winds that result from tropical cyclones have made a good combination that is favorable or the migration and dispersion of pests. The extreme events of droughts and floods for the country are predicted to increase because of the projected 2.5ºC increase in 2050 (Juma and Kelonye, 2016). The communities at the coast have been experiencing the effects of climate change exhibited by the saltwater intrusion from the rising sea levels. The increasing water levels of some of the Rift Valley lakes may be another result of climate change. The populations that are at risk because of the events include the marginalized communities, youth and the women. Climate change in the nation has also led to a disruption of ecosystem services that has affected the agricultural sector stated above (Kogo et al., 2021). It has affected the distribution of species which has led to an alteration in the management regimes efficiency. There is an expectation that the Kenyan wildlife sector shall continue feeling the impact of the change because of the shift on the rainfall amount and temperature, which alter the ranges of the species and common seasonal events (Onyango, 2020).

Some of the effects of the climate change in the country like floods, drought and increased heat have a negative effect on the health of people. Most Kenyans continue to suffer health wise from these effects. The risk of the water-borne diseases and spread of vectors is high. There is a projection that by 2070, approximately 70% of Kenyans shall be exposed to malaria (WHO, 2016). The projection has led to testing of malaria vaccines within the East African region to help protect individuals from it. Vaccination against malaria will see a reduced contraction rate, hence a reduction in the projected 70% exposure statistic. It is worth noting that this is the disease that has caused the death of 5% of children less than 5 years. There is also an expectation that Dengue fever shall increase by that time (WHO, 2016). One of the remedies that WHO offers is a vaccine called Dengvaxia, which is given to people in area where the disease is prevalent. WHO continues to support countries prone to the disease regarding its control, prevention and conforming to the Global Vector Control Response (2017-2030). The same report by WHO states that the mortality of people aged 5 years and above, which is related to heat stress shall rise to approximately 45 deaths for every 100,000 individuals by 2080 (WHO, 2016). Other deaths that are expected to rise will be because of diarrhea and malnutrition cases whereby diarrhea is expected to cause 13% of the children's deaths while malnutrition shall cause 20% of the deaths by 2050.

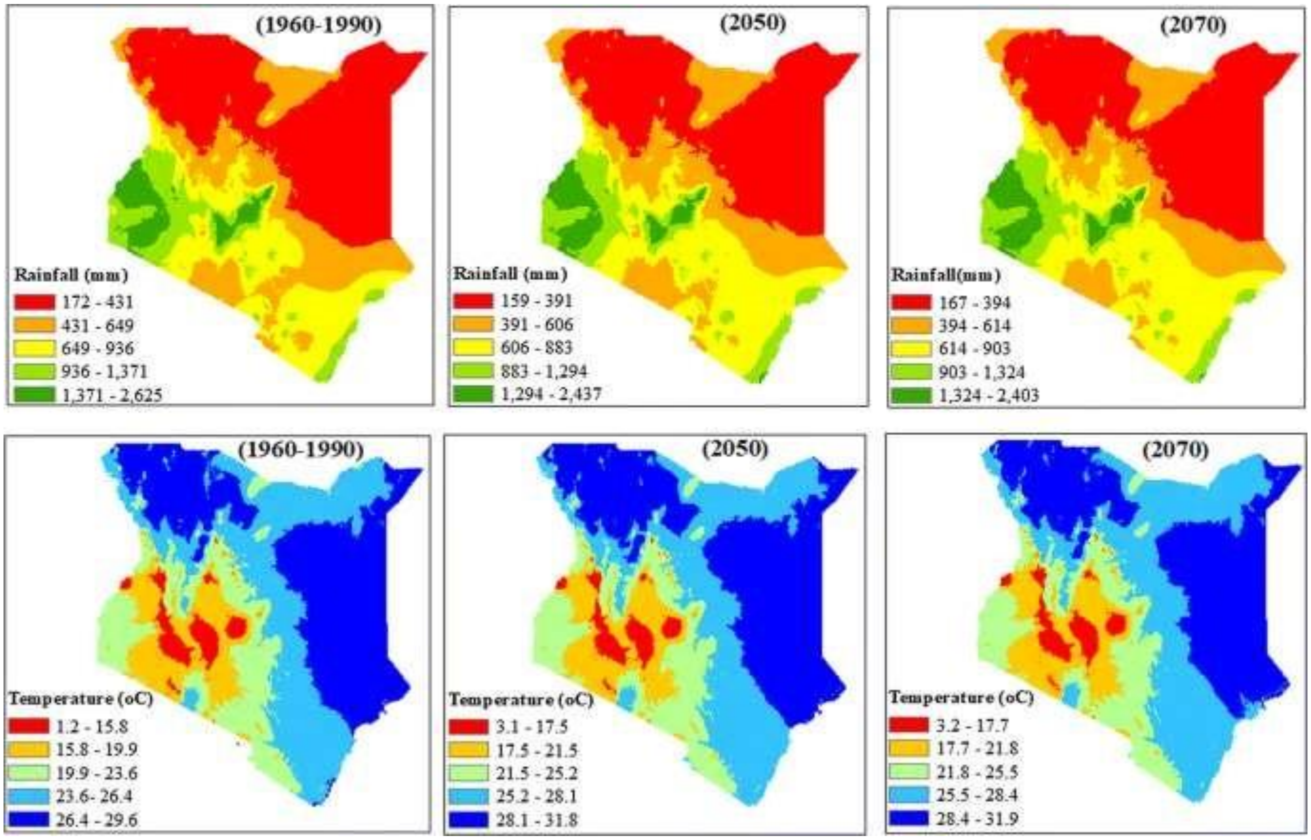


Figure 6: Rainfall and temperature changes over the years

(Kogo et al., 2021)

Figure 6 indicates the changes in temperature and rainfall amounts in different parts of Kenya. It can be noted that there is an increase in rainfall and temperature amounts with the increase in the number of years. It is a clear indication of climate change, which calls for inputs from different bodies to help mitigate the situation. Some of the bodies in the country that are associated with climate change include, the National Environment Management Authority (NEMA), the Ministry of Environment and Forestry, the Kenya Climate Innovation Center (KCIC), Water Resources Authority (WRA), Kenya Forestry Research Institute (KEFRI) and the Kenya Meteorological Department (KMD). All these agencies play a vital role in the different expertise areas related to eradicating and minimizing climate change. KEFRI is a vital body in this research because of the aspect of the Mau Forest inhabitance and eviction.

The Kenya Meteorological Department is vital because of the shifting patterns of the climatic conditions around Lake Nakuru. The department has assisted in hydrological studies of the lake in conjunction with other researchers that worked on effects of rainfall variability and streamflow on Lake Nakuru (Kimaru et al., 2019). Therefore, focus is paid on the water levels of Lake Nakuru and the rainfall amounts experienced at the Lake Nakuru station over time.

2.3 Impacts of Climate Change with regard to Lake Nakuru

2.3.1 Impacts of climate change on precipitation on lake catchment area

Science has proven that there is an exponential increase in the atmospheric capacity of holding moisture with an increase in temperature, which increases the capacity of heavy precipitation and flooding probabilities. Climate changes like the increase in temperatures, extreme storms and changes in the precipitation levels impacts in streams, rivers and lakes (Kimaru et al., 2019). Kimaru et al., (2019) studied temporal rainfall variability and discharge from River Njoro into Lake Nakuru. A SWAT model was applied in predicting streamflow in the river using hydrological indicators and meteorological drought indicators. The findings for streamflow indices and rainfall variability showed that the period 2009-2018 was wetter compared to the 1981-2009. The frequency of wet periods was higher than that of dry seasons from 2009-2010 at 60 and 40% for SPI (standardized precipitation index) and 90 and 10% for SDI (streamflow drought index) (Kimaru et al., 2019). These findings indicate that there was a shift in the weather patterns of Lake Nakuru since the rainfall amounts were higher as from 2009 compared to other previous years. The variability makes a pointer to climate change since the period of comparison is more than 3 decades. The study further agrees with the findings of Ampting (2023), who established an increase in precipitation amounts since 2010 around Lake Nakuru.

2.3.2 Impacts of climate change on Lake water levels

Climatic variability and the rising temperatures in Kenya have increased the severity of some extreme events, like the rising water levels of the lake. Increased temperature levels effects are felt by vulnerable shallow hydrological systems because of a reduced presence of fresh water. Jenkins et al. (2009) developed a water balance model for Lake Nakuru to help in decision making. The model based in the fluctuating water levels while exploring population growth around the area leading to a change in land use. It was established that the largest inflow into the lake was direct rainfall. The second one was tributary discharges while the least contributor was groundwater seepage. One of the recommendations of the study was improved monitoring of hydro-meteorological data coupled with efficient data management for the lake (Jenkins et al. 2009).

Other models for predicting lake water levels have been developed and can be applied in the case of Lake Nakuru. Delaney et al. (2022) utilized three different published regression models to predict water volumes for 4,000 different lakes. The first model involved utilizing the lakes' surface area as the independent variable while the second one utilized both the surface area and average change in surface area in a designated buffer area around the lake. A third model involved using the surface area with an assumption of the land surface area being a self-affine surface (Delaney et al., 2022). The third model allowed the Hurt coefficient to govern the surface area-lake volume relationship. The result was a difference of <2% between predicted volume and the actual volume of the lakes. The first (method using surface area alone), second (Heathcote method) and third (Cael method) regression models involving lakes' surface area are presented in equations 2.1,2.2 and 2.3 respectively.

$$V = aA^b \qquad \text{Equation 2.1}$$

$$V = A^c DE25^d \qquad \text{Equation 2.2}$$

$$V \propto A^{1+\frac{H}{2}} \qquad \text{Equation 2.3}$$

Where;

A-surface area of the lake

a and b- empirical constants

DE_{25}- Average elevation change within the length buffer equal 25% of the lake's diameter

c and d- empirical parameters

H- Hurst coefficient

Model determination can be done using the coefficient of determination (R^2) and Nash and Sutcliffe efficiency indicator. Both coefficients dictate that the more the values are close to 1, the more the predictive ability of the model (Chicco et al., 2021; Zeybek, 2018). According to Chicco et al. (2021), the coefficient of determination helps in examining how any differences of a single carriable can get explained by the differences in any second variable during an outcome prediction of a given scenario. It helps in determining the strength of any relationship. The Nash and Sutcliff model efficiency coefficient (NSE) is given by:

$$NSE = 1 - \frac{\sum_{t=1}^{T}\left(Qo^t - Qm^t\right)^2}{\sum_{t=1}^{T}(Qo^t - Qom)^2} \qquad \text{Equation 2.4}$$

Where:

Q_{om}- Observed values mean

Q_m- Modeled value

Q_o^t- Observed value at a time t

Lin et al. (2017) used NSE to determine the goodness of fit for daily runoff simulation using SWAT. A value of 0.65 of NSE was obtained, which was determined to be an ideal threshold predictive efficiency of the hydrological model obtained (Lin et al., 2017). NSE values of 0.84 and 0.89 were obtained when validating periods to generate monthly stream flows from random forest models for River Greater Zab and River Lesser Zab (Al Juboori, 2019). These values show a high predictive ability of the model. From the East African perspective, Nyeko (2015) used the same NSE coefficient in modelling lower Aswa basin in the northern part of Uganda. The researcher used SWAT and established an NSE value of 0.64 for the developed model (Nyeko, 2015). A 0.64 value shows a moderate satisfaction of the model's predictive ability. When SWAT model application in a data scarce Tanzanian complex catchment, Ndomba et al. (2008) achieved an NSE value of 54.6% indicating a moderate satisfaction of its predictive ability. Finally, a Kenyan application of the same parameter was applied by Ouedraogo et al. (2018), when there was modelling of River Mkurumudzi in Kwale county. An NSE value of 0.8 was achieved during model validation, which indicated a high predictive ability of the model. Furthermore, a model performance of 0.74 was achieved based on NSE criterion when modelling Masinga catchment using daily streamflow (Mutua and Klik, 2007). Therefore, it is evident that NSE is a critical criterion when determining the predictive ability of any hydrological model. The closer the NSE value to 1, the stringer the model with regards to its predictive ability.

Finally, increased water temperatures retard the deep lakes processes aimed at adding oxygen to the water in the water bodies and it leads to the creation of dead zones (Mbote, 2016). Therefore, some of the areas become unable to support aquatic life. The result is a production of increased fish mortality and toxic algal blooms. Ampting (2023) established a strong correlation between the increase in the Lake Nakuru water levels and the increase in precipitation amounts using change point analysis. The employment of a water balance model further emphasized the impact that the precipitation increase has had on the increasing lake water levels. According to Mbote (2016), flamingoes left Lake Nakuru and settled in Lake Bogoria and Lake Oloidein. The rising water levels could have reduced the breeding grounds of the flamingoes and reduced the food availability, which might have caused them to flee away. Furthermore, Mbote agrees that the flooding of the lake has changed biodiversity and aquatic life, including habitat submersion leading to environmental and ecological impacts around the lake. Using data obtained from Coupled Model Intercomparison Project Phase 5 (CMIPS), Mbote predicted future climate scenarios around the lake. The results helped establish that the result of lesser flamingoes and reduced phytoplankton population in the lake resulted from climate change (Mbote, 2016). He further established that phytoplankton density could be used to predict flamingoes' population.

Table 1 shows a summary of the literature on models with regards to the models' names and structures.

Table 1: Models' summary

Model name	Model structure	Reference
SWAT model	Semi-distributive	Kimaru et al. (2019)
Regression model	Polynomial	Delaney et al. (2022)
SWAT model	Semi-distributive	Lin et al. (2017)
Random forest models	Decision-tree	Al Juboori (2019)
Soil Moisture Accounting model	HEC-HMS	Ouedraogo et al. (2018)
SWAT model	Semi-distributive	Nyeko (2015)
Stream flow model	‘C’ programme file	Mutua and Klik (2007)
SWAT model	Semi-distributive	Ndomba et al. (2008)

2.4 Mau Forest Inhabitance and Eviction

Climate change has a negative effect on the regenerative process of forests after they get destroyed. This is through the limitation of tree survival and growth, increase in the population of pathogens and pests and increasing the likelihood of forest fires. Approximately 7.4% of the Kenyan land is under the cover of forests which play critical functions such as the improvement of water quality, absorption of greenhouse gases, prevention of soil erosion and provision of habitat for the Kenyan wildlife (Kweyu et al., 2020). However, the forest cover reduces at an estimated rate of 5,000 hectares annually. The loss of forest cover has affected the ecosystem services provided by the forests in different ways including biodiversity loss and diminished wood quality and yield (Mwaniki, 2016). The forest started getting inhabited in early 1993, which forced the government to start the eviction of people (Mwaniki, 2016). There was an estimated population of 50,000 people in the forest in 2005. According to Moinani and Barasa (2021), part of the population had title deeds whose source was questionable forcing the Kenyan government to evict people from the forest. Apart from inhabitance of people, there are other serious threats that the forest continues to face. Examples include extensive clearing of land to pave way for growth of exotic plants, conversion of land occupied by the forest for agricultural purpose, forest fires and increased excisions. Figure 7 below shows a map indicating the encroachment that the forest has experienced over time.

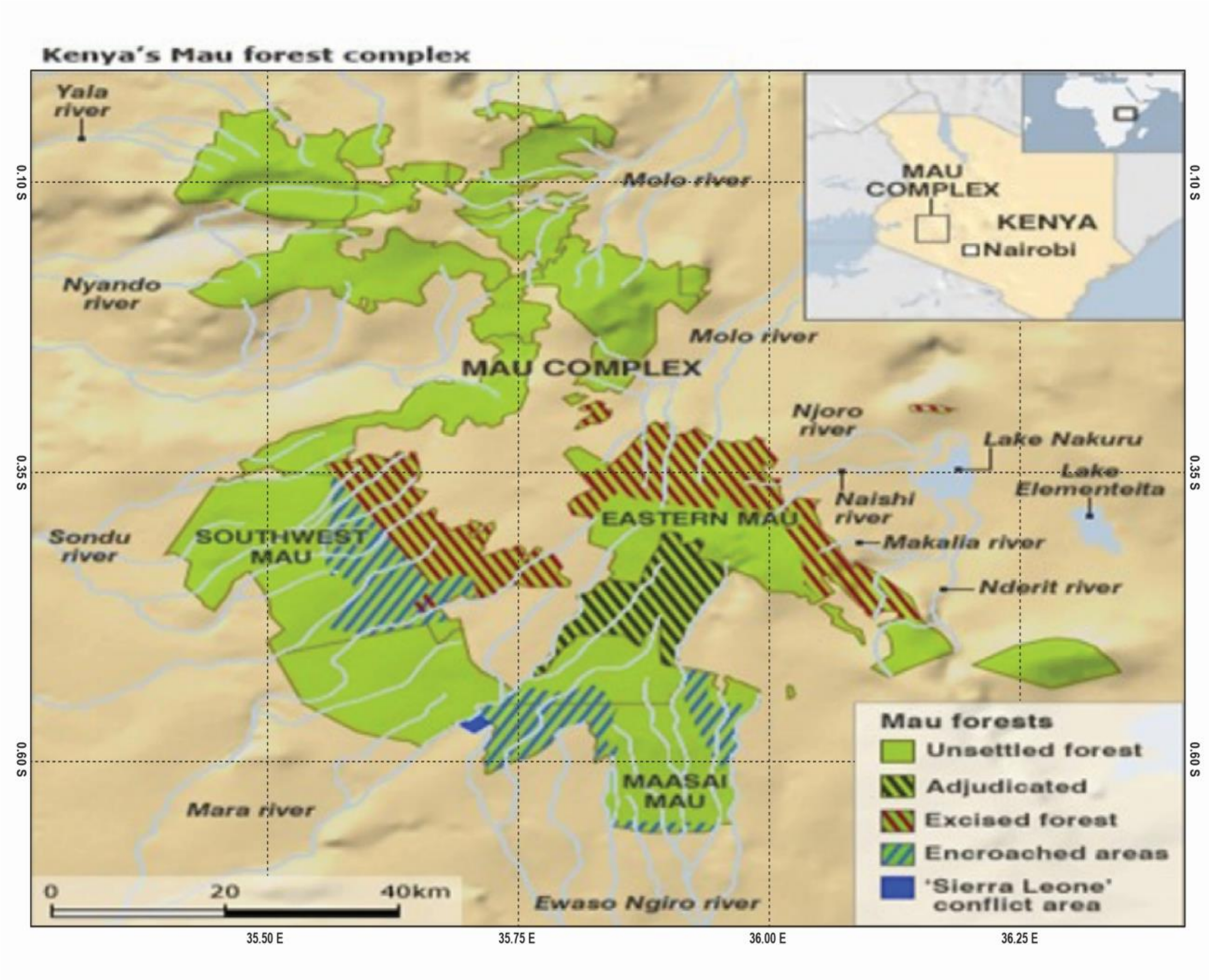


Figure 7: Map showing Mau Forest encroachment

(Chaudhry, 2019)

The eviction of people from East Mau by the Kenyan government has helped reclaim part of the forest that had initially been occupied. There have been changes in the land use practices in the region. Extensive degradation and deforestation are attributed to various causes. The first cause is that people are unable to comprehend the important role that forests play in the ecosystem (Mwaniki, 2016). Another cause is inadequate implementation of the Kenyan laws with regard to protecting the forests. There is a great implementation of policies related to macro-economic growth such as encouraging cash crop growth without considering the forest cleared to grow them (Albertazzi et al., 2018). Another major reason is the increase in population which exerts pressure on the available pieces of land. Finally, there is increased demand of charcoal and firewood, which are sources of energy.

2.5 Suggested Causes of the Rising Water Levels

There have been several scientific works done to establish the possible contributing causes to the rising water levels of Lake Nakuru. Some scientists have established tensional stress on the tectonic plates as a possible cause for the problem. Tectonics plates are known to create a near field and a far field. The near field is characterized by a localized area that responds to the effects of earth's activities. The far field is an earth area that is area away from the tensional and compressional stress fields. The stress regimes for the near field respond to the stress regimes of the far field. However, this happens with a time lag. Under this case, the Indian ocean is considered to be the far field body while the Rift Valley is considered to be a near field that responds to the Indian Ocean's pull (Mureithi, 2021).

The forest cover of Mau Forest has reduced significantly over the years. People have been encroaching the area without having proper knowledge of the detrimental effects they cause on the water catchment of River Njoro. There has also been an enhanced degradation of the riparian zones of the lake, which have increased the sedimentation levels of the lake (Iradukunda and Nyadawa, 2021). When a lake becomes shallow with a constant or increasing volume of water, the result is an increase in its water levels. Another suggested cause is the seasonal rainfall in the area combined with the varying evaporation levels that affect the response of the lake water levels (Kimaru et al., 2019). However, there is no sufficient scientific data to ascertain this claim. The identified gap is the foundation for this research project in connection with the climate change that is likely to have caused the rainfall variation. Another cause is increased land degradation that has caused an increased runoff of the water volume that flows directly into the lake after a heavy downpour (Iradukunda and Nyadawa, 2021).

2.6 GIS Role in the Assessment of Lake Water Levels

Geographic Information Systems continue to find lots of applications in different fields in the current dynamic world. Natural resources and the environment forms part of the key areas that the technology continues to benefit (Gharehbaghi and Scott-Young, 2018). Remote sensing, which forms a critical aspect of GIS, enables researchers to acquire information about any object or phenomenon without having to be in direct contact with them (Gomeseria, 2019). Under this study, the phenomenon is the rising water levels of Lake Nakuru and the increased encroachment of Mau forests. Mapping can be done to indicate the initial boundaries of the lake and the changes that continue to take place on them. For example, there is an expectation of a reduction in the area covered by Mau Forest because of encroachment and an increase in the area covered by Lake Nakuru because of flooding.

Hotz and Christian (2015) used remote sensing and GIS to monitor the water levels of Lake Etang Saumatre, a basin lake located in Haiti. Using Landsat imagery for the past 30 years, they found that there is a risk of a 20.6% future rise in the lake's water levels. The most vulnerable areas were the eastern and western parts because of their east/west location in the Hispaniola Rift Valley. El-Hadidy (2020) used the same system to monitor the shoreline changes that were taking place on Egypt's Lake Nasser. He found that sands were encroaching the lake from the north in sand sheets shapes and not dunes under the influence wind blowing from southeastward. However, it was not possible to determine the sand drift rates using remote sensing only. Satellite remote sensing may also be used in monitoring the changes in reservoirs and lakes' water levels, through the determination of the volumetric fluctuations at different time intervals (Keys and Scott, 2018). Spatial monitoring, remote sensing and GIS techniques were also used to monitor the Al-Razzaza lake's degradation (Mashee, 2020). Mashee found a major shortage of water cover in terms of area and depth of the lake because of the reduction in the normalized differences water index. The studies indicate the usefulness of the technology in the assessment of water levels in different lakes across the world. Therefore, the phenomenon in Lake Nakuru can still be adequately addressed through the employment of such techniques since they been used to study other lakes. Table 2 gives a summary of the GIS application in studying water level variation in different lakes.

Table 2: Summary of GIS application in studying lake water levels

GIS technique	Specific technique	Reference
Remote sensing	Landsat imagery and digitization	Hotz and Christian (2015)
GIS and remote sensing	Continuous monitoring and zoning	El-Hadidy (2020)
Moderate resolution imaging spectroradiometer satellite imagery	Satellite radar altimetry	Keys and Scott (2018)
GIS and remote sensing	Analysis of temporal data	Mashee (2020)

There are different remote sensing indices that have been developed, which relate to liquid water. They are applied in GIS to study changes in water levels and quality. The Normalized Difference Water Index (NDWI) us used when determining changes that relate to the quantity of water in water bodies. The index concept involves combining near infrared (NIR) and short-wave infrared (SWIR) reflectance (Pal and Ghosh, 2023). The construction for detecting Sentinel-2 NDWI for any waterbody detection can be done by NIR band 8A (864nm) and Green band 3 (559nm) (Twumasi et al., 2022). However, it is worth noting that there are suggestions for modification of this index to help improve the detection of open water through the use of SWIR instead of NIR spectral band. The index ranges from -1 to +1 where -1 represents no water content while +1 represents water content. The formula for the index is:

$$NDWI=(G-NIR)/(G+NIR) \qquad \text{Equation 2.5}$$

Where:

NDWI-Normalized Difference Water Index

NIR- Near-infrared

G-Green channels

The water index, which is a function of NDWI in clear water continues to face uncertainties with regards to being used in turbid water. Water that has experienced eutrophication presents another uncertainty to the index. The index uses linear discriminant analysis classification in determining the coefficient relating to an accurate segmentation training category area, thus improving its accuracy (Fisher et al., 2016). Ouma and Tateishi (2006) used the Water Index to rapidly map changing shorelines of 5 lakes in East Africa including Lake Bogoria, Elementaita, Naivasha, Baringo and Nakuru. The automated water extraction index (AWEI) is another index for mapping water bodies. Feyisa et al. (2014) introduced the technique to improve the accuracy of classification in areas that contain dark surfaces and shadows, which other classification methods may fail or give errors during the process. Feyisa et al. (2014) tested the index by the use of Landsat 5 TM images for different water bodies in South Africa, Ethiopia, Denmark, New Zealand and Switzerland. AWEI index gave a better performance in their results when compared to NDWI and Maximum Likelihood classifiers.

2.7 Kenyan Legal Framework Regarding Forestry and Water Resources use

Kenya has stringent policies and laws that guide the usage of natural resources including the water and forest resources (Kenya, 2013). The laws are considered to be among the stringent ones across the world. The forest laws are important in ensuring that the there is an adherence to forest management practices in a sustainable manner. The adherence helps raise the confidence of the consumers of the wood and forest products, which are legally harvested and obtained within the country. There have been different forest reforms that have taken place in the country in the recent years. The reforms paved way for repealing the Forest Act 385 and enacting the 2005 Forest Act which placed KFS as a semi-autonomous corporation (Kenya, 2013). The reforms also led to the formation of the Forest Conservation and Management Act 2016, which brought the light to forest resources management under Article 69 of the Kenyan Constitution.

The article brought into effect the sustainable development and management of forests including their rational usage and conservation for the realization of the country's socio-economic development. The act requires measures to be taken to manage and conserve both the public, private and community forest land that are in need of special protection (Kenya, 2013). It also defines the forest rights and presents rules for using the forest land. Another important provision of the act is public participation by the communities through the community forest association (Kenya, 2013). Protection of water resources and indigenous forests is also captured in the act. Some of the guiding principles of the act a sourced from Kenya (2013) include:

1. Good governance as directed by Kenya constitution's Article 10.
2. Public service and values highlighted in Article 232.
3. Public participation and involvement.
4. Best international practices in forest conservation and management.
5. Coordination and consultation between the county governments and the national government.
6. Protection of intellectual and knowledge proper rights regarding forests.

The act gives the cabinet secretary the responsibility of developing forests policies that ensure the sustainable usage of the forest resources (Kenya, 2013). The main body that is in charge of administering the act is KFS (Mwaniki, 2016). However, it is the responsibility of the county governments established under the 2010 constitution to implement the policies as provided for in section 21 of the act, which directs them to develop report on the forest activities service on an annual basis (Mwaniki, 2016). The KFS board is also required to develop reports on the forests status and forwarded to the Cabinet Secretary once in two years. A goal of having a 10% forest cover in the country is the main motivation behind the enactment of the laws. The act has direct reference to the encroachment that has been taking place in Mau forests, leading to a great reduction in the forest land. Therefore, it is the responsibility of every person to ensure the protection and conservation of the forests.

The National Environment Management Authority (NEMA) is the central body that talks care of environmental and natural resources matters. It is responsible of taking stock of all the natural resources within the country while guiding their conservation and utilization one of the laws that guide NEMA in taking actions is the EMCA act (CAP 387), which gives NEMA the mandate of supervising and coordinating the environmental matters within the country's border (Kenya, 2013). The entity also establishes and reviews guidelines related to land use patterns and determining the impact that they have both on the quantity and quality of the natural resources, including lakes and rivers. The Water Act 2016 gives provision for regulating, managing and developing water resources and the sewerage and water services in accordance with the constitution. Different entities are established by the act including WRA, NWHSA and WASREB which have different responsibilities as far as water use and conservation is concerned (Kenya, 2013). The provisions under EMCA act 1999 which relate to the protection and conservation of water resources and pollution control are exercised subject to specific provisions laid out in the water act.

2.8 Summary of Literature Review

Climate change continues to negatively impact hydrological bodies at the international, regional and local levels. Rising temperature levels and increased precipitation amounts are a result of climate change that affects terrestrial and aquatic ecosystems. One notable impact is variation in water levels of different lakes including Lake Tanganyika, Turkan and Victoria at regional level. Rift Valley lakes' water variation particularly Lake Nakuru's case is one event resulting from the shift in climatic conditions at the local level. Some of the attributed causes include changes in land use practices in the catchment areas, sedimentation and changes in weather conditions. Its flooding has resulted in a change in the ecology of the lake and hence migration of birds like flamingoes to nearby Lake Bogoria and Oloiden. Different regression models like the Heathcote and Cael models, which use a lake's surface areas as a variable have been used to predict water levels of different lakes. Finally, there exists a legal framework in the Kenya Constitution perspective that protects and governs the use of forests and water resources.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Research design

The study was quantitative in nature as numerical data was analyzed and findings established. The chosen study period was 30 years from 1990, which is three decades. The first step involved analyzing changes in rainfall amounts received by the area to achieve the first objective. There was analysis of changes in River Njoro flows to achieve the second objective. The changes were determined using annual standard deviations, inter annual variations and series correlation. The next step involved analyzing indicators of climate change, which were set to be changes in rainfall, River Njoro flows and temperature. The confidence interval for the means of the 3 decades for the set indicators was established and the changes explained to achieve the third objective. Landsat 8 and QGIS was then were used in determining the changes in the surface area of the lake over time before development of polynomial regression model. R-software was used in model development and analysis.

3.2 Assessing the long-term change on rainfall amounts in the contributing catchment area around Lake Nakuru

3.2.1 Data collection

Rainfall data was collected from the Kenya Meteorological department based in Dagoretti. It is the principle meteorological department for the country and it receives data from the different weather stations across the country. Focus was paid on validated monthly rainfall data from the Lake Nakuru meteorological data from 1990 to 2020.

3.2.2 Data analysis

The rainfall was input into excel and a time series drawn. A frequency distribution table was developed before drawing the cumulative frequency polygon. The means for the different periods were established and compared to determine any changes in the rainfall amounts. The data was divided into 3 decades namely 1990-1999, 2000-2009 and 2010-2019. Mean rainfall for every decade was calculated to determine the decade that had the highest amount of rainfall. The data was confirmed to be normally distributed by the use of a Q-Q plot. The development of the Q-Q plot entailed ranking the annual mean rainfall, finding the percentile, calculating the theoretical z-scores and the actual z-scores and finally plotting the two scores to determine whether the points lie on the straight line. The annual standard deviation, inter-annual variations and series autocorrelation were determined to establish the changes in rainfall.

3.3 Assessing the long-term changes in River Njoro flows into Lake Nakuru

3.3.1 Data collection

Data on River Njoro flows since 1990-2019 was collected from the Water Resources Authority (WRA) of Kenya. It is the body responsible for equitably and sustainably allocating water resources according to the competing water needs. It has data regarding the different hydrological bodies in the country, including River Njoro. The gauging station on River Njoro gives readings of river flows, which are stored by the authority.

Secondary data on Mau Forest encroachment since 1990 was collected from the Kenya Water Towers Agency. Tree cover loss data was collected in ha/year. The data on land cover trends of forests and cropland in Mau East Forest was collected from the KEFRI (Kenya Forestry Research

Institute, Research department at Muguga. Accessed in December 2021). The base year for the land cover trends data was 1990.

3.3.2 Data analysis

Average annual flows for River Njoro were calculated for the same period. An annual hydrograph for River Njoro flows was drawn. Mean flows for decades 1990-1999, 2000-2009 and 2010-2019 were determined to establish the decade in which the river had the highest flows. An annual hydrograph for River Njoro was developed by plotting the average annual flows (m^3/s) against the number of years. The years with peak flows were determined from the hydrograph. To determine the changes in River Njoro flows, the inter annual variations, serial autocorrelation and annual standard deviation were determined.

To show the evidence in land use changes which contributed to the changing River Njoro flows, data on Mau Forest encroachment was input into Microsoft Excel (Version 2013). Tree cover loss data was converted into hectares for the different years since 1990. The data represented the amount of tree loss in Mau East due to human encroachment. A bar graph was drawn to give a visual representation of annual tree cover loss. The land cover trends for the forests and cropland both within the buffer zone and gazette forest zone were established and represented on a line graph.

For temperature, maximum and minimum temperature values for the Nakuru station for every month was input into Microsoft Excel (Version 2013). The mean annual temperature was calculated by dividing the total values of the 12 months for every year by 12. A time series for the maximum and minimum temperature was developed using the mean values. The mean temperature values for the decades 1990-1999, 2000-2009 and 2010-2019 were calculated and a bar graph drawn to establish the warmest decade.

3.4 Evaluation of the changes in rainfall changes and River Njoro flows as indicators of climate change

3.4.1 Data collection

Maximum and minimum temperature of Lake Nakuru area was collected from the Kenya Meteorological Department in Dagoretti. It was crucial in evaluating the trend in the temperature of the area and establishing the warmest decade. The data was collected for a period of 30 years from 1990 to 2020.

3.4.2 Data analysis

The mean annual values of rainfall were calculated by dividing the sum of mean monthly rainfall amounts by 12 for every year. The 30-years period was divided into three decades and the mean decade rainfall amounts determined by dividing the sum of mean annual rainfall for the 10 years by 10. There was a comparison of the mean decade values of rainfall amongst the 1990-1999, 2000-2009 and 2010-2019 decades. The confidence intervals for the annual means were calculated using the 'CONFIDENCE' function in Microsoft Excel at an alpha value of 0.05. The inter-annual variation of rainfall amounts was determined using the coefficient of variation and standard deviation. These aspects were analyzed to establish any changes in rainfall amounts that would implicate climate change.

The mean annual values of River Njor flows were determined by dividing the sum of mean monthly flows by 12 for every year. The 30-years period was divided into three decades and the mean decade River Njoro flows was determined by dividing the sum of mean flows for the 10 years by 10. The confidence intervals for the annual means were calculated using the 'CONFIDENCE' function in Microsoft Excel at an alpha value of 0.05. The inter-annual variation of River Njoro flows was determined using the coefficient of variation, series autocorrelation and standard deviation. The aspects were analyzed to determine whether there was any indication of climate change. The same procedure was repeated for maximum temperature data. The variations in the three indicators were used to establish climate change in the area.

3.5 To develop a model to predict the surface area variations of Lake Nakuru using Geographic Information Systems

3.5.1 Data collection

The data was collected from Water Resources Authority and Landsat images in combination with the GIS techniques. Landsat images were taken for the different years (1990-2019) and later processed in QGIS to give the areas of Lake Nakuru (in km^2). The procedure of digitizing the shoreline of Lake Nakuru from Landsat 8 images in QGIS involved the following procedure:

i) Acquisition of Landsat 8 images- Landsat 8 imagery for Lake Nakuru and its environs for the years 1999, 2004, 2009, 2014 and 2019 were obtained from the USGS Earth Explorer website (https://earthexplorer.usgs.gov/).

   2019 Landsat Product Identifier: LC08_L1TP_169060_20190920_20200826_02_T1

   2014 Landsat Product Identifier: LC08_L1TP_169060_20141211_20200910_02_T1

2009 Landsat Product Identifier: LE07_L1TP_169060_20090220_20200912_02_T1

2004 Landsat Product Identifier: LE07_L1TP_169060_20041004_20200915_02_T1

1999 Landsat Product Identifier: LE07_L1TP_169060_19991023_20200918_02_T1

Images with 0% cloud cover were selected. Level 2 products that have been geometrically and radiometrically corrected were selected.

ii) Loading Landsat 8 image in QGIS- QGIS was opened and Landsat 8 image bands for the year 1999 were added to a new project as a raster layer. The bands loaded include bands 5, 4 and 3.

iii) Preprocessing- The images were used to create a colour infrared composite image. This band combination is also called the near-infrared (NIR) composite. The Normalized Difference Water Index (NDWI) was used.

iv) Zooming and panning the lake area- The specific area for the location of Lake Nakuru was navigated using the zoom and pan tools in QGIS

v) Addition of a new shapefile layer- A new shapefile layer was created in QGIS to store the digitized shoreline as a polygon feature. This was done by going to "Layer">"Create Layer">"New Shapefile Layer"

vi) Digitization of the shoreline- QGIS was set to minimize the topology errors that result from on-screen digitization. The shoreline was digitized using the "Add Polygon Feature" tool in the digitizing toolbar. The lake's shoreline was carefully traced by clicking on the satellite image to add vertices that define the polygon. This was done until the entire shoreline was traced.

vii) Addition of attributes- Step (ii) to step (vi) were repeated for images for years 2004, 2009, 2014 and 2019. An attribute for "Year" was added. This was the column used to input the digitized shoreline the rest of the years in the period of study.

viii) Visualization of the lake boundary- The lake shorelines for the different years were styled with different colours representing the different years. Finally, a map layout was created.

ix) Calculation of the area- A new field was created in the Field Calculator Dialog to store the calculated area. A new field named 'Area' was created and the field type was set as 'Decimal'. In the expression area, the formula '$area' was entered. After clicking 'OK' in the Field Calculator dialog, the calculated area values were added to the new field in the attribute table.

3.5.2 Data analysis

Landsat 8 imagery and QGIS software helped determine changes in Lake Nakuru's areas since 1990. QGIS was used in development of the lake area maps. A Q-Q plot was used to determine whether the lake area data was normally distributed. A line graph was drawn to show the trend in the Lake Nakuru areas over the years.

Lake area data over the different years, rainfall data and River Njoro flows data were input into R-studio for the development of a predictive model. A script for the development of a polynomial regression model was developed and run in R. The model performance was assessed using the Nash and Sutcliff coefficient (NSE), coefficient of determination (R^2), Mean Square Error (MSE) and unbias.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Objective 1: Long-term change on rainfall amounts in the contributing catchment area around Lake Nakuru

The Frequency distribution in Table 3 represent rainfall changes around Lake Nakuru over time since 1990-2019. The table was drawn from the comprehensive data on monthly rainfall amounts experienced by Lake Nakuru area (see Appendix 5), which was used to draw the mean annual rainfall histogram (see Appendix 6).

Table 3:Frequency distribution table for rainfall

Class intervals	Midpoints	Frequency	Cum. Freq.
50-60	55.0	4	4
60-70	65.0	6	10
70-80	75.0	7	17
80-90	85.0	2	19
90-100	95.0	7	26
100-110	105.0	2	28
110-120	115.0	2	30

From the rainfall data (see Appendix 5), the time series in Figure 8 was drawn to indicate the variations in the rainfall amounts.

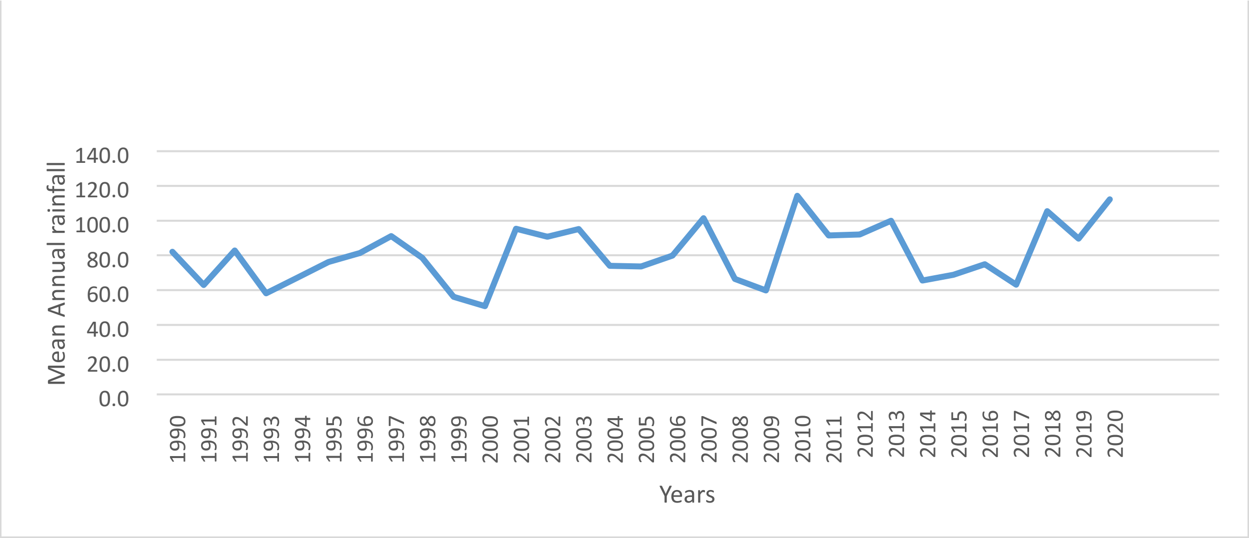


Figure 8:Mean annual rainfall time series

From the time series above, it can be seen that Lake Nakuru area received the highest amounts of rainfall as from 2010. The warmest decade (2010-2020) exhibited large amounts of rainfall compared to other decades. It is only after 2010 that mean annual rainfall started hitting figures above 100 mm. Dividing the mean rainfall amounts into three decades and finding the average of every decade, it becomes evident that 2010-2019 was the decade with the highest rainfall amounts with a value of 86.6mm compared to 1990-1999 and 2000-2009 that had values of 73.7 and 78.7mm, respectively.

The inter-annual variation, changes in standard deviation and series autocorrelation over the years gave a detailed analysis of the changes in rainfall over time. For inter-annual variation, the coefficient of variation was used in determining rainfall variation. The formulas used for Coefficient of variation (CV) and standard deviation calculation were:

C.V= (Standard deviation)/Mean Equation 4.1

$$\sigma = \sqrt{\frac{\sum(xi - \bar{x})^2}{N}}$$ Equation 4.2

Where;

σ - Standard deviation, x̄ - Mean, xi - Terms in the data set and n - Total number of terms

Table 4 gives the values for annual standard deviation and coefficient of variation for the 30 years period for rainfall changes.

Table 4:Annual standard deviation and coefficient of variation for rainfall changes

Year	Annual std. dev	CV	Year	Annual std. dev	CV
1990	50.69	0.618	2006	46.46	0.558
1991	36.32	0.553	2007	51.39	0.487
1992	51.03	0.592	2008	49.19	0.711
1993	27.49	0.454	2009	55.42	0.891
1994	40.14	0.574	2010	67.65	0.568
1995	38.73	0.488	2011	53.68	0.564
1996	52.46	0.617	2012	71.49	0.747
1997	72.66	0.766	2013	63.01	0.606
1998	42.10	0.515	2014	32.32	0.474
1999	34.58	0.592	2015	52.10	0.727
2000	47.35	0.896	2016	39.18	0.502
2001	55.66	0.560	2017	54.50	0.830
2002	52.71	0.558	2018	86.84	0.790
2003	73.29	0.740	2019	67.74	0.726
2004	47.60	0.618	2020	51.71	0.443
2005	44.59	0.581			

From Table 4 above, the annual standard deviation ranged from 27.49 in 1993 to 86.84 in 2018. This indicates a huge deviation of the rainfall amounts in 2018 from the mean annual rainfall value. The lowest and largest standard deviation values for the1990-1999 decade ranged from 27.49 in

1993 to72.66 in 1997, respectively. For the decade 2000-2009 decade, they were 44.59 in 2005 and 73.29 in 2003. For the decade 2010-2019, they ranged from 32.32 in 2014 to 86.84 in 2018. The shift from low standard deviation values of 27.49 in the 1990-1999 decade to high values of 86.84 in the 2010-2019 decade indicate climate change in the area. It means that there is a huge deviation in the rainfall amounts from the mean annual ones in the 2010-2019 decade, which also informs increased runoff and flooding of Lake Nakuru. The same case is supported by the inter-annual variation in rainfall, indicated by the changing coefficients of variation. The coefficients of variation ranged between 0.454-0.594 in 1990-1999 and 0.487-0.896 in 2000-2009. It ranged between 0.502-0.83 in 2010-2019 (see Table 4). There are large variations in the rainfall amount as from 2010, which informs the increased rainfall amounts that the area received from that year leading to an increase in the runoff volumes, hence the flooding of the lake.

The serial autocorrelation values determined using the R-software are indicated in Figure 9:

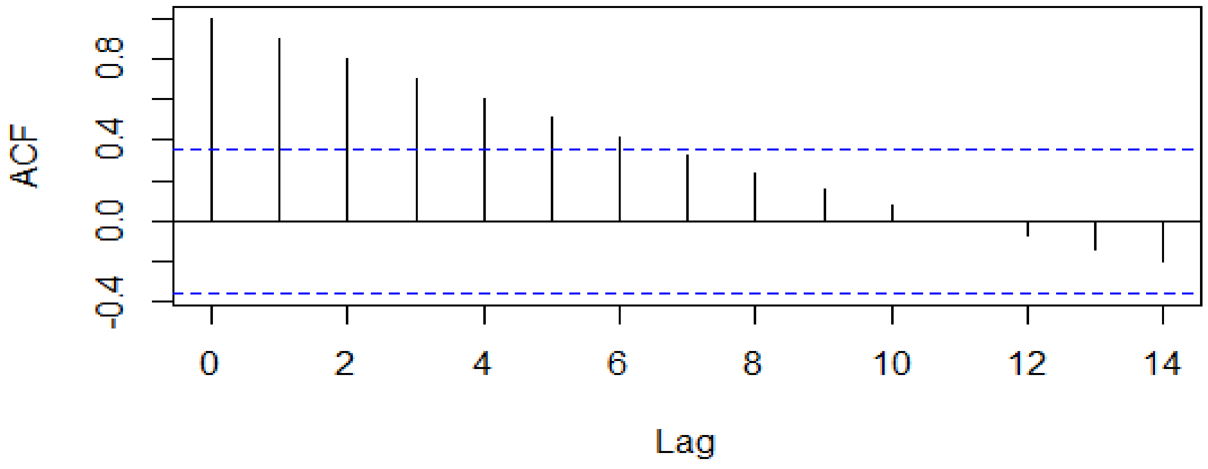


Figure 9:Serial autocorrelation for rainfall

At lag 1, the series autocorrelation was 0.9. This showed a positive correlation between the data. The value kept on reducing further away from 1 with the increase in the lags. For example, at lag

5, the value was 0.5. The increasing number of lags represents the increasing years since 1990. It is evident that there was aa negative series correlation at lag 14 with a value of -0.4. The negative series autocorrelation started appearing at lag 11, which represents years in the 2010-2019 decade. Therefore, the negative values indicate a shift in the rainfall data from the previous decades which indicates that climate change has taken place in the area.

4.2 Objective 2: Assessing the long-term changes in River Njoro flows into Lake Nakuru

River Njoro flows over the years (1990-2019) are shown in Table 5 below:

Table 5: Mean annual flows for River Njoro

Mean annual flows of River Njoro (m^3/s)			
Year	**River flows**	**Year**	**River flows**
1990	0.92339	2005	0.65873
1991	0.22093	2006	1.35682
1992	0.09997	2007	3.56392
1993	0.23433	2008	0.03923
1994	0.51055	2009	0.56328
1995	0.07664	2010	0.7855
1996	0.14874	2011	0.96845
1997	0.45106	2012	1.91583
1998	1.78562	2013	1.68549
1999	0.16217	2014	0.04613
2000	0.15323	2015	1.85579
2001	0.82565	2016	0.45289
2002	0.12856	2017	0.20596
2003	0.16222	2018	0.35273
2004	0.32152	2019	0.59867

From Table 5, River Njoro experienced the highest amounts of flows in 2012, which amounted to an annual average of 1.9158 m^3/s. The least river flows were experienced in 2008 with an annual average of 0.0392 m3/s. The annual hydrograph in Figure 10 represents the river flows for Njoro based on the data in Table 5.

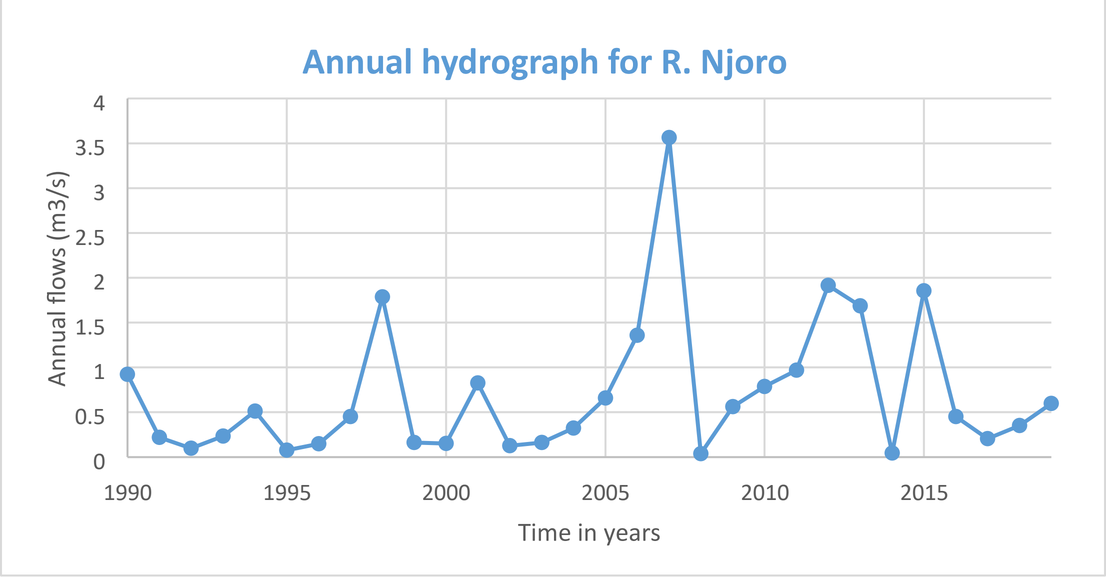


Figure 10: Annual hydrograph for River Njoro

From the hydrograph in Figure 10, it can be seen that the river experienced peak flows in 1994, 1998, 2001, 2007, 2012, 2015 and 2019. The average decade flows for 2010-2019 and 2000-2009 were higher than those of 1990-1999. However, those of decade 2010-2019 exceeded the other decades.

Inter-annual variation and annual standard deviation gave a detailed analysis of the changes in the flows over time. For inter-annual variation, the coefficient of variation was used in determining rainfall variation. Table 6 below shows the standard deviation and coefficient of variations values for River Njoro flows:

Table 6: Annual standard deviation and coefficient of variation for River Njoro flows

Year	Annual Std. dev	CV	Year	Annual Std. dev	CV
1990	1.526751	1.655683	2005	1.220114	1.852215
1991	0.379884	1.719455	2006	1.687564	1.064511
1992	0.099894	1.084237	2007	6.132541	1.720729
1993	0.412675	1.761088	2008	0.016594	0.423009
1994	0.614032	1.202678	2009	0.616357	1.043635
1995	0.075297	0.982452	2010	1.345462	1.897362
1996	0.224366	1.508437	2011	1.563535	1.543635
1997	0.516208	1.144434	2012	2.135264	2.576846
1998	2.042178	1.143681	2013	2.024421	1.847464
1999	0.167496	1.094499	2014	0.019659	0.426147
2000	0.157654	1.546363	2015	2.253391	1.214247
2001	1.436541	1.563526	2016	0.342648	0.756576
2002	0.134561	1.453634	2017	0.190916	0.926944
2003	0.166542	1.083673	2018	0.450331	1.066399
2004	1.056763	1.065412	2019	0.624708	1.043496

From Table 6, annual standard deviation for River Njoro flows ranged from 0.016594 in 2008 to 2.256691 in 2015. This indicates a huge deviation of the flows in 2015 from the mean annual rainfall value. The lowest and largest standard deviation values for the1990-1999 decade ranged from 0.075297 in 1995 to 1.526751 in 1990, respectively. For the decade 2000-2009 decade, they were 0.016594 in 2008 and 6.132541 in 2007. For the decade 2010-2019, they ranged from 0.019659 in 2014 to 2.253391in 2015. This variation in standard deviation is an indicator of changing flows of the river as a result of the changing rainfall amounts, which has been established to implicate climate change. The change is also indicated by the changing coefficients of variation. CV ranged between 0.982452-1.761088 in 1990-1999 and 0.423009-1.852215 in 2000-2009. It ranged between 0.426147-2.576846 in 2010-2019 (see Table 4). There are large variations in the River Njoro flows as from 2010 because of the variation in rainfall amounts that the area received from that year leading to an increase in the runoff volumes, hence the flooding of the lake.

Serial autocorrelation for River Njoro flows as developed by the R-software is indicated in Figure 11.

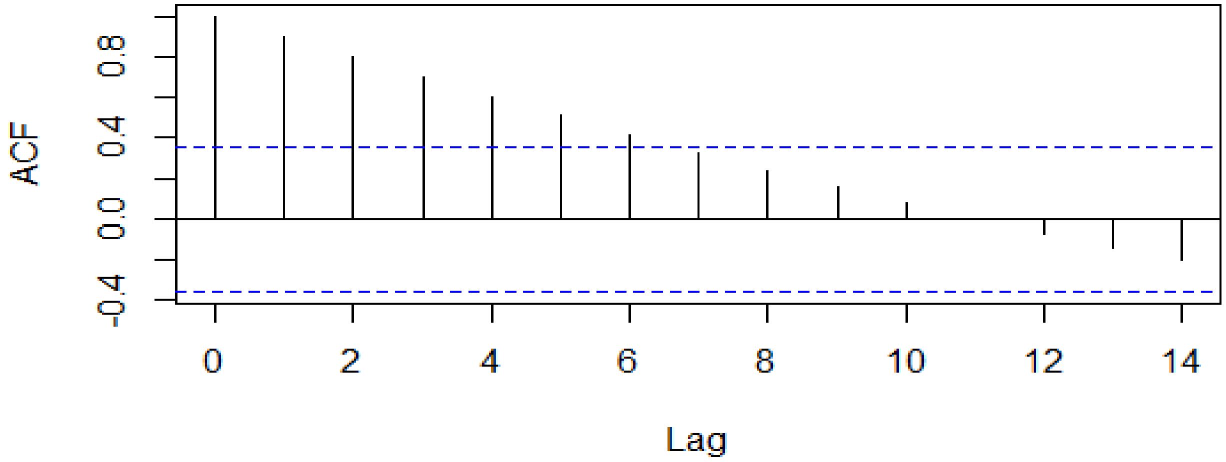


Figure 11:Serial autocorrelation for River Njoro flows

The serial autocorrelation at lag 1 was 0.9, which shows a positive correlation. It was 0.6 at lag 3 and 0.38 at lag 7. The serial autocorrelation values kept on reducing and achieved a 0 value at lag 11. Negative correlation started being seen as from lag 12 at -0.1 to lag 14 where the value was 0.2. The negative correlation in the late lags represents values in the 2010-209 decade, which shows that a huge variation of River Njoro flows in that decade when compared to the previous two decades under study. The negative correlation gives evidence that climate change has taken place in the area.

There is also evidence on land use changes that explain the increased runoff. East Mau has been experiencing tree cover loss annually. Figure 12 shows that East Mau has lost tree cover every year since 1990 for 3 decades. There has been a remarkable loss of the trees, which is informed by the encroachment of people into the forest.

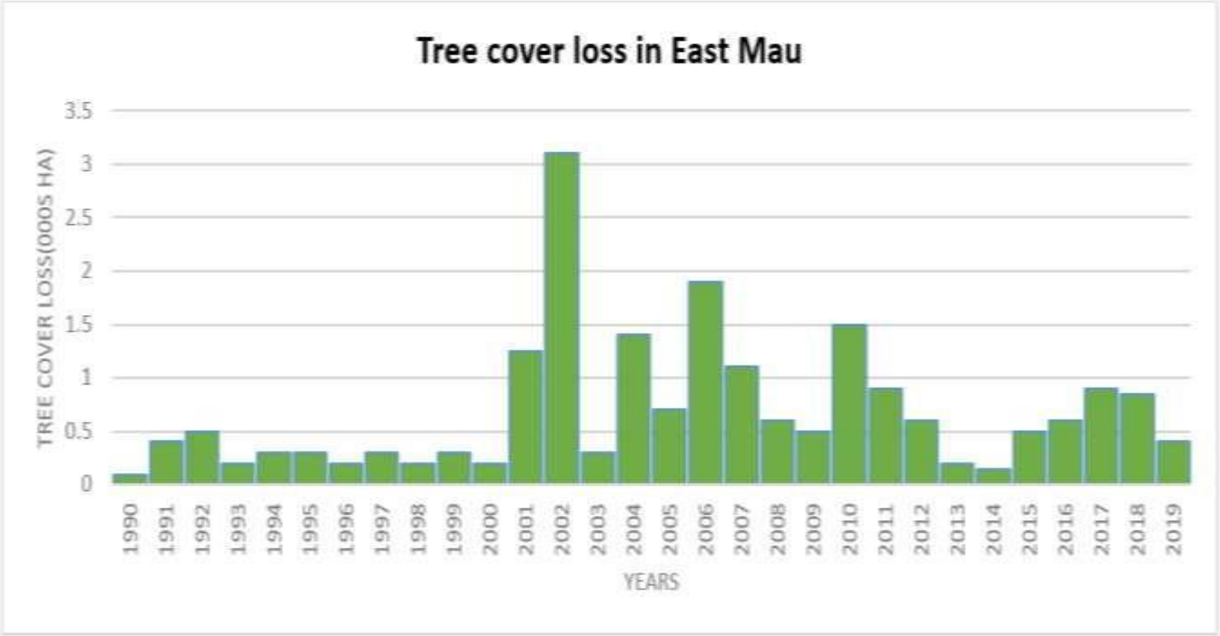


Figure 12: A bar graph representing tree cover loss in East Mau

Apart from human encroachment, Kinyajui (2009) agrees that forest fires reduce tree cover in Mau Forest. From Figure 12, it can be seen that Mau East experienced the largest tree cover loss in 2002 at approximately 31,000 hectares. This is an indication of a massive number of people that encroached the forest during 2002 in search of land for settling and cultivation. However, there was a sudden decrease in the loss from 2002 to 2003, which indicates the year when the Kenyan government started massively evicting people from the forest. According to Kweyu et al. (2020), the 2002 national election brought in leaders whose environmental policy included eviction of forest settlers. Figure 8 shows that the period with the lowest tree cover loss was between 1990-2000, with the highest loss during that time being in 1992 at 500 hectares. The decade with the highest tree cover losses was 2001-2010. It was followed by a decline of tree cover loss from 2011, which is a scenario informed by forest conservation initiatives and the intensified efforts of the government to evict people from the area (Mutune et al., 2017). The encroachment of people in the forest is marked by changing land cover trends. There has been changing cropland and forest areas within both the forest buffer and gazette zones, as shown in Figure 13 developed from data forest/cropland data (see Appendix 2).

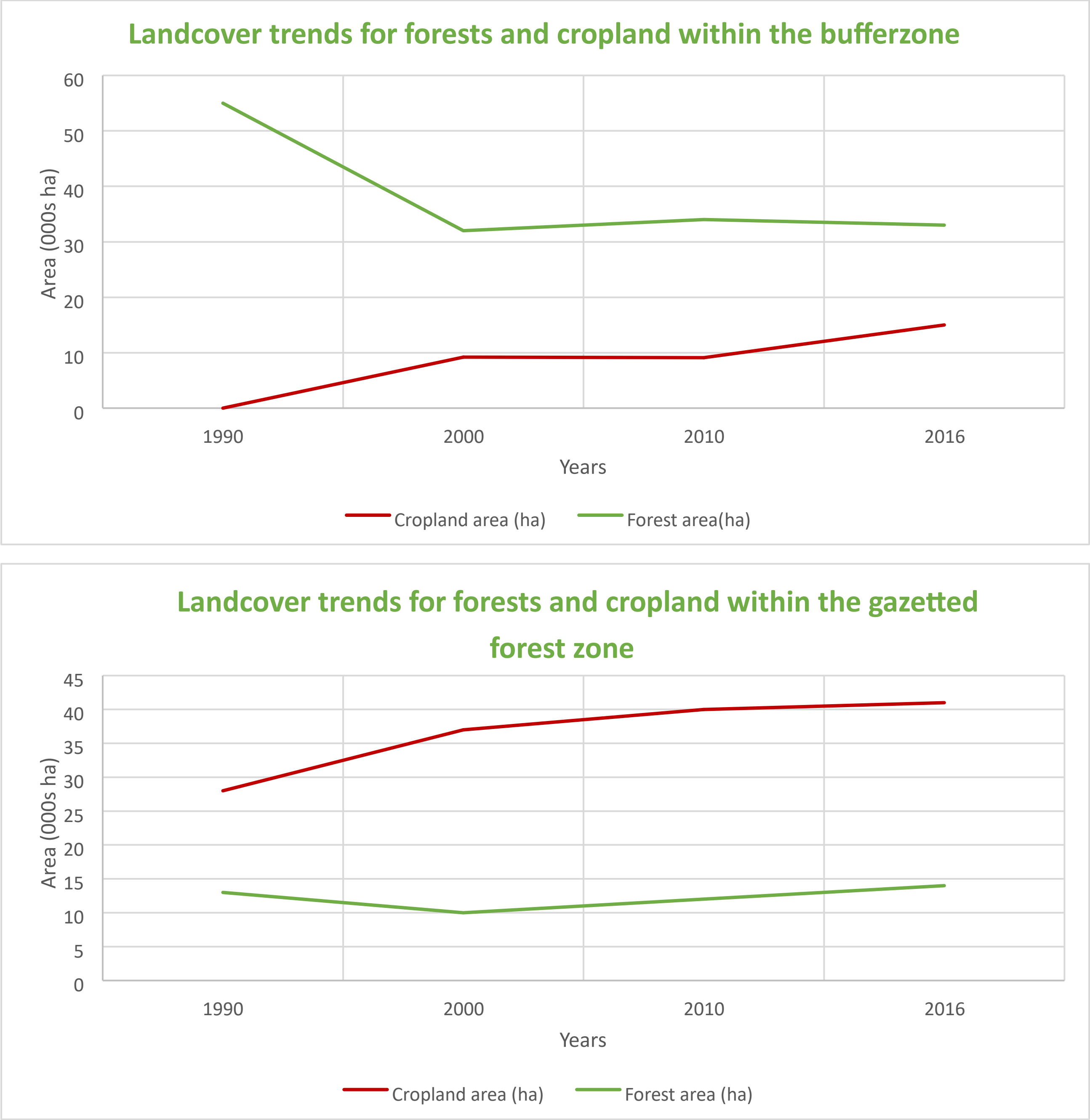
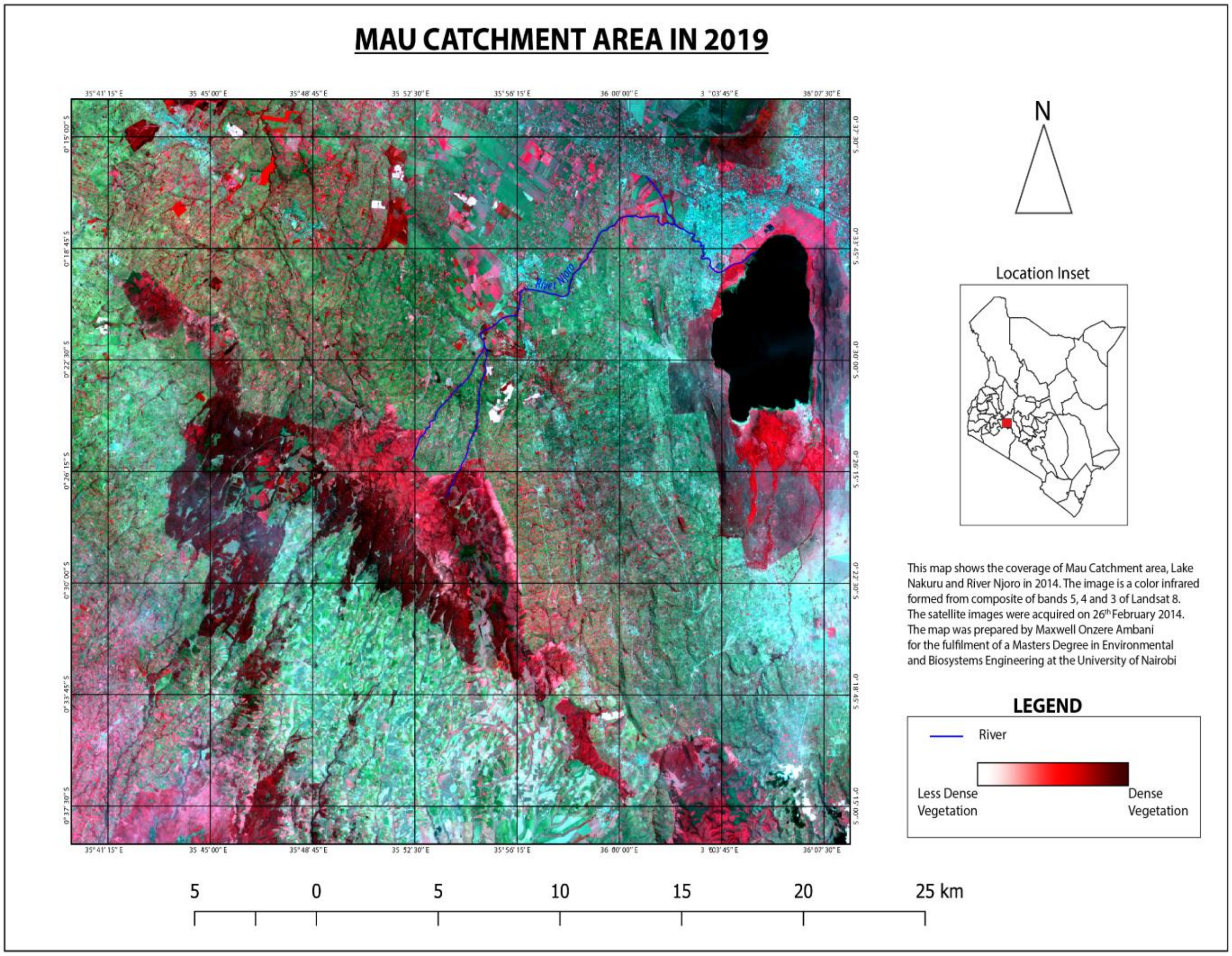


Figure 13: Land cover trends in Mau East

From Figure 13, it can be seen that 2016 was marked with the highest area of cropland both within the gazette forest zone and the buffer zone. The cropland in 2016 was higher than the other years in both areas because there was more cultivation in the forest that year compared to the rest of the years. The one in the buffer zone accounted for 15 hectares while the one in the gazette area accounted for 41 hectares. This is a clear indication that the forest has been encroached and people are practicing cultivation.

It can be seen that there was a steady increase in the cropland area from 1990 to 2016 (see Figure 9). In 1990, there was no forest land within the buffer zone used to grow crops. However, the slow encroachment saw a rise to 9.2 ha in 2000, 9.1 ha in 2010 and 15 ha in 2016. Within the same buffer zone, there was a reduction in the forest area from 55 ha in 1990 to 33 ha in 2016. An increase in the cropland area is marked by a reduction in the forest area within the buffer zone. The same trend has been observed within the gazetted forest area. Within this area, there has been an increase in the cropland area from 28 ha in 1990 to 41 ha in 2016. The forest area reduced from 13 ha in 1990 to 10 ha in 2000 before increasing to 14 ha in 2016. All these results are an indication that people have continue to encroach the forest. The result of the encroachment is loss of forest cover leading to a change in climatic conditions, which impact the linked hydrological bodies to the forest.

Figure 14 shows a map indicating the connection between Mau Forest, River Njoro and Lake Nakuru. Mau East is the major catchment area for River Njoro, which flows into Lake Nakuru. Therefore, an effect of the forest means a destruction of the natural water balance in the hydrological bodies like River Njoro, which in the end affect the water levels of Lake Nakuru.



This map shows the coverage of Mau Catchment area, Lake Nakuru and River Njoro in 2014. The image is a color infrared formed from composite of bands 5, 4 and 3 of Landsat 8. The satellite images were acquired on 26th February 2014. The map was prepared by Maxwell Onzere Ambani for the fulfilment of a Masters Degree in Environmental and Biosystems Engineering at the University of Nairobi

Figure 14: A map showing Mau catchment and its connection with Lake Nakuru

4.3 Objective 3: Evaluation of indicators of climate change

Climate change is defined as the long-term shifts in the weather patterns of a place. The period for the study was 30 years, which fits the long-term aspect in the definition. The meteorological factors involved in the determination of climate change were temperature, rainfall and River Njoro flows.

4.3.1 Rainfall change

The shift in the rainfall pattern of the area has been established under objective 1. The change is indicated by the changing annual standard deviations and coefficients of variation (see section 4.1). The high standard deviation values of up to 86.84 within the 2010-2019 decade indicate a huge deviation of the monthly rainfall amounts from the mean annual rainfall values. The highest deviation in the 1990-1999 and 2000-20009 decades were 72.66 and 73.29, respectively. The shift in the deviation shows a changed rainfall pattern and amounts that the area receives, hence implicating the occurrence of climate change. Furthermore, there is a high inter-annual variation in the rainfall amounts between 2010-2019, which is indicated by the 0.502-0.83 coefficient of variation values. These figures show a shift from the 0.454-0.594 CV values for the 1990-1999 decade (see section 4.1). The change is also evidenced by the negative series autocorrelation for rainfall values in the 2010-2019 decade compared to the previous decades.

The confidence interval for the means of the 3 decades were essential in supporting the change in rainfall amounts received by the area. Using an alpha value of 0.05, the confidence interval for 1990-1999, 2000-20009 and 2010-2019 were 6.94, 9.88 and 10.4, respectively. Table 7 gives the mean values for the 3 decades as far as rainfall amounts are concerned.

Table 7: Mean decade rainfall amounts

DECADE	1990-1999	2000-2009	2010-2019
Mean rainfall	73.7	78.7	86.6

From Table 7, the confidence interval for 1990-1999, 2000-20009 and 2010-2019 were 73.7±6.94, 78.7±9.88 and 86.6±10.4 mm, respectively. It means that the range for rainfall amounts in 1990-1999 was 66.76 and 80.64 mm. The range for 2000-20009 decade was 68.82 and 88.58mm while that one for 2010-2019 was 76.2 and 97mm. The confidence interval indicates an increasing trend in the amount of rainfall that the area has been receiving, with the 2010-2019 decade being the decade that the area experienced the highest rainfall amounts among the 3 decades. The shift in the rainfall amount experienced in the area over 30 years depicts climate change.

4.3.2 Changing River Njoro flows

The high annual standard deviation for River Njoro flows to values of 2.256691 m^3/s in 2015 is an indicator of climate change. The largest annual standard deviation values for the1990-1999, 2000-2009 and 2010-2019 decades were 1.526751, 6.132541 and 2.253391 m^3/s, respectively. The variation in standard deviation is an indicator of changing flows of the river caused by changing rainfall amounts. Furthermore, there was a high inter-annual variation in the flows which is indicated by CV values between 0.426147-2.576846 in 2010-2019. These figures show a shift from the 0.982452-1.761088 CV values for the 1990-1999 decade (see section 4.2).

The confidence interval for the means of River Njoro flows for the 3 decades was determined to determine any changes. An alpha value of 0.05 was adopted in the determination of CI for River Njoro flows changes. The confidence interval for 1990-1999, 2000-20009 and 2010-2019 were

0.31267, 0.62302 and 0.41017, respectively. Table 8 gives the mean values for the 3 decades as far as River Njoro flows are concerned.

Table 8: Mean decade flows for River Njoro

DECADE	1990-1999	2000-2009	2010-2019
Mean flows	0.461341	0.777316	0.886744

From Table 8, the confidence interval for River Njoro flows for 1990-1999, 2000-20009 and 2010-2019 were 0.461341±0.31267, 0.777316±0.62302 and 0.886744±0.41017 m^3/s, respectively. It means that the range for the flows in 1990-1999 was 0.148671 and 0.774011 m^3/s. The range for 2000-20009 decade was 0.154296 and 1.400336 m^3/s while that one for 2010-2019 was 0.476574 and 1.296914 m^3/s. From these results, it is noted that the minimum flows in the 1990-1999 decade was 0.148671m3/s while that for 2010-2019 decade was 0.476574 m3/s. The huge variation in the flows is informed by the increasing rainfall amounts (see section 4.3.1), indicating that the area has experienced climate change. Furthermore, the changes in land use changes analyzed in section 4.2 helps explain the changing trend in River Njoro flows.

4.3.3 Temperature changes

Table 9 shows the temperature levels that Lake Nakuru area has experienced since 1990. The comprehensive mean monthly values for temperature are attached in the appendices section (see Appendix 3 and 4).

Table 9:Mean annual temperature values (°C) for the Nakuru station values

Year	Min. temp.	Max. temp.	Year	Min. temp.	Max. temp.
1990	10.6	25.2	2005	11.5	26.1
1991	10.6	26.0	2006	12.4	25.7
1992	10.9	25.5	2007	12.0	25.2
1993	10.9	25.8	2008	12.1	25.7
1994	11.4	25.6	2009	12.4	27.0
1995	11.3	25.8	2010	12.7	25.3
1996	11.2	25.6	2011	12.2	25.8
1997	11.5	25.6	2012	11.9	25.6
1998	12.4	25.2	2013	12.2	25.6
1999	11.6	26.0	2014	12.4	26.1
2000	12.0	26.6	2015	12.5	26.7
2001	12.0	25.4	2016	11.6	26.4
2002	11.9	25.8	2017	10.6	26.6
2003	12.0	25.6	2018	10.7	25.7
2004	11.8	25.8	2019	12.0	26.4

The mean annual temperature values were achieved by finding the average of the temperature readings every year during the study period. Figure 15 shows a time series for temperature (both maximum and minimum temperature).

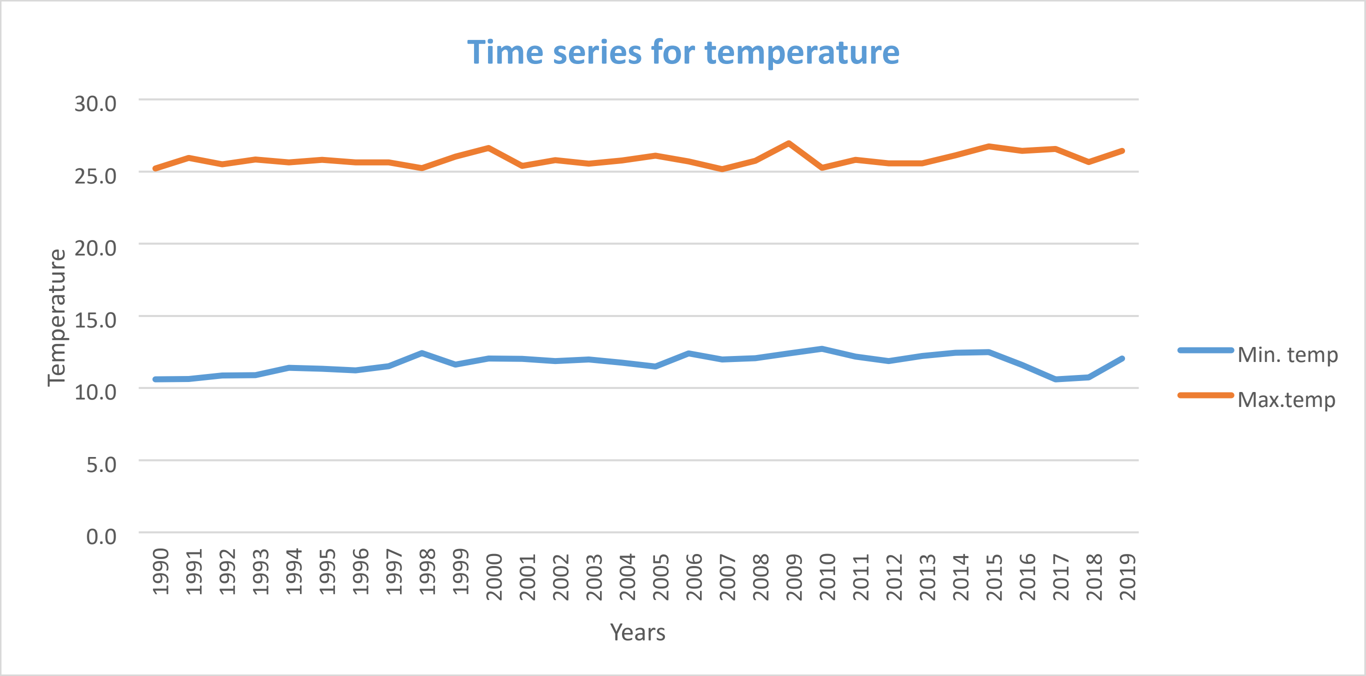


Figure 15:Temperature time series

The maximum temperature values are of more importance because they determine the evapotranspiration rates in an area. From Figure 15, it can be seen that the peak values for maximum temperatures were in the years 2009 and 2000. A closer look at the maximum temperature values of 2013 and 2019 depicts that they were the years with the highest values compared to the prior years. The graph seems to have a large deviation from the 25°C, unlike the other years. 2013-2019 are also the years that experienced the least levels of minimum temperature. High maximum temperature levels coupled with low minimum temperature values indicate high evapotranspiration rates, which increase the amount of moisture in the air and hence lead to an increase in rainfall amounts.

Table 10 below gives the values for annual standard deviation and coefficient of variation for the 30 years period for maximum temperature changes.

Table 10:Standard deviation and coefficient of variation for temperature variation

Year	Annual std. dev	CV	Year	Annual std. dev	CV
1990	0.884	0.035	2005	1.993	0.076
1991	1.683	0.065	2006	1.901	0.074
1992	2.183	0.086	2007	1.292	0.051
1993	1.423	0.055	2008	1.236	0.048
1994	2.300	0.090	2009	1.334	0.049
1995	1.541	0.060	2010	0.976	0.039
1996	1.903	0.074	2011	1.784	0.069
1997	2.304	0.090	2012	1.921	0.075
1998	1.431	0.057	2013	1.505	0.059
1999	1.465	0.056	2014	1.039	0.040
2000	1.795	0.067	2015	1.779	0.067
2001	1.537	0.061	2016	1.651	0.062
2002	1.249	0.048	2017	2.028	0.076
2003	1.872	0.073	2018	1.826	0.071
2004	1.324	0.051	2019	2.299	0.087

From Table 10 above, the annual standard deviation for maximum temperature ranged from 0.884 in 1990 to 2.299 in 2019. The 2.99 value in 2019 shows a huge deviation of maximum temperature values from the mean value for that year. The lowest and largest standard deviation values for the1990-1999 decade ranged from 0.884 in 1990 to 2.304 in 1997, respectively. For the decade 2000-2009 decade, they were 1.236 in 2008 and 1.993 in 2005. For the decade 2010-2019, they ranged from 0.976 in 2010 to 2.299 in 2019. The shift from low standard deviation values of 0.884 in the 1990-1999 decade to high values of 2.299 in the 2010-2019 decade indicate climate change in the area. It means that there is a huge deviation in the maximum temperature values from the mean annual ones in the 2010-2019 decade. High maximum temperature values mean increased evapotranspiration rates, leading to increased water content in the atmosphere, hence high rainfall amounts. The increased rainfall amounts increase runoff leading to flooding of Lake Nakuru. The same case is supported by the inter-annual variation in maxim temperature, indicated by the changing coefficients of variation. The coefficients of variation ranged between 0.035-0.09 in 1990-1999 and 0.048-0.076 in 2000-2009. It ranged between 0.039-0.087 in 2010-2019. There are notable temperature variations from 2010, indicating an increase in the temperature that the area receives, hence implicating the occurrence of climate change.

The confidence interval for the means of maximum temperature of the 3 decades were essential in supporting the change in temperature experienced by the area. Using an alpha value of 0.05, the confidence interval for 1990-1999, 2000-20009 and 2010-2019 were 0.166, 0.32 and 0.285, respectively. Table 11 below gives the mean values for the 3 decades as far maximum temperature is concerned.

Table 11: Mean decade temperature values (°C)

DECADE	1990-1999	2000-2009	2010-2019
Mean max. temp	25.6	25.9	26.0

From Table 11, the confidence interval for 1990-1999, 2000-20009 and 2010-2019 were 25.6±0.166, 25.9±0.32 and 26.0±0.285 °C, respectively. It means that the range for maximum temperature in 1990-1999 was 25.434 and 25.766 °C. The range for 2000-20009 decade was 25.58 and 26.22 °C while that one for 2010-2019 was 25.715 and 26.285 °C. The confidence interval indicates an increasing trend in maximum temperature that the area has been experiencing, with the 2010-2019 decade being the decade that the area experienced the highest temperature among the 3 decades. The shift in the rainfall amount experienced in the area over 30 years depicts climate change. The findings conform to the ones of Oiro et al. (2020), who established 2010-2019 to be the warmest decade in history evidencing climate change. High maximum temperature levels accompanied by low levels of minimum temperature means that there were high evapotranspiration rates between 2010-2019. High evapotranspiration rates lead to increased amounts of rainfall (Odongo et al., 2019).

4.4 Objective 4: Development of a model to predict the surface area variations of Lake Nakuru using Geographic Information Systems

4.4.1 Lake Nakuru water levels

There have been cases of flooding of Lake Nakuru. The data in Table 12 shows the varying water levels of Lake Nakuru. It is presented in terms of the area of the lake over the since 1990.

Table 12: Water levels of Lake Nakuru in surface area coverage (km^2)

Lake Nakuru area (km^2)			
Year	**Area**	**Year**	**Area**
1990	34.85	2006	37.51
1991	32.28	2007	38.12
1992	34.91	2008	39.17
1993	32.18	2009	36.42
1994	32.85	2010	38.86
1995	31.28	2011	42.25
1996	31.58	2012	48.17
1997	32.56	2013	52.88
1998	32.91	2014	55.28
1999	41.41	2015	54.4
2000	37.19	2016	55.68
2001	35.88	2017	55.18
2002	36.16	2018	57.04
2003	37.38	2019	57.83
2004	38.35	2020	62.26

2005	36.51

From the Table 12, it can be seen that Lake Nakuru has been flooding, especially in the last decade. The year that Lake Nakuru experienced the highest water levels was 2020 with a surface area coverage of 62.26 km^2. The lowest water levels were experienced in 1995 at a surface are coverage of 31.28 km^2. The line graph in Figure 16 shows the trend in the rising water levels of the lake since 1990.

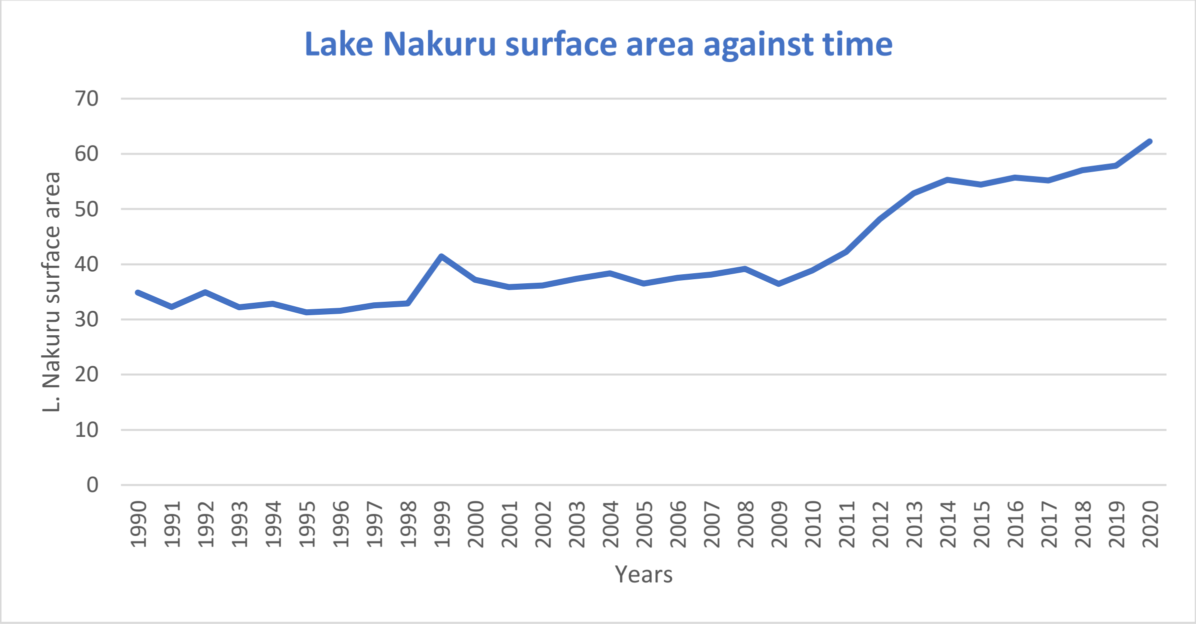


Figure 16: The trend of rising Lake Nakuru water levels

Figure 16 shows a rising trend of the rising water levels. The surface area of the lake which represents its water levels was between 30 km^2 and 40 km^2 in the years 1990-1998. There was a sudden rise in the water levels in 1999 to 41.41 km^2. The trend observed in 2000 to 2010 maintained the level between 30 km^2 and 40 km^2. However, there was a sudden shock in the rising levels from 2010 onwards up to 2020 where the level hit a maximum value of 62.26km^2. The flooding is in agreement with the findings of Osio et al. (2018), who observed a sudden increase in the lake water levels from 2010. Another observation from the graph is that the period 2010-2020 is when the lake experienced high levels of flooding. This is in resonance with the high amount of rainfall and temperatures experienced during the same period. According to Kimaru et al. (2019), the decade from 2010 was wetter with regards to Lake Nakuru than the previous decades. It is therefore, evident that the decade 2010-2019 had the highest amounts of rainfalls, highest amounts of temperature, highest River Njoro flows and a subsequent high levels of Lake Nakuru flooding (see sections 4.1.2, 4.1.3 and 4.2). All these aspects represent the impact of climate change as climatic conditions are not normal with the previous decades. The map in Figure 17 gives an indication of the increment in the water levels of the lake.

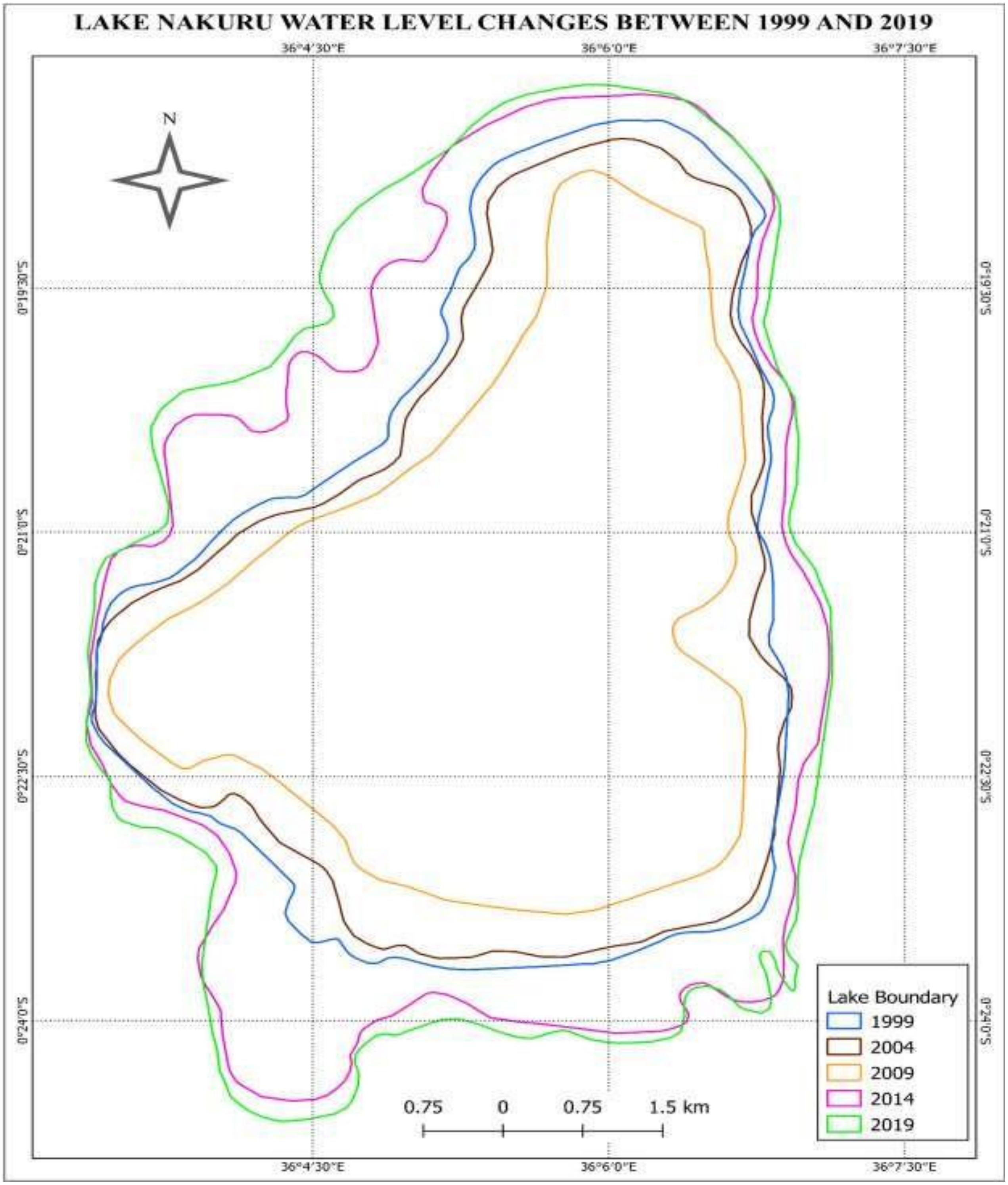


Figure 17: A map showing Lake Nakuru flooding over time

From Figure 17, the lake's area in 2019 represented by the green polygon was the highest among the other years under comparison indicating the highest water levels experienced by the lake. This is in agreement with the 57.83 km^2 area covered by the lake in 2019 (see Table 5). This was followed by the year 2014 represented by the purple polygon, where the lake covered 55.28 km^2. The year 2009, which is represented by the yellow polygon shows that the lake covered 36.42 km^2.The trend shown by this map developed using QGIS is in agreement with the data in Table 12 collected from the Water Resources Authority. The trend shows a continued increase in the lake water levels with an increase in the number of years.

4.4.2 The prediction model

The Table 13 shows the coefficients developed from model development using R software.

Table 13:Model coefficients

	Estimate	**Standard error**	**t value**	**Pr(>|t|)**
Intercept	40.90233	0.50203	81.473	<2e-16
poly(x1,3)1	-1.87230	3.18344	-0.588	0.5630
poly(x1,3)2	0.54709	2.90889	0.188	0.8527
poly(x1,3)3	-0.487155	3.01827	-1.614	0.1222
poly(x2,3)1	-0.65802	3.33687	-0.197	0.8457
poly(x2,3)2	-0.71735	2.88567	-0.059	0.9532
poly(x2,3)3	-6.33860	2.90434	-2.182	0.412
poly(x3,3)1	43.23665	3.00960	14.366	5.32e-12
poly(x3,3)2	17.88745	2.85928	6.256	4.15e-06
poly(x3,3)3	-0.06695	3.12665	-0.021	0.9831

The standard error values from Table 13 are within the range of 0.50203 and 3.33687. The small values of standard error show a small difference between the estimated and true values. The t-values run up to a great value of 81.473, which indicates a high confidence of the output coefficients acting as predictors. The pr |t | values that are greater than the p-value of 6.561e-10 from Table 15 shows a statistically significant relationship between predictor and response variables. From Table 13, x1, x2 and x3 represents mean annual rainfall amounts, mean annual River Njoro flows and years, respectively. The following polynomial regression model was developed to help predict the water levels of Lake Nakuru with time.

$$w = 40.90233 - 1.87230r + 0.54709r^2 - 0.487155r^3 - 0.65802f - 0.17135f^2 - 6.3386f^3 + 43.23665y + 17.88745y^2 - 0.06695y^3 \qquad \text{Equation 4.3}$$

Where:

w-Lake water levels,

r-Mean annual rainfall amounts

f-Mean annual River Njoro flows

y- Years

The prediction interval of the model is 30 years, which is informed by the period of data collection for its variables. A plot of the residuals vs. predicted values of the model is shown in Figure;

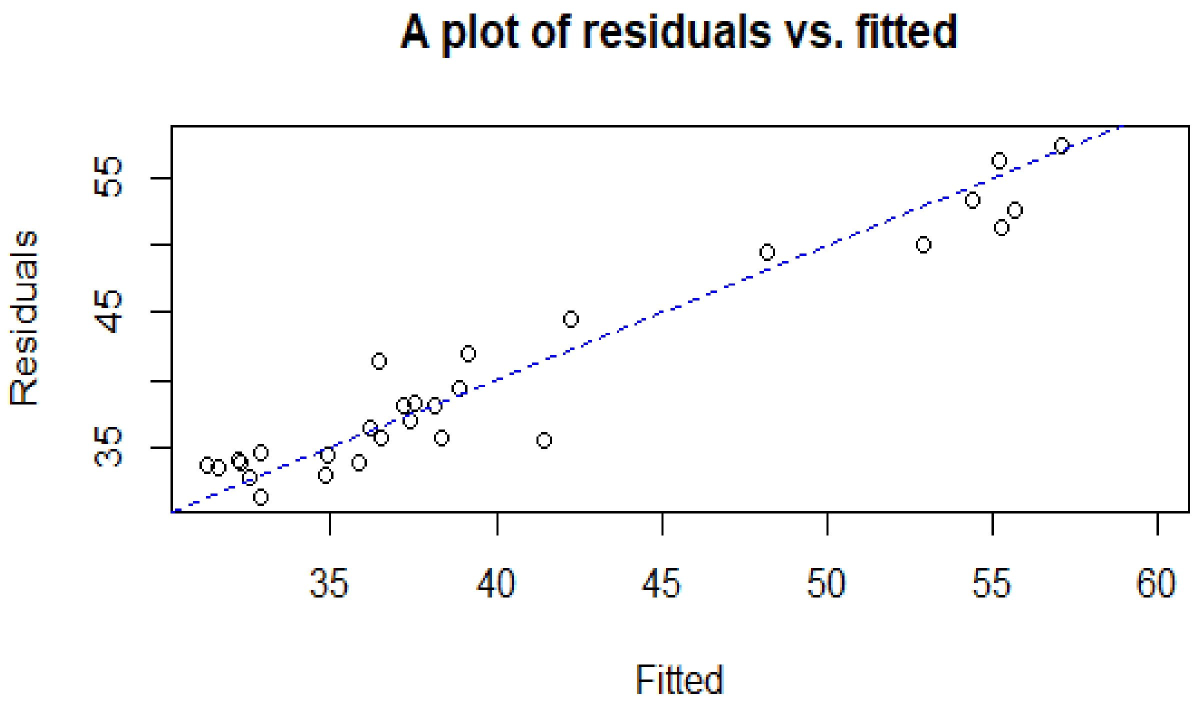


Figure 18:Residuals vs fitted plot

From Figure 18, it is evident that there is no clear pattern amongst the residual, which indicates a random distribution. A random distribution for the plot is a requirement for a good model. Table 14 shows the regression statistics for the model.

Table 14:Regression statistics

Regression Statistics	
R Square	0.9343
Adjusted R Square	0.9048
Residual Error	2.75
Bias	7.1056e-16
Root Mean Square Error (RMSE)	3.8918e-15
Nash and Sutcliffe Efficiency (NSE)	0.934
Observations	30

From Table 14, an R^2 value of 0.9343 means that the model has high predictive ability and can be used to predict the lake's water level since it is a value that is close to 1. An adjusted R^2 value of 0.9048 indicates the predictors in the model add significantly to its predictive power. A 2.75 value for the standard error shows a better fit of the polynomial regression model to the data. The Nash and Sutcliffe efficiency of the model is 0.934 indicating a strong predictive ability of the model. Furthermore, the low bias value of 7.1056e-16 indicates that the model closely matches the data and there is a very low error rate. A very low Root Mean Square Value (RMSE) of 3.8918e-15 indicates a better fit of the model. Therefore, the developed model has a better fit and high predictive power and can be used to predict the water levels of the lake over time.

4.5 Summary of findings

Climate change is a major contributor to the rising water levels of Lake Nakuru. There is a huge variation of rainfall amounts from 2010, which is supported by large standard deviations, inter-annual variations and negative autocorrelation values for the 2010-2019 rainfall data compared to other decades. High rainfall amounts in the 2010-2019 decade, together with land use changes led to increased River Njoro flows within the same decade. The highest river flows were experienced in the 2010-2019 decade averaging a value of 0.8867 m^3/s. This was a large shift from the 0.46134 m^3/s flows experienced in the decade 1990-1999. There was a variation in the temperature levels experienced in the area within the 2010-2019 decade, when compared to other decades. There were high levels of maximum temperature experienced within the 2010-2019 decade, which resulted to a mean decade value of 26°C compared to 25.9°C of 2000-2009 and 25.6°C of 1990-1999. Increased maximum temperature values means that there were high levels of evapotranspiration in the area, which is attributed to the high rainfall amounts in the area because of the high levels of water in the atmosphere. These changes were evidenced by the inter annual variations, changing annual standard deviation and the lack of series autocorrelation when the data for the three decades was compared. The changes in rainfall amounts, River Njoro flows and temperature were indicators that climate change had taken place in the area. A polynomial regression model was developed, which can used to predict Lake Nakuru water levels. The development of the model was necessitated by the third research question that sort to find out how well the lake's water levels can be predicted. An R2, bias, RMSE and NSE values of 0.9343, 7.1056e-16, 3.8918e-15 and 0.934, respectively were an indication of its high predictive ability.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

There has been a change in rainfall amounts experienced by the area over the 3 decades. The average rainfall values for the 1990-1999, 2000-2009 and 2010-2019 decades were determined to be 73.7mm, 78.7mm and 86.6mm, respectively. The rainfall annual standard deviation ranged from 27.49 in 1993 to 86.84 in 2018. The shift from low standard deviation values of 27.49 in the 1990-1999 decade to high values of 86.84 in the 2010-2019 decade indicate climate change in the area. The high inter-annual variation in rainfall amounts between 2010-2019 was indicated by the 0.502-0.83 coefficient of variation values. These figures show a shift from the 0.454-0.594 CV values for the 1990-1999 decade. Furthermore, there was negative series autocorrelation for rainfall values in the 2010-2019 decade compared to the previous decades.

There were changes in River Njoro flows over the 3 decades of study. The lowest and largest standard deviation values for the flows for 1990-1999, 2000-2009 and 2010-2019 decades ranged from 0.075297-1.526751, 0.016594-6.132541 and 0.019659-2.253391, respectively. The variation is an indicator of changing flows of the river as a result of the changing rainfall amounts. The coefficients of variation (CV) ranged between for 1990-1999, 2000-2009 and 2010-2019 were 0.982452-1.761088, 0.423009-1.852215 and 0.426147-2.576846, respectively. There were large variations in the River Njoro flows as from 2010 because of the variation in rainfall amounts that the area received from that year leading to an increase in the runoff volumes, hence the flooding of the lake. There was a negative correlation in flows for the 2010-209 decade from the other decades, indicating a change in the river flows. There was evidence of a change in land use practice that contributed to the change. The increased tree cover loss in East Mau, which is River Njoro's catchment supports the change in the flows.

The change in rainfall, River Njoro flows and temperature are indicators of climate change in the area. The rainfall amounts confidence interval for 1990-1999, 2000-20009 and 2010-2019 were 73.7±6.94, 78.7±9.88 and 86.6±10.4 mm, respectively. This meant that the range for rainfall amounts in 1990-1999 was 66.76-80.64 mm while that for 2000-20009 was 68.82-88.58mm. The one for 2010-2019 was 76.2-97mm. The results indicated an increasing trend in the amount of rainfall that the area has been receiving, indicating climate change. The confidence interval for River Njoro flows for 1990-1999, 2000-20009 and 2010-2019 were 0.461341±0.31267, 0.777316±0.62302 and 0.886744±0.41017 m^3/s, respectively. The results mean that the ranges for the flows in 1990-1999, 2000-2009 and 2010-2019 were 0.148671-0.774011, 0.154296-1.400336 and 0.476574-1.296914 m^3/s, respectively. The variation in the flows is informed by the increasing rainfall amounts, indicating that the area has experienced climate change. Furthermore, the confidence interval for maximum temperature for 1990-1999, 2000-20009 and 2010-2019 were 25.6±0.166, 25.9±0.32 and 26.0±0.285 °C, respectively. The range for maximum temperature in 1990-1999, 2000-20009 and 2010-2019 were 25.434 and 25.766, 25.58-26.22 and 25.715-26.285 °C. The results indicate an increasing trend in maximum temperature that the area has been experiencing, with the 2010-2019 decade being the decade that the area experienced the highest temperature among the 3 decades. The changes in the three indicators confirm that climate change has taken place in the area, which has had an effect on the flooding of Lake Nakuru.

Finally, the highest and lowest water levels of Lake Nakuru were 62.26km^2 and 31.28km^2 experienced in 2020 and 1995 respectively. The areas of the lake between 1990 -2010 were averagely between 30 and 40km^2. It was established that the water levels from 2010-2020 exceeded the average values, which is in correspondence with the decade that the area received the highest rainfall amounts, highest maximum and lowest minimum temperature. The prediction model shown in Equation 5.1 was established to predict the water levels of the lake.

$$w = 40.90233 - 1.87230r + 0.54709r^2 - 0.487155r^3 - 0.65802f - 0.17135f^2 - 6.3386f^3 + 43.23665y + 17.88745y^2 - 0.06695y^3 \quad \text{Equation 5.1}$$

Where; w-Lake water levels, r-mean annual rainfall amounts, f-mean annual River Njoro flows and y- years. The model's R^2 and Nash and Sutcliffe efficiency values were 0.9343 and0.934, indicating that the model has high predictive ability and can be used to predict the lake's water level since it is a value that is close to 1. The model is key in ensuring that future water levels can be predicted and the information relayed for people to come up with mitigation measures aimed at either reducing or eradicating any impacts. The results are also crucial in justifying any measures taken by the relevant authorities to save the environment in the area. Therefore, it forms a basis for policy change regarding safeguarding the environment.

6.2 Recommendations

From the results of this research, the following recommendations are made:

- There has to be continuous monitoring, recording and analysis of the meteorological parameters (rainfall and temperature) within the area to help in the assessment of any variability or change from the normal patterns
- Watershed management to help minimize any human factors that contribute to a change in the lake's feeder river's flows, an example being sediment management

- An acknowledgement of the connection between the lake water levels and the watershed calls for a coordinated management of the lake and the natural resources connected to it, through involvement of relevant stakeholders
- Other indicators of climate change in the area need to be assessed
- A lake balance model should be developed using a watershed/catchment-based model like SWAT (Soil Water Assessment Tool) using the latest bathymetry survey to help in investigating whether hydrometeorological data confirms the variability in lake water levels like the developed model in this study

REFERENCES

Albertazzi, S., Bini, V., Lindon, A., & Trivellini, G. (2018). Relations of power driving tropical deforestation: a case study from the Mau Forest (Kenya). *Belgeo. Revue belge de géographie*, (2).

Al-Juboori, A. M. (2019). Generating monthly stream flow using nearest river data: assessing different trees models. *Water Resources Management*, *33*(9), 3257-3270.

Ampting, R. (2023). Rising lakes in the Kenyan Rift Valley. Lake Nakuru flooding: An analysis of the impact of spatial-temporal variability of precipitation and changes in moisture source and climate drivers.

Bowman, M., & Minas, S. (2019). Resilience through interlinkage: the green climate fund and climate finance governance. *Climate policy*, *19*(3), 342-353.

Cahill, A. E., Aiello-Lammens, M. E., Fisher-Reid, M. C., Hua, X., Karanewsky, C. J., Yeong Ryu, H., ... & Wiens, J. J. (2013). How does climate change cause extinction?. *Proceedings of the Royal Society B: Biological Sciences*, *280*(1750), 20121890.

Chaudhry, S. (2019). Politics of land excisions and climate change in the Mau Forest Complex: A case study of the South-Western Mau Forest. *Journal of Sustainability, Environment and Peace*, *1*(2), 52-62.

Chemoiwa, E. J., Oyoo-Okoth, E., Mugo-Bundi, J., Njenga, E. W., Matany, E. C., Korir, R. J., & Ngugi, C. C. (2015). Elemental ratios (C: N) and stable isotopic composition of dominant rotifer species in a tropical eutrophic alkaline–saline Lake Nakuru (Kenya). *Hydrobiologia*, *747*(1), 97110.

Chicco, D., Warrens, M. J., & Jurman, G. (2021). The coefficient of determination R-squared is more informative than SMAPE, MAE, MAPE, MSE and RMSE in regression analysis evaluation. *PeerJ Computer Science*, *7*, e623.

Choi, D., Gao, Z., & Jiang, W. (2020). Attention to global warming. *The Review of Financial Studies*, *33*(3), 1112-1145.

Chrisphine, O. M., Odhiambo, A. M., & Boitt, K. M. (2016). Assessment of hydrological impacts of Mau Forest, Kenya. *Hydrology: Current Research*, *7*(1).

Colman, R., & Soden, B. J. (2021). Water vapor and lapse rate feedbacks in the climate system. *Reviews of Modern Physics*, *93*(4), 045002.

Cooke, G. D., Welch, E. B., Peterson, S., & Nichols, S. A. (2016). *Restoration and management of lakes and reservoirs*. CRC press.

Dimitrov, R. S. (2016). The Paris agreement on climate change: Behind closed doors. *Global environmental politics*, *16*(3), 1-11.

Di Virgilio, G., Evans, J. P., Blake, S. A., Armstrong, M., Dowdy, A. J., Sharples, J., & McRae, R. (2019). Climate change increases the potential for extreme wildfires. *Geophysical Research Letters*, *46*(14), 8517-8526.

El-Hadidy, S. M. (2020). Monitoring shoreline changes and aeolian sand encroachment, Nasser Lake, Egypt, using remote sensing and GIS techniques. *Arabian Journal of Geosciences*, *13*(24), 1-14.

FAO (2010). Managing forests for climate change. Available at www.fao.org/3/i1960e/i1960e00.pdf

Federici, S., Tubiello, F. N., Salvatore, M., Jacobs, H., & Schmidhuber, J. (2015). New estimates of CO_2 forest emissions and removals: 1990–2015. *Forest Ecology and Management*, *352*, 89-98.

Feyisa, G. L., Meilby, H., Fensholt, R., & Proud, S. R. (2014). Automated Water Extraction Index: A new technique for surface water mapping using Landsat imagery. *Remote sensing of environment*, *140*, 23-35.

Fisher, A., Flood, N., & Danaher, T. (2016). Comparing Landsat water index methods for automated water classification in eastern Australia. *Remote Sensing of Environment*, *175*, 167-182.

Gao, H., Bohn, T. J., Podest, E., McDonald, K. C., & Lettenmaier, D. P. (2011). On the causes of the shrinking of Lake Chad. *Environmental Research Letters*, *6*(3), 034021.

Gharehbaghi, K., & Scott-Young, C. (2018, March). GIS as a vital tool for Environmental Impact Assessment and Mitigation. In *IOP Conference Series: Earth and Environmental Science* (Vol. 127, No. 1, p. 012009). IOP Publishing.

Gomeseria, R. (2019). Importance of Remote Sensing & Monitoring in Engineering Projects. *Available at SSRN 3926465*.

Grafton, R. Q., Pittock, J., Davis, R., Williams, J., Fu, G., Warburton, M., ... & Quiggin, J. (2013). Global insights into water resources, climate change and governance. *Nature Climate Change*, *3*(4), 315-321.

Herrnegger, M., Stecher, G., Schwatke, C., & Olang, L. (2021). Hydroclimatic analysis of rising water levels in the Great rift Valley Lakes of Kenya. *Journal of Hydrology: Regional Studies*, *36*, 100857.

Hongo, P. O., & Mulaku, G. C. (2021). Flooding of Lake Nakuru National Park and Its Effects on the Resident Wildlife. *Journal of Geographic Information System*, *13*(6), 660-670.

Hotz, H. M., & Christian, A. D. (2015). Using GIS and Remote Sensing to Analyze Lake Level Rise of Étang Saumâtre, Haiti. *International Journal of Geospatial and Environmental Research*, *2*(1), 6.

Iradukunda, P., Sang, J. K., Nyadawa, M. O., & Maina, C. W. (2020). Sedimentation effect on the storage capacity in lake Nakuru, Kenya. *Journal of Sustainable Research in Engineering*, *5*(3), 149-158.

Iradukunda, P., Sang, J. K., Nyadawa, M. O., & Maina, C. W. (2020). Sedimentation effect on the storage capacity in lake Nakuru, Kenya. *Journal of Sustainable Research in Engineering*, *5*(3), 149-158.

Iradukunda, P., & Nyadawa, M. O. (2021). Impact of Sedimentation on Water Seepage Capacity in Lake Nakuru, Kenya. *Applied and Environmental Soil Science*, *2021*.

Isupova, M. V. (2019). The effects of the Ili River runoff and water regulation function of the delta on the changing water level of Balkhash Lake depending on the delta forest coverage. *Water Resources*, *46*(1), S29-S42.

Jebiwott, A., Ogendi, G. M., Agbeja, B. O., Alo, A. A., & Kibet, R. (2021). Mapping the trends of forest cover change and associated drivers in Mau Forest, Kenya. *Remote Sensing Applications: Society and Environment*, *23*, 100586.

Jenkins M., McCord S. and Edebe J. (2009). Sustaining lake levels in Lake Nakuru, Kenya: Development of a water balance model for decision making. *Global livestock CRSP, University of California-Davis.*

Juma, S. G., & Kelonye, F. (2016). Projected rainfall and temperature changes over Bungoma county in western Kenya by the year 2050 based precise modeling system. *Ethiopian Journal of Environmental Studies and Management*, *9*(5), 625-640.

Keli, M. M. (2022). Analysis of spatial and seasonal variations of water quality using statistical, CCME-WQI and GIS methods in Nakuru municipality, Kenya (*Doctoral dissertation, University of Eldoret*).

Kenya, L. O. (2013). *The constitution of Kenya: 2010*. Chief Registrar of the Judiciary.

Keys, T. A., & Scott, D. T. (2018). Monitoring volumetric fluctuations in tropical lakes and reservoirs using satellite remote sensing. *Lake and Reservoir Management*, *34*(2), 154-166.

Kinyanjui, M. J. (2009). The effect of human encroachment on forest cover, composition and structure in the western blocks of the Mau forest complex. *Department of Natural Resources (Forestry) of Egerton University, Egerton University. Doctor of Philosophy Degree*.

Kimaru, A. N., Gathenya, J. M., & Cheruiyot, C. K. (2019). The temporal variability of rainfall and streamflow into lake Nakuru, Kenya, assessed using SWAT and hydrometeorological indices. *Hydrology*, *6*(4), 88.

Kogo, B. K., Kumar, L., & Koech, R. (2021). Climate change and variability in Kenya: a review of impacts on agriculture and food security. *Environment, Development and Sustainability*, *23*(1), 23-43.

Kolleck, N., Well, M., Sperzel, S., & Jörgens, H. (2017). The power of social networks: how the UNFCCC secretariat creates momentum for climate education. *Global Environmental Politics*, *17*(4), 106-126.

Koutsoyiannis, D. (2020). Revisiting the global hydrological cycle: is it intensifying?. *Hydrology and Earth System Sciences*, *24*(8), 3899-3932.

Kulkarni, S., Dhakar, K., & Joshi, A. (2019). Alkaliphiles: diversity and bioprospection. In *Microbial diversity in the genomic era* (pp. 239-263). Academic Press.

Kweku, D. W., Bismark, O., Maxwell, A., Desmond, K. A., Danso, K. B., Oti-Mensah, E. A., ... & Adormaa, B. B. (2017). Greenhouse effect: Greenhouse gases and their impact on global warming. *Journal of Scientific research and reports*, 1-9.

Kweyu, R. M., Thenya, T., Kiemo, K., & Emborg, J. (2020). The nexus between land cover changes, politics and conflict in Eastern Mau forest complex, Kenya. *Applied Geography*, *114*, 102115.

Lin, F., Chen, X., & Yao, H. (2017). Evaluating the use of Nash-Sutcliffe efficiency coefficient in goodness-of-fit measures for daily runoff simulation with SWAT. *Journal of Hydrologic Engineering*, *22*(11), 05017023.

Lindsey, R., & Dahlman, L. (2020). Climate change: Global temperature. *Climate. gov*, *16*.

Louman, B., Keenan, R. J., Kleinschmit, D., Atmadja, S., Sitoe, A. A., Nhantumbo, I., ... & Morales, J. P. (2019). SDG 13: Climate action—impacts on forests and people. *Sustainable development goals: their impacts on forests and people*, 419-444.

Mashee, F. K., Ali, A. R. B., & Jasim, M. S. (2020). Spatial monitoring for degradation AlRazzaza Lake by analysis temporal of remote sensing data using geographic information system techniques. *J Biosci*, *14*, 4777-4781.

Mbote, B. W. (2016). *Assessing the impacts of climate variability and climate change on biodiversity in Lake Nakuru, Kenya* (Doctoral dissertation, University of Nairobi).

Moinani, A. M., & Barasa, M. N. (2021). Language and ecology: a systemic functional grammar analysis of the Mau forest conservation in Kenya. *European Journal of Applied Linguistics Studies*, *3*(2).

Mureithi. F. (2021). *Kenya: Why Lake Nakuru Water Levels Keep Rising*. allAfrica.com. Retrieved 22 July

2021, from https://allafrica.com/stories/202011160326.html#:~:text=Since%202012%2C%20the%20water%20levels,significant%20increase%20in%20lake%20area.

Mutua, B. M., & Klik, A. (2007). Predicting daily streamflow in ungauged rural catchments: the case of Masinga catchment, Kenya. *Hydrological sciences journal*, *52*(2), 292-304.

Mutune, J. M., Hansen, C. P., Wahome, R. G., & Mungai, D. N. (2017). What rights and benefits? The implementation of participatory forest management in Kenya: The case of Eastern Mau Forest Reserve. *Journal of sustainable forestry*, *36*(3), 230-249.

Mwaniki, S. K. (2016). *The Role of the Kenya Forest Service in the Management of Land Degradation and Environmental Conflict in the Mau Forest Complex* (Doctoral dissertation, University of Nairobi).

Nathan, R. J., McMahon, T. A., Peel, M. C., & Horne, A. (2019). Assessing the degree of hydrologic stress due to climate change. *Climatic Change*, *156*(1), 87-104.

Nerini, F. F., Sovacool, B., Hughes, N., Cozzi, L., Cosgrave, E., Howells, M., ... & Milligan, B.

(2019). Connecting climate action with other Sustainable Development Goals. *Nature Sustainability*, *2*(8), 674-680.

Nyashina, G. S., Vershinina, K. Y., Shlegel, N. E., & Strizhak, P. A. (2019). Effective incineration of fuel-waste slurries from several related industries. *Environmental research*, *176*, 108559.

Nyeko, M. (2015). Hydrologic modelling of data scarce basin with SWAT model: capabilities and limitations. *Water Resources Management*, *29*, 81-94.

Odongo, V. O., van Oel, P. R., van der Tol, C., & Su, Z. (2019). Impact of land use and land cover transitions and climate on evapotranspiration in the Lake Naivasha Basin, Kenya. *Science of the total environment*, *682*, 19-30.

Oiro, S., Comte, J. C., Soulsby, C., MacDonald, A., & Mwakamba, C. (2020). Depletion of groundwater resources under rapid urbanisation in Africa: recent and future trends in the Nairobi Aquifer System, Kenya. *Hydrogeology Journal*, *28*, 2635-2656.

Onyango, H. P. (2020). *Mapping The Flooding Of Lake Nakuru National Park And Its Effects On Resident Wildlife* (Doctoral dissertation, University of Nairobi).

Osio, A., Lefèvre, S., Ogao, P., & Ayugi, S. (2018, June). OBIA-based Monitoring of Riparian Vegetation Applied to the Identification of Degraded Acacia Xanthophloea along Lake Nakuru, Kenya. In *GEOBIA 2018-From pixels to ecosystems and global sustainability* (pp. 18-22).

Ouédraogo, W. A. A., Raude, J. M., & Gathenya, J. M. (2018). Continuous modeling of the Mkurumudzi River catchment in Kenya using the HEC-HMS conceptual model: Calibration, validation, model performance evaluation and sensitivity analysis. *Hydrology*, *5*(3), 44.

Ouma, Y. O., & Tateishi, R. (2006). A water index for rapid mapping of shoreline changes of five East African Rift Valley lakes: an empirical analysis using Landsat TM and ETM+ data. *International Journal of Remote Sensing*, *27*(15), 3153-3181.

Pal, S., & Ghosh, R. (2023). Resolution effects on ox-bow lake mapping and inundation consistency analysis in moribund deltaic flood plain of India.

Porter, J. R., Challinor, A. J., Henriksen, C. B., Howden, S. M., Martre, P., & Smith, P. (2019). Invited review: Intergovernmental Panel on Climate Change, agriculture, and food—A case of shifting cultivation and history. *Global change biology*, *25*(8), 2518-2529.

Qiu, J. (2018). World Meteorological Organization: scaling the peaks for social benefits. *National Science Review*, *5*(6), 947-952.

Raudkivi, A. J. (2013). *Hydrology: An advanced introduction to hydrological processes and modelling*. Elsevier.

Sayer, J., Sheil, D., Galloway, G., Riggs, R. A., Mewett, G., MacDicken, K. G., ... & Edwards, D. P. (2019). SDG 15 Life on land–the central role of forests in sustainable development. In *Sustainable Development Goals: Their Impacts on Forest and People* (pp. 482-509).

Cambridge University Press.

Schleiss, A. J., Franca, M. J., Juez, C., & De Cesare, G. (2016). Reservoir sedimentation. *Journal of Hydraulic Research*, *54*(6), 595-614.

Tongwane, M. I., & Moeletsi, M. E. (2018). A review of greenhouse gas emissions from the agriculture sector in Africa. *Agricultural Systems*, *166*, 124-134.

Twumasi, Y. A., Merem, E. C., Namwamba, J. B., Asare-Ansah, A. B., Annan, J. B., Ning, Z. H., ... & McClendon-Peralta, J. (2022). Flood Mapping in Mozambique Using Copernicus Sentinel-2 Satellite Data. *Advances in Remote Sensing*, *11*(3), 80.

Voiland A, Stevens J. (2021). Lake Victoria's rising water levels. Available at: https://earthobservatory.nasa.gov/images/148414/lake-victorias-rising-waters

WHO. (2016). *Climate and health country profile 2015: France* (No.

WHO/FWC/PHE/EPE/15.36).

Xu, R., Yu, P., Abramson, M. J., Johnston, F. H., Samet, J. M., Bell, M. L., ... & Guo, Y. (2020). Wildfires, global climate change, and human health. *New England Journal of Medicine*, *383*(22), 2173-2181.

Zeppetello, L. R. V., Parsons, L. A., Spector, J. T., Naylor, R. L., Battisti, D. S., Masuda, Y. J.,

& Wolff, N. H. (2020). Large scale tropical deforestation drives extreme warming. *Environmental Research Letters*, *15*(8), 084012.

Zeybek, M. (2018). Nash-Sutcliffe efficiency approach for quality improvement. *J. Appl. Math. Comput*, *2*, 496-503.

APPENDICES

Appendix 1: Tree cover loss in Mau East

Year	Tree cover loss (000's ha)	Year	Tree cover loss (000's ha)	Year	Tree cover loss (000’s ha)
1990	0.1	2000	0.2	2010	1.5
1991	0.4	2001	1.25	2011	0.9
1992	0.5	2002	3.1	2012	0.6
1993	0.2	2003	0.3	2013	0.2
1994	0.3	2004	1.4	2014	0.15
1995	0.3	2005	0.7	2015	0.5
1996	0.2	2006	1.9	2016	0.6
1997	0.3	2007	1.1	2017	0.9
1998	0.2	2008	0.6	2018	0.85
1999	0.3	2009	0.5	2019	0.4

Appendix 2: Land cover trends of forests and cropland

Land cover trends for cropland and forests				
	Within the buffer zone		Within the gazetted forest zone	
Year	Cropland area (ha)	Forest area (ha)	Cropland area (ha)	Forest area (ha)
1990	0	55	28	13
2000	9.2	32	37	10
2010	9.1	34	40	12
2016	15	33	41	14

Appendix 3: Mean annual minimum temperature for Nakuru (^{o}C)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Mean annual Min. temp.
1990	9.0	11.1	11.9	12.8	11.8	10.3	10.3	10.9	9.4	9.9	10.1	9.8	10.6
1991	10.0	10.1	11.0	11.6	12.6	11.5	11.4	10.3	9.5	9.6	9.6	10.2	10.6
1992	10.0	10.9	11.2	12.4	11.7	11.8	10.9	11.1	10.1	10.6	9.2	10.6	10.9
1993	11.0	10.6	9.2	10.9	12.6	12.3	11.9	10.4	10.3	10.2	10.7	10.5	10.9
1994	10.3	10.8	12.0	13.1	11.9	12.2	11.7	11.5	9.9	10.3	12.2	10.8	11.4
1995	9.9	11.0	12.0	12.5	12.6	12.3	11.7	11.3	11.4	11.0	11.0	9.2	11.3
1996	9.6	11.7	11.8	12.1	13.0	12.9	11.5	11.0	10.5	10.1	10.8	9.7	11.2
1997	10.0	9.5	11.1	13.4	11.3	11.8	11.6	10.6	9.5	12.4	13.4	13.6	11.5
1998	13.4	11.9	12.5	13.9	14.4	12.3	12.7	12.1	11.6	11.9	10.3	12.1	12.4
1999	10.4	9.7	12.6	12.6	12.0	11.9	11.9	12.1	11.3	11.7	12.1	11.2	11.6
2000	10.9	10.5	12.0	13.4	13.0	12.7	13.1	12.1	11.7	12.0	11.9	11.2	12.0
2001	12.8	11.0	12.4	13.4	13.1	12.0	11.9	11.7	10.5	11.9	12.4	11.0	12.0
2002	11.7	10.9	12.4	12.9	12.8	11.5	11.1	12	10.5	11.5	12.6	12.6	11.9
2003	10.3	11.1	11.8	13.4	13.9	13.1	12.4	12.4	11.2	11.4	12.2	10.5	12.0
2004	11.7	12.3	12.2	13.6	12.1	11.5	11.1	11.6	11.4	11.1	11.3	11.2	11.8
2005	10.7	10.7	12.3	12.3	12.9	11.8	11.2	12.0	11.9	11.0	10.9	10.2	11.5
2006	10.6	10.7	12.8	13.5	13.4	12.1	12.8	12.2	12.2	12.0	13.3	13.4	12.4
2007	12.0	12.2	11.3	12.7	13.2	13.4	12.3	12.1	11.8	10.5	11.3	10.8	12.0
2008	10.9	11.5	12.5	12.2	12.2	12.7	12.7	12.6	12.1	12.4	12.2	10.8	12.1
2009	11.2	11.8	12.5	13.3	13.1	11.6	12.0	12.7	12.4	13.3	12.3	12.7	12.4
2010	12.2	13.5	13.4	13.8	13.9	12.9	12.7	12.8	12.1	12.8	11.5	10.9	12.7
2011	10.8	11.1	12.5	12.3	12.6	13.1	11.9	12.6	12.2	12.2	13.3	11.5	12.2
2012	9.0	10.3	11.4	13.9	13.2	12.9	12.4	12.0	11.6	12.0	11.6	12.0	11.9
2013	11.8	11.2	12.3	13.3	12.6	12.6	12.1	12.1	12.2	11.7	12.3	12.3	12.2
2014	10.9	12.7	12.6	12.1	13.5	13.2	12.7	12.4	11.6	12.9	12.7	12.1	12.4
2015	10.6	12.1	12.1	14.0	14.1	13.5	11.4	11.9	11.8	13.0	13.2	12.2	12.5
2016	12.9	12.2	12.7	13.8	13.0	11.4	11.7	10.8	10.3	10.2	10.4	9.9	11.6
2017	8.7	10.6	11.1	11.3	12.5	11.1	11.7	10.8	10.6	9.9	9.9	8.8	10.6
2018	9.4	9.1	11.9	13.2	12.7	12.0	10.9	10.7	9.4	10.0	9.5	10.1	10.7
2019	8.9	8.9	9.2	12.2	13.4	14.1	12.7	12.1	12.5	13.0	13.6	13.9	12.0

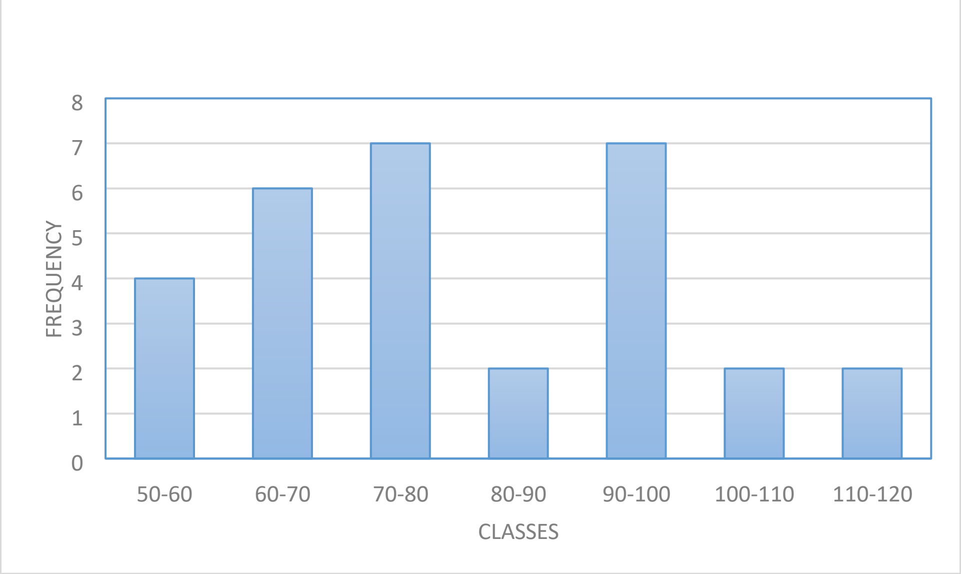
Appendix 4: Mean annual maximum temperature for Nakuru (^{o}C)

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Aug	Nov	Dec	Mean annual Max. temp.
1990	25.7	27.2	24.9	24.4	24.6	24.6	24.6	24.4	26.6	25.8	24.6	25.2	25.2
1991	27.7	29.3	28.3	25.3	25.5	25.0	22.9	24.9	26.0	25.5	24.6	26.4	26.0
1992	28.3	28.8	29.5	27.0	24.6	24.7	22.7	23.3	24.5	24.3	24.1	24.2	25.5
1993	23.7	25.7	28.4	26.9	25.8	23.9	23.8	25.3	26.8	27.3	25.7	26.7	25.8
1994	28.9	29.2	28.9	26.5	24.6	23.9	22.9	23.7	26.0	25.5	22.0	25.5	25.6
1995	28.6	28.6	26.7	26.6	25.4	26.1	23.3	25.4	25.3	24.3	24.7	24.8	25.8
1996	27.8	28.8	27.9	26.7	25.5	22.8	23.0	24.3	25.0	25.5	23.6	26.7	25.6
1997	28.3	29.8	29.2	24.6	24.7	24.5	23.1	24.5	27.6	24.7	22.9	23.8	25.6
1998	24.0	26.9	28.1	26.9	25.3	23.4	23.4	24.7	25.7	25.8	24.3	24.3	25.2
1999	28.0	29.3	27.1	26.0	25.2	26.0	24.3	24.4	26.2	26.4	24.4	25.1	26.0
2000	28.4	29.4	29.6	27.7	27.2	25.8	24.4	24.1	26.1	26.4	24.4	26.2	26.6
2001	26.1	28.9	27.3	24.1	25.0	23.9	23.8	24.6	25.7	25.9	23.4	26.0	25.4
2002	26.3	28.9	27.1	25.4	25.0	24.7	25.4	24.7	26.8	25.9	24.9	24.4	25.8
2003	26.3	29.2	29.2	26.2	24.1	23.8	23.9	23.3	25.3	25.3	24.4	25.7	25.6
2004	26.7	27.6	28.4	25.2	25.5	23.8	25.0	25.2	26.3	24.9	24.0	26.5	25.8
2005	28.2	29.9	28.8	26.9	24.5	24.4	23.2	24.6	24.7	25.4	25.3	27.4	26.1
2006	27.8	29.9	27.7	24.9	24.4	24.7	24.0	24.8	26.4	26.6	23.3	23.9	25.7
2007	25.9	26.5	27.7	26.1	25.0	23.5	23.1	23.6	24.8	25.3	24.7	25.9	25.2
2008	27.1	28.1	27.8	25.5	25.7	25.4	24.4	24.6	25.8	24.3	24.6	25.9	25.7
2009	27.5	28.9	30.1	27.0	25.7	26.1	26.1	27.0	27.7	25.9	25.9	25.7	27.0
2010	26.2	27.1	25.6	25.4	24.9	24.3	24.0	24.2	24.9	24.9	24.7	26.9	25.3
2011	28.1	29.3	28.4	26.9	25.4	25.0	24.7	23.8	24.6	24.5	24.2	24.8	25.8
2012	27.9	28.3	29.5	26.1	23.9	23.8	23.1	24.1	25.2	25.3	24.6	25.0	25.6
2013	26.7	28.5	28.4	25.1	25.0	24.1	24.1	23.9	25.7	25.9	24.7	24.7	25.6
2014	27.7	27.5	28.0	26.4	25.8	25.1	24.9	25.1	26.0	26.0	25.0	26.1	26.1
2015	28.5	30.0	29.7	26.3	24.9	25.0	25.6	27.1	27.4	26.5	24.6	25.2	26.7
2016	26.5	28.7	30.2	27.0	25.2	25.2	24.4	24.5	26.7	26.9	25.1	26.7	26.4
2017	28.9	29.2	30.2	28.4	24.9	26.6	24.7	24.5	24.7	25.5	24.3	26.9	26.6
2018	27.9	29.9	25.9	24.1	24.1	23.6	23.2	24.7	26.0	26.0	26.4	26.0	25.7
2019	28.2	29.7	30.3	29.7	26.5	24.3	24.2	24.4	26.1	24.7	25.1	24.1	26.4

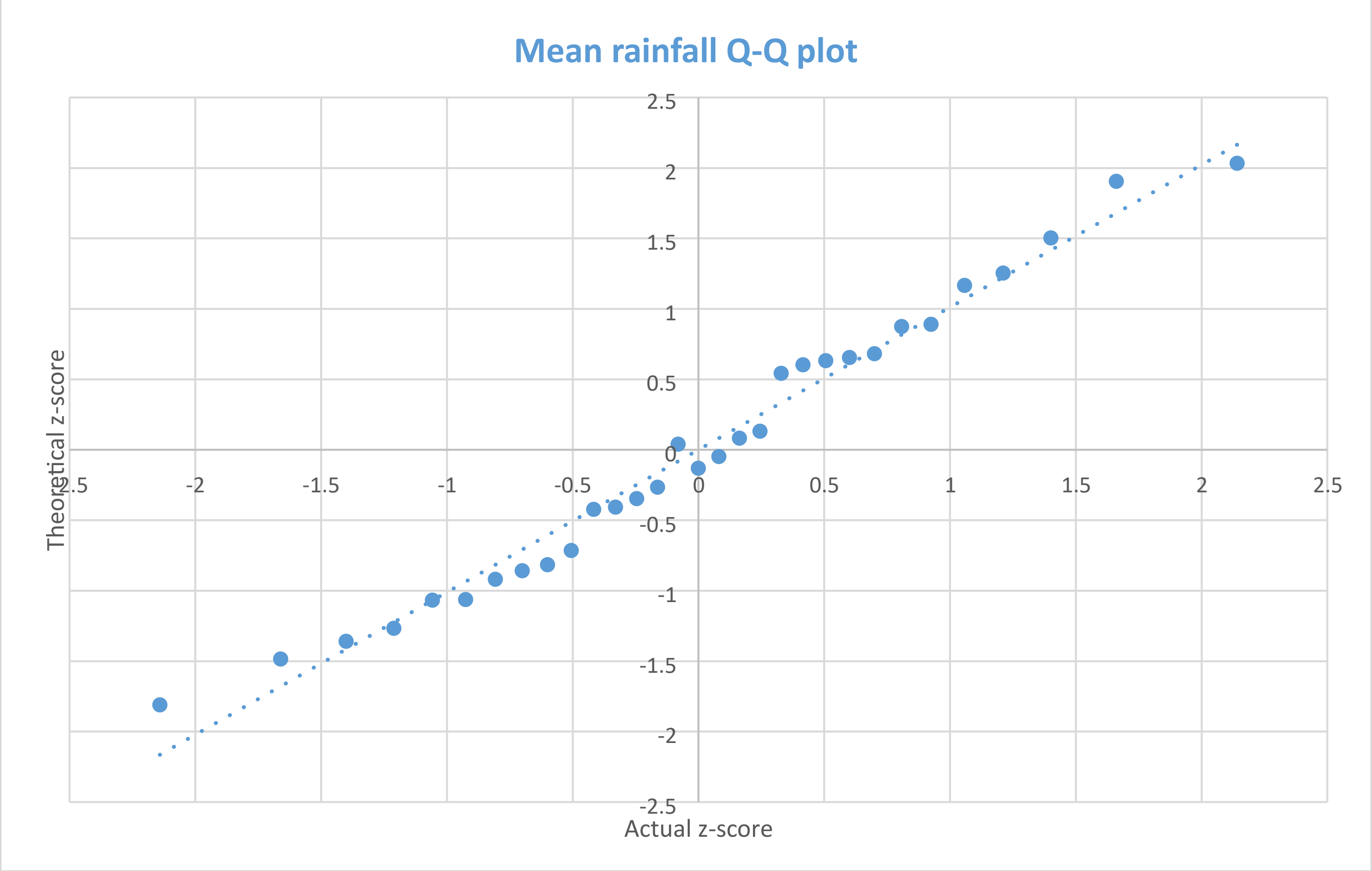
Appendix 5: Rainfall data for Lake Nakuru weather station (in mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean annual rainfall
1990	42.2	78.6	153.6	207.0	125.9	30.3	54.5	57.8	46.6	70.9	64.6	52.6	82.1
1991	49.1	1.5	140.9	104.2	54.0	40.5	73.2	84.4	86.2	44.7	60.4	17.6	63.1
1992	41.3	4.7	13.3	139.5	137.3	52.4	142.0	161.0	76.2	106.6	49.4	70.7	82.9
1993	89.0	111.2	9.2	38.9	76.9	80.4	63.1	65.4	38.8	42.6	56.8	26.6	58.2
1994	0.0	20.9	73.9	115.0	100.8	117.6	75.0	106.9	51.6	43.5	93.5	7.7	67.2
1995	2.8	29.5	103.2	68.9	87.4	128.5	40.8	110.8	90.2	131.5	78.7	43.4	76.3
1996	8.0	o	70.4	45.8	81.4	143.9	194.3	101.0	85.5	64.1	96.1	4.4	81.4
1997	10.5	0.0	21.9	207.0	55.4	71.0	118.3	100.6	45.1	178.9	222.3	63.0	91.2
1998	127.2	61.4	46.2	90.5	176.0	108.3	58.9	67.9	74.4	46.9	80.5	4.3	78.5
1999	15.0	0.0	114.5	100.3	49.2	26.5	62.4	99.3	32.7	37.5	76.3	60.0	56.1
2000	0.0	0.0	0.0	37.7	30.9	40.6	108.5	150.6	41.2	61.1	115.8	22.9	50.8
2001	70.7	18.2	83.2	204.1	47.9	133.5	146.4	164.4	82.4	88.1	96.6	9.7	95.4
2002	39.9	17.5	117.6	188.6	107.3	73.7	78.0	68.1	11.1	124.4	91.3	170.6	90.7
2003	50.2	1.5	83.7	113.2	266.6	97.7	78.66	220.4	57.1	92.9	52.2	27.7	95.2
2004	80.5	15.2	52.8	210.1	99.1	45.2	28.3	91.1	54.1	76.4	53.4	81.4	74.0
2005	19.3	18.5	82.1	87.6	134.5	103.7	67.0	105.3	154.4	68.6	24.0	19.5	73.7
2006	20.9	13.2	85.7	113.9	115.1	67.1	70.9	88.7	32.0	57.0	188.0	106.6	79.9
2007	57.7	128.6	28.3	157.0	134.8	106.3	162.8	145.0	148.7	92.1	46.2	9.6	101.4
2008	15.7	6.5	87.3	48.7	34.0	36.5	72.3	89.2	105.5	175.7	118.8	8.0	66.5
2009	15.0	0.7	11.6	109.5	184.3	15.3	14	37.4	46.5	79.3	67.1	136.4	59.8
2010	9.0	151.9	225.7	144.5	156.2	35.5	111.8	169.4	161.1	147.4	45.6	13.9	114.3
2011	1.1	0.1	104.6	52.6	111.4	109.0	178.7	120.7	143.4	114.1	124.9	37.7	91.5
2012	0	33.6	8	274.3	170.2	62	110.3	102.71	108.3	101.7	70	62.8	92.0
2013	27	0.8	74.8	232.7	80.1	159.6	173.9	113	133.6	54.6	64.8	84.9	100.0
2014	12.6	19.6	60.2	92.9	106.4	79.1	63.8	92.1	11.3	98.2	82	67.9	65.5
2015	0	3.8	11.8	149.6	108.1	63.2	41.8	20.6	102.5	62.7	142	120.6	68.9
2016	70.91	24.2	49.4	158.2	121.4	62.3	86.62	62.22	89.92	89.8	81.22	3.24	75.0
2017	3.8	14.8	4.2	35.2	92.1	36.7	148.5	90.7	150.9	130.5	44.8	5.1	63.1
2018	12.3	3.1	153.8	294.6	208.4	197.5	123.7	69.7	68.5	53.1	33.6	48.3	105.6
2019	4	5.5	5.4	86.3	80.8	198.6	101.4	91.1	55	144.6	82.5	220.7	89.7
2020	39	35.2	119.8	130.3	133.3	128.5	159.4	116.6	105	58.8	90	230.8	112.2

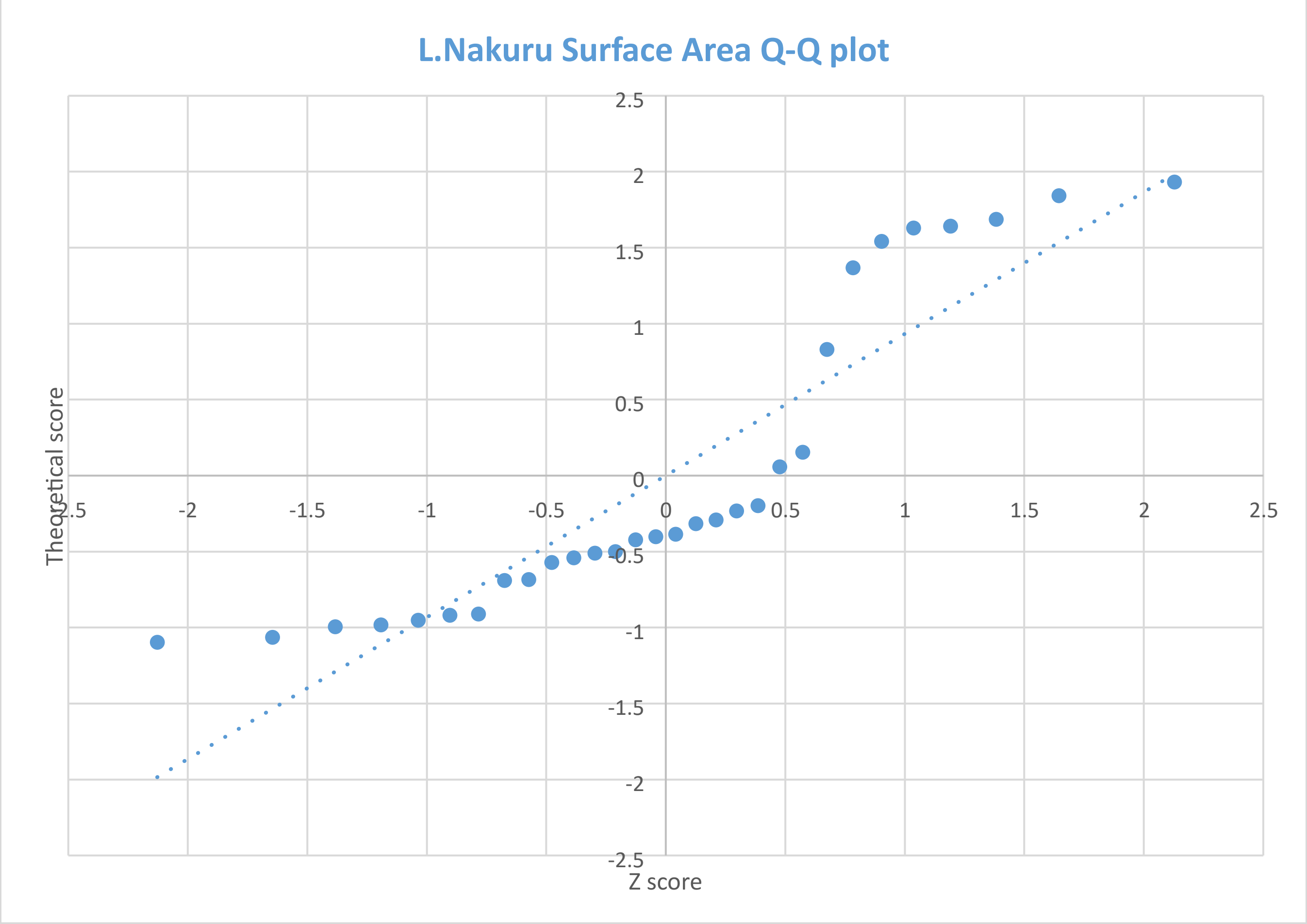
Appendix 6: Mean annual rainfall histogram for lake Nakuru



Appendix 7: Q-Q Plot for Mean Annual Rainfall

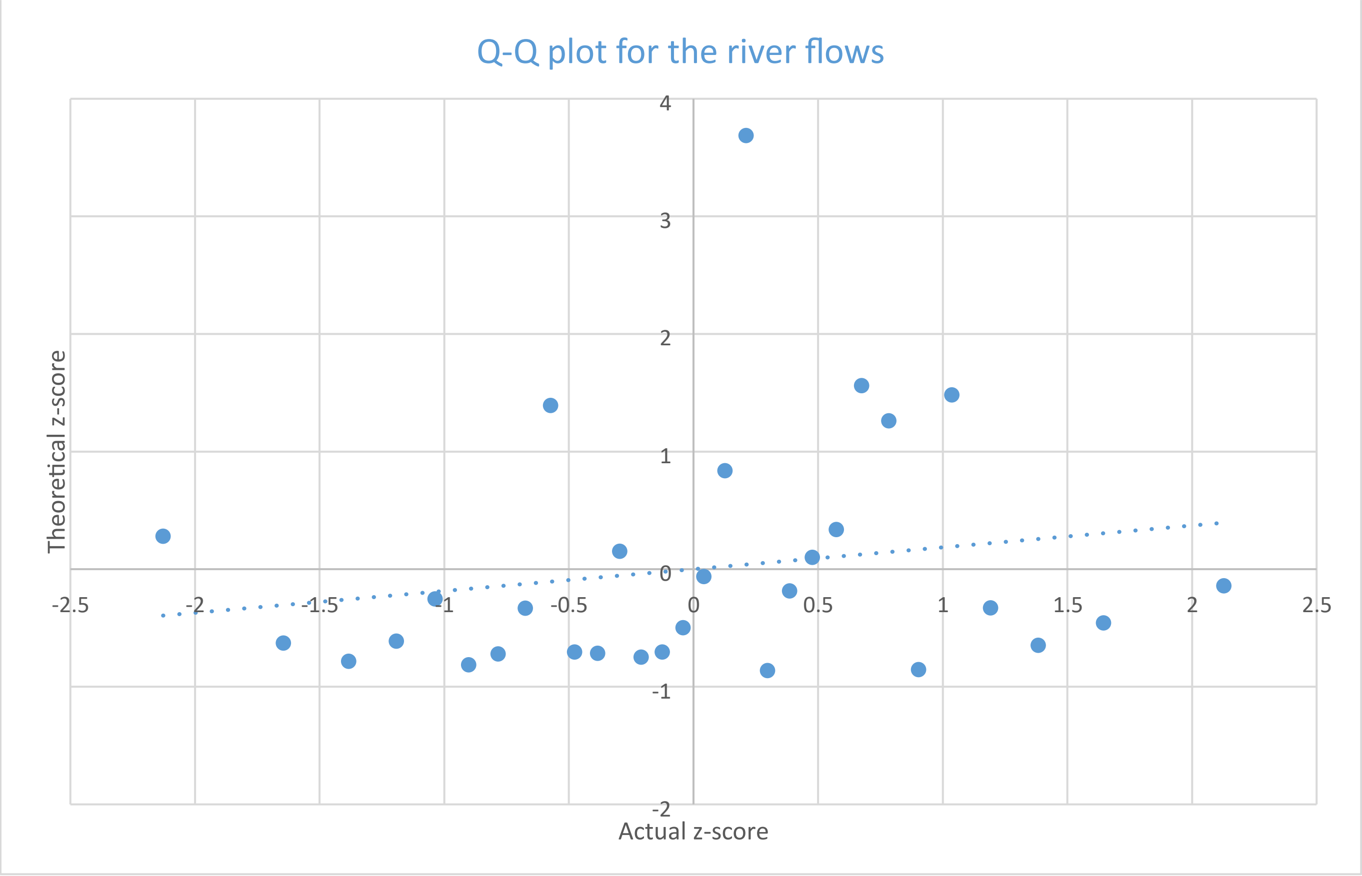


Appendix 8: Q-Q Plot for Lake Nakuru Surface Area

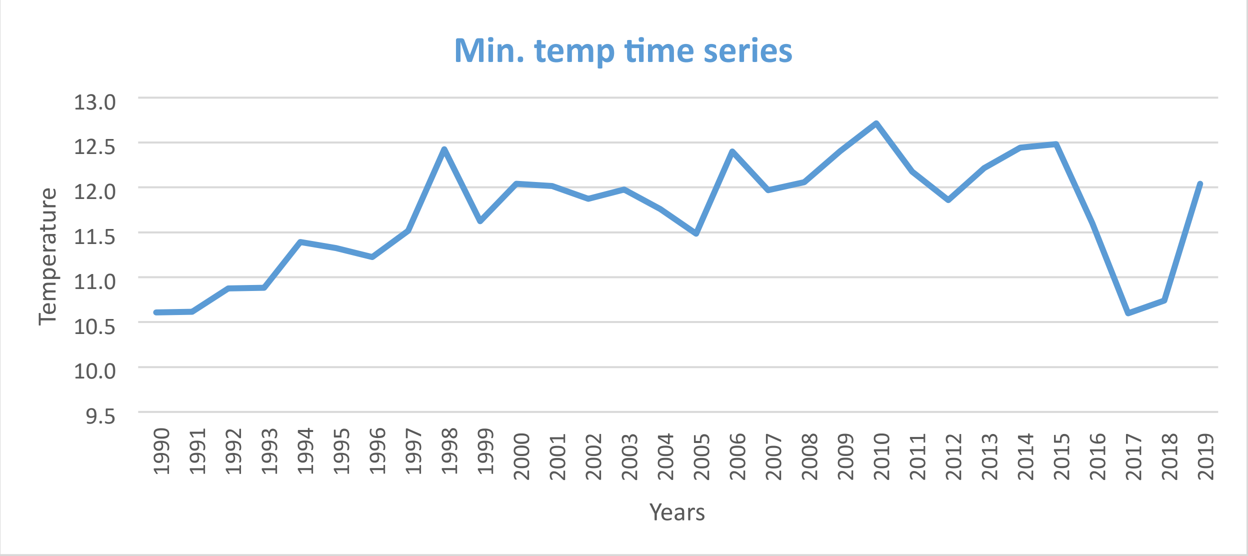


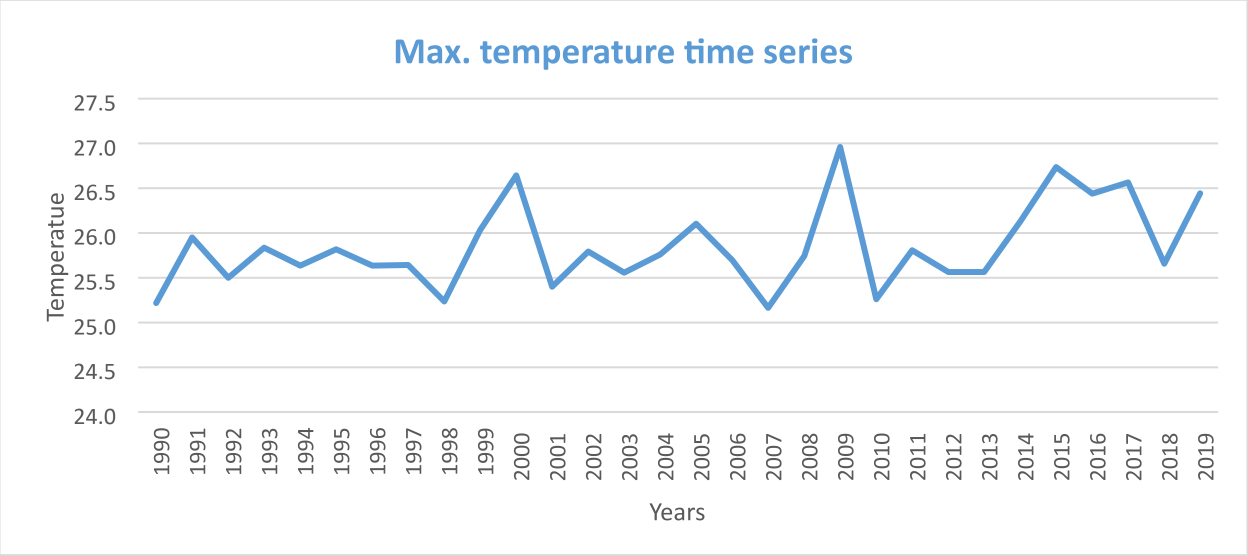
Appendix 9: Q-Q plot for River Flows

Necessitating log transform because the data is not normally distributed



Appendix 10: Time Series for Maximum and Minimum Temperature





Appendix 11: R script for the development of the polynomial regression model

```
R version 4.3.1 (2023-06-16 ucrt) -- "Beagle Scouts"
Copyright (C) 2023 The R Foundation for Statistical Computing
Platform: x86_64-w64-mingw32/x64 (64-bit)

R is free software and comes with ABSOLUTELY NO WARRANTY.
You are welcome to redistribute it under certain conditions.
Type 'license()' or 'licence()' for distribution details.

R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in publications.

Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.

[Workspace loaded from ~/model/.RData]

> x1=All_data$Rainfall
> x2=All_data$`Njoro flows`
> x3=All_data$Year
> x4=All_data$`Max. temp.`
> y1=All_data$`Water levels`
> model1=lm(formula = y1~poly(x1,3)+poly(x2,3)+poly(x3,3),data=All_data)
> summary(model1)

> plot(fitted(model1)~y1)
> cor(fitted(model1),y1)^2
[1] 0.9343493
> abline(a=35,b=55)
> plot(fitted(model1)~y1)
> abline(a=0,b=1)
> plot(fitted(model1)~y1,main="A plot of residuals vs. fitted",ylab="Residual
s",xlab="Fitted",ylim=c(min(y1),max(y1)),xlim=c(min(fitted(model1)),max(fitte
d(model1))))
> abline(a=0,b=1,lty=20,col="blue")
> Bias=mean(y1-fitted(model1))
> RMSE=sqrt(sum(y1-fitted(model1))^2/length((y1-fitted(model1))))
> rsquare=cor(fitted(model1),y1)^2
> NSE=1-sum((y1-fitted(model1))^2)/sum((y1-fitted(model1))^2)
> stata=data.frame(Bias,RMSE,rsquare,NSE)
> View(stata)
```