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DEPARTMENT OF GEOSPATIAL AND SPACE TECHNOLOGY

ESTABLISHING THE RELATIONSHIP BETWEEN LULC CHANGES, TEMPERATURE, PRECIPITATION AND WATER LEVEL RISE: CASE STUDY OF LAKE NAKURU BASIN, KENYA.

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A Project Report submitted to the Department of Geospatial and Space Technology in partial fulfillment of the requirements for the award of the Degree of Master of Science in Geographic Information Systems of the University of Nairobi.

JULY 2022

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DEDICATION

I dedicate this work to God for His grace and my parents for their constant support and prayers.

ACKNOWLEDGEMENT

Prof Simon Onywere and Dr. Siriba provided great assistance and support in conceptualizing this project, and I am grateful for their help.

ABSTRACT

Kenya's Rift Valley lakes have been rising at an alarming rate since the occurrence of the El Nino event in (1997-1998) leading to flooding. These floods have posed a significant threat to the region's socioeconomic progress. Homes, schools, transport network, wildlife habitats, and places of worship among others have been submerged and destroyed leading to displacement of several thousands of people and wildlife. The presence of sediment on the roads and rivers within the catchment clearly shows that increased human activities has led to increased soil erosion which has contributed to the lake siltation that has led to the rising water level in the rift valley lakes. An active tectonic belt, climate change, and increased human activity in the lake basin are all probable causes of the water level rise. However, for this study only LULC changes, temperature and precipitation will be considered. The main objective of this research was to establish whether LULC changes, temperature and precipitation have an effect on the water level rise. To achieve the first objective, Google Earth Images between 1990 to 2020 were digitized to produce the lake horizontal extent while the 12.5m DEM was used to generate 2m interval contour lines. The horizontal extent and the contour lines were overlaid and contours lines that were found to be along the horizontal extent were selected to represent the vertical extent of the lake for the four years. For the second objective, a correlation coefficient matrix between LULC changes, temperature, precipitation and the rising water level was done to establish their relationship. Landsat Images between 1990 to 2020 were pre-processed, and classified into seven LULC classes (forests, water bodies, grasslands, settlements, agriculture, barelands and shrubs) using maximum likelihood supervised classification. For the third objective, select within a source feature method was used to identify infrastructure affected. The results show that the vertical extent of the lake has increased by 9 metres from 1759 m in 1990 to 1768 m in 2020, horizontally the lake extent has increased from 35.60 Km^2 in 1990 to 67.07 Km^2 in 2020 which is a 31.47 Km^2 (88.4%) increase. With reference to the second objective, it was found out that there is a relation between LULC changes, temperature, precipitation and the water level rise in the lake. There is a very strong positive correlation (Corr = 0.964327) between precipitation and water level rise. These makes precipitation the main probable cause of water level rise in Lake Nakuru, among other probable causes. Built-up areas have increased from 17.35 Km^2 in 1990 to 99.71 Km^2 in 2020 (474%). However, forest cover has been decreasing from 376.52 Km^2 in 1990 to 154.53 Km^2 in 2020 (59.04%). Annual mean precipitation has increased by 950% from 826.79 mm in 1990 to 2020 mm in 2020, with the massive increase taking place between the year 2010 and 2020. The annual average temperatures have also increased from 23.37^{0}C in 1990 to 24^{0}C in 2020. In terms of the infrastructure affected, 178 building structures, 4 Road networks and one powerline have been submerged and destroyed. The study, recommends that a research considering all probable cause of the lake level rise be done using a much higher resolution DEM and Images for more accurate results. We also recommend that a research to identify the most appropriate contour line to be used to create riparian zone along the lake be done.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABREVIATIONS AND ACRONYMS

DEM Digital Elevation Model

EO Earth Observation

GIS Geographic Information System

KFS Kenya Forest Service

KWS Kenya Wildlife Services

KWT Kenya Water Towers Agency

KWTA Kenya Water Towers Agency

LBDA Lake Basin Development Authority

LULC Land use land cover

NASA National Aeronautics and Space Administration

SRTM Shuttle Radar Topography Mission

WRA Water Resource Authority

VNIR Visible and Near Infrared

SWIR Short Wave Infrared

1 INTRODUCTION

1.1 Background

At a height of 5,755 feet (1,754 meters) above sea level, Lake Nakuru is one of several shallow (2.8m), alkaline-saline lakes in Kenya's Rift Valley, spanning from northern Tanzania through Kenya and Ethiopia. The lake's richness of algae attracts many flamingos and other species. It also features warthogs, baboons, and other massive species, such as Eastern black rhinos and southern white rhinos, making the lake a popular tourist destination (Obando et al., 2016). Direct rainfall and surface runoff from the Mau escarpment's Enduro, Makalia, Larmudiac, and Enderit rivers provide most of the lake's recharge. The rivers only reach the lake through surface runoff when there is a lot of rain. Eburru, Bahati, and the Mau escarpment drainages convey runoff only during severe rainstorms but never gets to the lake (Omondi & Musula, 2011). The runoffs are brief and abruptly end as they approach the Kiwi and Bahati plains parallel to the Rift Valley's axis (Onywere et al., 2013).

Early in the 1990s, the lake water-level dropped dramatically, but it has since recovered, with the catchment experiencing an increased runoff in 1997-1998 (El Nino event) and 2003. In 2010, the runoff exceeded the average day flow into the lake (2.615m^3/second) (UNDP, 2021). The lake extent increased by 34.9 Km^2 (over 100 percent increase by surface area) from 31.8 Km^2 in January 2010, to 65 Km^2 in October 2010 due to the rains of May and September 2010 (Onywere et al., 2013).

The water levels rise has caused infrastructure and property destruction and large-scale displacements. Still, it has also led to the loss of human, livestock, and wildlife lives and increased incidents of human-animal conflict and ecological or environmental degradation (UNDP, 2021). Flamingos have been forced to migrate to Lake Bogoria in search for food supply (Obando et al., 2016).

An active tectonic belt, climate change, and human activity in the lake basin are to blame for this disaster (Herrnegger et al., 2021; Obando et al., 2016; Shayegan & Badakhshan, 1996). Stratification and mixing cycles have developed as a consequence of the daily changes in heating and cooling (Downing et al., 2006). Because of this, during the rainy season, downstream riparian areas are more likely to flood and during the dry season, the base stream flow is reduced. These are serious problems for the ecology and the economy. During the rainy season, substantial volumes of surface runoff occur due to changes in LULC within the catchment of the lake, while infiltration and deep percolation are reduced as a consequence of increased human activities. Dry season flows may be drastically reduced even when yearly runoff increases due to a lack of ground water recharge (Wantzen et al., 2008). Soil erosion and surface runoff during rainstorms have risen due to increasing farming in poorly consolidated sections of the catchment area. This has increased the lake's water level (Onywere et al., 2013).

More than 90,000 square kilometers of lake-like surface water were lost to global evaporation between 1984 and 2015, whereas 184,000 square kilometers of fresh surface water were created elsewhere (Pekel et al., 2016). There is just 1% of a net loss of permanent water in Oceania. The rest of the continents show a net growth. However, reservoir filling and climate change are also contributing to the increase (Lutz et al., 2014). Increased population density can have an impact on local hydrology by reducing the extent of freshwater, increasing water abstractions, draining marshes and wetlands, as reported by Prigent et al., (2012). This suggests that human activities on continental surface freshwater have had a global scale effect. Tides in Bangladesh's Sundarbans region, as well as previous tide-gauge analyses, show that the country's relative sea level has risen far faster than previously thought (Pethick & Orford, 2013). Estuary channels that have been bounded by embankments have seen an increase in Effective Sea Level Rise (ESLR) owing to greater tidal range.

According to Ayenew and Legesse's study, excessive water abstraction has decreased the surface area of certain Ethiopian lakes, while increasing surface runoff and groundwater inputs have enlarged others (2007). Deforestation, soil degradation, and over-irrigation have taken a toll on a few Rift Lakes. Since human activities and climate and geological changes have affected the lakes' hydrological environment and water quality, the salinity and primary ion composition have also changed dramatically in certain lakes. Recent poor use of water from key streams draining the lake basins, according to a new research, has played a substantial part in the Rift Valley's dramatic alterations, even though climate and land use changes have played a role. The underlying cause and the interconnections between the many potential reasons must be given high importance in order to deal with the increasing water levels problem and its impacts. Lake Nakuru being one of the Rift valley lake must be experiencing the same challenges hence the motivation for this research.

1.2 Problem Statement

Human activities within the lake's water basin, as well as climate change, are likely to be the primary causes of Lake Nakuru's water level rise, as evidenced by rising levels of rainfall and temperature at most rainfall gauging stations. Because of the lakes' fragile ecosystem, increasing freshwater inflow has caused instability, which has had an effect on species' resilience and dispersion. For example, changes in water availability, water quality, and evapotranspiration may have a significant impact on ecosystem structure and function. There has been a dramatic increase in water levels in the lakes that is attributed to many factors such as active tectonic belt, climate change, and increased human activity in the lake basin with the main probable cause still a challenge.

As a result, the lake's water has been diluted, lowering its salinity (alkalinity). Because of the low salinity and siltation, flamingos have been forced to move due to the lack of algae on which they rely. There are no more flamingos in the Lake Naivasha, but they have moved to the nearby lakes of Oloidien and Bogoria. The presence of birds of the duck family has resulted in a shift in water life and biodiversity. This inner circle road around the lake has been largely obliterated by the lake's rising waters. The loss of and damage to road infrastructure is making it increasingly difficult and dangerous for tourists to access the park. The destruction of development infrastructure including the office facilities at the main gate from flooding is evident. The introduction of saline water from the rising level of the Lake and the Loss of biodiversity, e.g., acacia trees, is an area of concern. Monitoring and documenting the lake's water level extent and ecology, as well as their impact on infrastructure development, the preservation of biodiversity, and plant regeneration, is necessary. Establishing whether there is any relationship between probable causes and the water level variations will help strike the root cause of the problem. Since flood water is likely to remain for some time and thus pose the same challenges that now require preparedness and monitoring.

1.3 Objectives

The main objective of this study was to establish the relationship between probable causes and the water level variations in the lake. More specifically, this study sought to achieve the following specific objectives:

(i) Determine the extent to which the water level has increased in the lake, between 1990, and 2020.

(ii) Determine whether LULC changes, Temperature, Precipitation has an effect on the water level rise in Lake Nakuru.

(iii) Identify the infrastructure that have been affected as result of the water level rise in Lake Nakuru, between 1990 and 2020.

1.4 Research Questions

The main research questions that forms the basis of this study are:

i. What is the vertical and horizontal extent to which the water level has increased in the lake, between 1990 and 2020?

ii. Is there a relationship between LULC changes, Temperature, Precipitation and the rising water level in Lake Nakuru?

iii. How many infrastructures have been affected as result of the water level rise in Lake Nakuru, between 1990 and 2020?

1.5 Research Matrix

In order to complete my project, a research matrix containing the objectives, research questions, methods, data and the expected output was generated as shown in Table 1.1

Table 1.1: Research Matrix

Objective	Research Question	Methods	Data	Output

1. Determine the extent to which the water level has increased in the lake, between 1990 and 2020.	1. What is the vertical and horizontal extent at which the water level has increased in the lake, between 1990 and 2020?	• Image interpretation
		• Area Computation
		• Generation of Contour and selection of the one that is close to the horizontal extent of the lake
			• Landsat
			• Google earth Images
			• DEM
				• For each of the four epochs
				  • Vertical extent
				  • Horizontal extent
				• A map of the horizontal extent for the 4 epochs

2. Determine whether LULC changes, Temperature, Precipitation has an effect on the water level rise in Lake Nakuru.	2. Is there a relationship between LULC changes, Temperature, Precipitation and the rising water level in Lake Nakuru?	• Image interpretation • Creation of Correlation matrix (LULC & water level, temperatures, precipitation and water level rise)	• LULC • Temperatures and precipitation • Water level	• Correlation Matrix
3. Identify the infrastructures that have been affected as result of the water level rise in Lake Nakuru, between 1990 and 2020.	3. How many infrastructures have been affected as result of the water level rise in Lake Nakuru, between 1990 and 2020?	• Overlay analysis	• OSM features (buildings, powerline and roads) • Water level	• Number of features (buildings, powerline and roads) that have been affected • Map of the affected features

1.6 Justification for the Study

The increasing water levels of the Rift Valley Lakes have been a significant issue for the country's socio-economic growth. Various hypotheses have been advanced to explain the rise in water levels, but the reality is that various factors are at play. Hydro-meteorological considerations, such as increased rainfall and river flow into lakes, have shown that climate change has enhanced moisture availability in the tops. Land-use changes have also increased soil runoff, contributing to siltation of the lake, as seen by the sediment load in rivers. A critical factor in the management of Rift Valley lakes is that they are all situated on faulted terrain in the Eastern Africa Rift Valley. Because of this change in the composition of the lake water, biodiversity has been affected. Flamingos, who rely on algae for their diet, have vanished from the lake due to the lake's alkalinity changing. The loss of riparian vegetation has severely affected the lakes' biodiversity. As a result of the area's lakes losing their beautiful appeal, tourism has declined significantly, reducing earnings. The Covid-19 mobility restriction and travel advice have exacerbated the tourist crisis.

About 75,987 households have been displaced, and 379,935 individuals have been affected by the increasing water levels in Lake Nakuru since 2010 (UNDP, 2021). Due to the loss of assets such as residences, grazing grounds, and agricultural fields that were destroyed or isolated by floodwaters, the lives of those affected have been disturbed. Farming and fishing are the primary economic activities here. Because of the deterioration of infrastructure due to the rising water levels, people now have to rely on boat transportation to get around the flooded areas, including health care facilities, markets, primary and secondary schools, electricity lines, once-thriving hotels, fish landings, and processing facilities, resorts, and lodges and curio shops.

Flood risk and vulnerability mapping is the topic of much research (Westen, 2013). Here we see a lack of investigation into the main possible reasons for lake Nakuru's growing water level or even the primary cause of the lake's rising water level. This study aims to establish whether LULC changes, temperatures and precipitation has an effect on the water level rise, and if Yes which one is the main probable cause, therefore the need for this study.

1.7 Scope of work

Lake Nakuru, one of the significant rift valley lakes that flooding difficulties have plagued over the last decade, is our focus in this research. Analysis, mapping, and quantification of LULC changes was carried out utilizing GIS, Remote sensing, Landsat images between the year 1990 and 2020 and a 12.5m Digital elevation model raster data set collected from the Joint Research Centre. To classify the Landsat images into seven LULC classes (forests, water bodies, grasslands, settlements, agriculture, barelands and shrubs), a maximum likelihood supervised classification was used and the area computed for various years. To better understand how the climate has changed over time, the annual mean precipitation and temperature data from the Kenya Meteorological Department between the year 1990 and 2020 was used. The relationship between Climate change (Annual mean Precipitation and Temperature) and human activity (LULC changes) in the lake basin has been studied in this study to help determine the link between these factors and the lake's water level fluctuations in the future. Temperature, precipitation and LULC changes within the catchment are the only probable causes of the rising water level in the lake examined in this study. The study will also focus solely on assessing and quantifying infrastructure developments (buildings, powerline and roads) affected by the rising water levels in the lake rather than any other effects and repercussions.

1.8 Organization of the report

The research project is organised into five chapters aligned to the research objectives. These chapters may be read independently but a more comprehensive pictures emerges through reading all the five chapters together in a systematic way from chapter one to chapter five due to the linkages between them. They begin with Introduction, Literature Review, Material and Methods, Results and discussions, and lastly Summary, Conclusions and Recommendations.

Chapter one: Gives the background and the context of the study, problem statement, objectives, research questions, research matrix, justification of the study and the organization of the Research project chapters.

Chapter two: Describes the probable causes of the rising water phenomenon, the impacts of rising water levels in Lake Nakuru both on environmental and socio-economic activities. A research gap that this study seeks to bridge is also highlighted. The chapter also establishes the conceptual framework that links various elements such as Precipitation, Temperatures, LULC (forests, water bodies, grasslands, settlements, agriculture, bare lands and shrubs) as causes of the lake water level rise.

Chapter three: Describes the areas of study, the datasets and formats that was used in the study. The chapter presents the methods that were used in the analysis to get results and in achieving the study objectives.

Chapter four: Presents the Results and discussions according to the study objectives.

Chapter five: Gives the summary of the study, conclusions and the recommendations of this study.

2 LITERATURE REVIEW

This chapter describes the theoretical and conceptual framework to establish the relationship between land use land cover, temperatures, precipitation, and water level rise in the lake. The chapter will also outline the impacts of rising water levels in Lake Nakuru on environmental and socio-economic activities. It establishes the conceptual framework that links various elements such as Precipitation, Temperatures, LULC (forests, water bodies, grasslands, settlements, agriculture, bare lands and shrubs) as causes of the lake water level rise. A research gap that this study seeks to bridge is also highlighted.

2.1 The probable cause of the rising water phenomenon

Water levels in rift valley lakes have been a nightmare in recent years. This disaster has caused the deaths of many people and animals; it has submerged and destroyed property; and it has caused significant damage to the economic operations of many individuals (Ayenew & Legesse, 2007). An active tectonic belt, climate change, and increased human activity in the lake basin are all probable causes of the water level rise (Herrnegger et al., 2021). Climate change causes temperature to increase resulting to air becoming warmer and more moisture evaporating from land and water into the atmosphere. These results to more rain and snow (precipitation) and more heavy downpours (IPCC, 2014). Increased Land use changes due to increased human activities in the basin has led to deforestation, soil erosion and increased water surface runoff (Ouko et al., 2016). An active tectonic belt, can interfere with ground water flow resulting into increased underground water intake (Delvaux, 1995).

Freshwater intake has generated instability in the lakes' ecology because of the ecosystem's fragility, which has affected species' adaptability and distribution in the lakes (Bergner et al., 2009). There was an inter-annual variability and a large seasonal of inundation extent from 1993 to 2007, with an overall decrease of 6% in the global mean maximum inundated area, primarily in subtropical and tropical South Asia and South America (Prigent et al., 2012). Denser populations may have an influence on hydrology by increasing water abstractions, reducing the freshwater extent, draining marshes and wetlands, meaning that human actions on continental surface freshwater have a world scale effect (Herrnegger et al., 2021).

In Ethiopia, the Rift Valley lakes water resources have been the focus of large-scale development during the last decades, according to a study by Ayenew and Legesse (2007). Aquaculture, soda extraction, fish farming, and leisure all take use of the lakes and the streams that flow into them. They also provide as a haven for various wild mammals and native birds. Ethiopia's greatest mechanized irrigated crops and commercial fisheries are found in the Rift Valley. Water abstraction has caused a few of the lakes' surface areas to shrink, while others have grown in size due to increased water surface runoff and groundwater influx that has percolated down through the soil (Ayenew & Legesse, 2007; Belete et al., 2016; Yihdego et al., 2017).

Geological constraints such as erodible soils, rockslides, landslides and asbestos bearing rocks are believed to be influencing the present elevation of Rift Valley Lakes, notably Lake Victoria, which is governed by the Nyazian Rift (Bruijnzeel, 2004). All of the rift basins are linked mechanically by rift oblique faulting zones. These lakes were formed during the Pleistocene geological era when the Great Eastern Africa Rift Valley was built (Bhandari et al., 2016). The Pleistocene lakes, which at the time covered a significantly greater area, were already in place. Both historically and more recently, between 1901 and 1963, there has been a significant increase in the extent of the lakes. Dykes and sills emplacement beneath volcanic centers also results in the formation of pressurized magma chambers, which continue to destabilize the immediate regional stress field (Baker, 1986).

Surface water runoff into and across the plateaus of the Great Eastern Africa Rift Valley affect the rift escarpments and fault alignments in the rift valley floor, which continue to shape the contemporary lake's morphology (Boitt, 2016; Kolding & van Zwieten, 2012). Due to the high plateaus' role in the region's climatic cycles and increasing rainfall, they also regulate and influence the intensity and pattern of rainfall. This has an impact on the hydrodynamic recharge of the lakes (Baker, 1986). In all these studies, we see a lack of investigation into the main possible reasons for the alarming rift valley lake's growing water levels or even whether the probable causes have a positive or negative correlation between them (independent variables) and the lake water level (dependent variable), therefore the need for this study. This research will investigate whether there is any relationship between the probable causes and the water level rise, and if yes what is the main probable cause, a question that has not been addressed in any of the previous studies.

2.1.1 Climate Change

The cognizance of the level to which the society, environment, and economy can be affected by the change in climate has increased. At regional and local scale, increasing greenhouse gases, mainly carbon dioxide, has led to long-term climate change. These encompass changes in timings and amounts of precipitation, temperatures, extreme weather like droughts and heavy precipitation, wind patterns, and heatwaves (IPCC, 2014). Precipitation patterns are influenced by moisture availability and circulation patterns of the atmosphere and are unevenly distributed across the globe. These precipitation patterns are anticipated to change since the temperature is changing, influencing the moisture availability and the atmospheric circulation patterns.

The amount, frequency, intensity, and nature of precipitation change. Precipitation has increased and decreased in most parts of Northern Europe, North America, South America, Africa, the Mediterranean, and southern Asia (IPCC, 2014; Trenberth & Shea, 2006). The world-leading international organizations in climate change research associate climate change with human causes through activities that increase emissions of heat-absorbing GHGs (IPCC, 2014). These emissions change the atmosphere's composition and vary the natural climate witnessed over a relatively extended period. Climate change is the state variation of the climate that can be predictable by mean fluctuations or the inconsistency of its characteristics, for decades or longer (IPCC, 2014).

2.1.2 Human activities

Human impacts on the lake began as early as 1650 AD when Lamb et al., (2003) discovered earliest presence of maize pollen in cores. Because of the increased population, there has been a steady expansion in broad farming and rapid urbanization (Vörösmarty et al., 2000). The rise in female fertility and in-migration have contributed significantly to the significant increase in population (MacDonald, 2010). In 1975, the average number of children per homestead (from each married woman) was 8.1; today, the figure is at 4.5 per woman, but it is still higher than the global average of 2.8 (Nakuru County, 2018). The demand for drinkable water by the population surrounding the lake, according to the 1999 population census report, is extremely high, far exceeding the supply. Some residents have decided to dig their boreholes because of the region's limited water resources. Because the lake is hydraulically tied to the groundwater system, the sinking of boreholes has resulted in water abstraction faster than natural replenishment, resulting in a drop in groundwater level and lake level (Yihdego et al., 2017).

In the previous three decades, the effects of industrialization have been seen. As a result, deforestation has intensified searching for fresh land for industries and worker settlements. Deforestation has increased runoff and erosion, silting the lake (Boitt, 2016). Because the lake's surface area to volume ratio increases, siltation poses a significant threat to evaporation (Clites et al., 2014). The rapid rise of an industry generating various gases has increased greenhouse gases (CO_2, CH_4, N2O, and CFCs). These gases will substantially impact global temperatures and raise the overall evaporation rate (Kadioğlu et al., 1997).

Agriculture accounts for 75% of the country's GDP, and the rift valley, known as the "farmer capital," is rich in the agricultural hinterland and well-known for its agro-based industry (Nakuru County, 2018). Water resource demand is increasing as a result of intensive urban farming. In his research in the area, Alfarra, (2004) discovered that the basin is vulnerable to a cone of depression and decreasing groundwater levels. Weathered soils from volcanic and basement rocks are highly infiltrative and absorptive, indicating that irrigation requires more water than usual moderate soils (Raini, 2009). Cultivation in the upper sections (the highlands and along the feeder rivers of Lake Naivasha) has also revealed increased siltation levels, putting the lake's depth of 20m and overall water quality in jeopardy (Onywere et al., 2013).

2.2 Impacts

2.2.1 Environmental Impacts

Several important Ramsar sites and wildlife sanctuaries in Lake Nakuru were destroyed, causing substantial damage to the area's unique biodiversity. According to this dynamic interaction of trees, plants, and the essential habitat for animal species, the increasing waters of the lakes have had a severe influence on the areas around the lakes (UNDP, 2021). Some species of plants and animals have been wiped off totally. One of the worst-hit species was the acacia tree, which dried up and eventually fell. In most lakes, there has been an increase in human-wildlife confrontations since hippopotamus graze freely in previously populated areas (Jotikapukkana et al., 2010).

2.2.2 Social Economic Impacts

It is no secret that the Rift Valley's lakes and dams have had a tremendous influence on biodiversity and socioeconomics, affecting the local flora, animals, and people's lives (UNDP, 2021). In addition to the destruction of livelihoods and essential infrastructure such as roads, schools, health centers and hotel facilities, fish processing facilities at fish landing locations have been damaged. These have had an impact on the local economy. More than 379,935 individuals have been threatened by the rising floods, which have affected an estimated 75,000 houses (UNDP, 2021). However, water level rise in the lakes has also helped the fishing business with an expected rise in fisheries. Invasive aquatic plants like water hyacinth have expanded into previously untouched wetland regions due to increasing water levels (UNDP, 2021).

2.3 Research gap

In all these studies, its clear that the main possible reason for the alarming rift valley lake's growing water levels is inconclusive. Whether or not the probable causes have a positive or negative correlation between them (independent variables) and the lake water level (dependent variable) is not clear, therefore the need for this study. This research will investigate whether there is any relationship between the probable causes and the water level rise, and if yes what is the main probable cause, a question that has not been addressed in any of the previous studies.

2.4 Conceptual Framework

Lake water level rise in the rift valley has resulted to flooding around the lake leading to flooding. These floods have posed a significant threat to the region's socioeconomic progress. Homes, schools, transport network, wildlife habitats, and places of worship among others have been submerged and destroyed leading to displacement of several thousands of people and wildlife. The presence of sediment on the roads and rivers within the catchment clearly shows that increased human activities has led to increased soil erosion which has contributed to the lake siltation that has led to the lake’s rising water level. An active tectonic belt, climate change, and increased human activity in the lake basin are all probable causes (independent variables) of the water level rise (dependent variable).

In this study, the focus is to find whether a relationship (Correlation coefficient matrix) exist between these causes and the water level rise, and if yes what is the main cause. LULC /Human activities (Forest, Built-up/settlement, Agriculture, Shrubs, Barelands and Grasslands) and Climate Change (Temperatures and Precipitation) are the probable causes (Independent variables) of the rising water level (Dependent variable) in Lake Nakuru. The correlation matrix between the two variables gives the relationship between the variables and the main probable cause as shown in Figure 2.1.

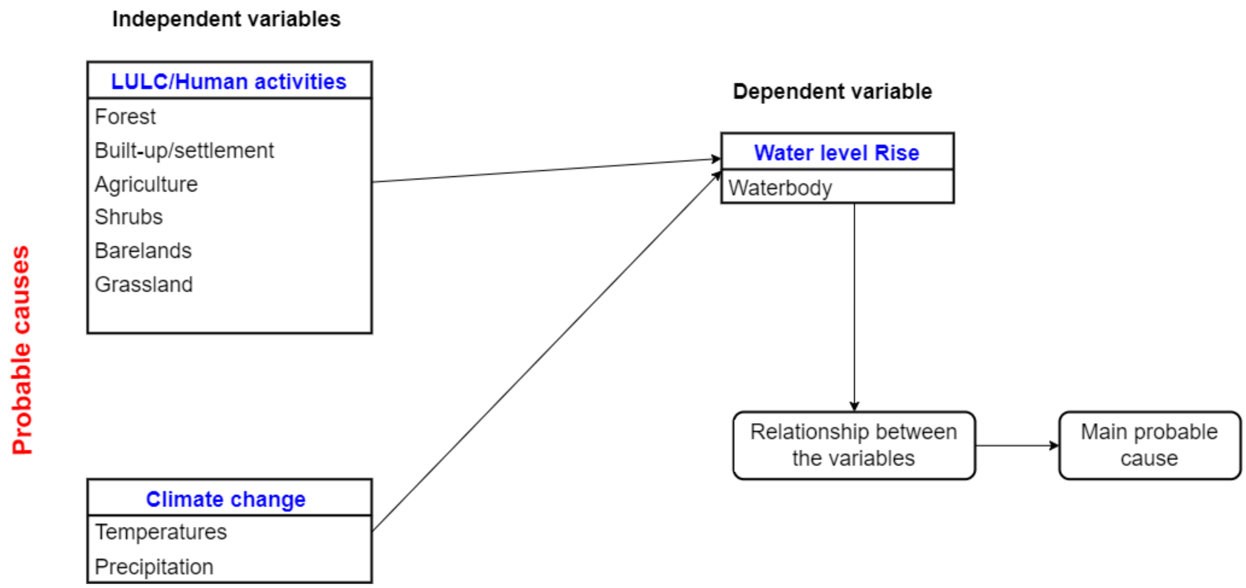

Figure 2.1: Conceptual Framework

3 MATERIALS AND METHODS

This section presents the methods and the data that were used in the analysis to get results and in achieving the study objectives.

3.1 Area of Study

3.1.1 Location

Lake Nakuru basin serves as a catchment for the Lake Nakuru which is a saline lake found in Nakuru County. The basin lies between latitude 0°10'00"S and 0°45'00"S and longitude 35°48'30"E and 36°14'18"E and covers an area of 1,564.5 Km^2. The area is surrounded by Nyandarua county to the North Eastern, Narok County to the South and Baringo to the North Western side as shown in Figure 3.1.

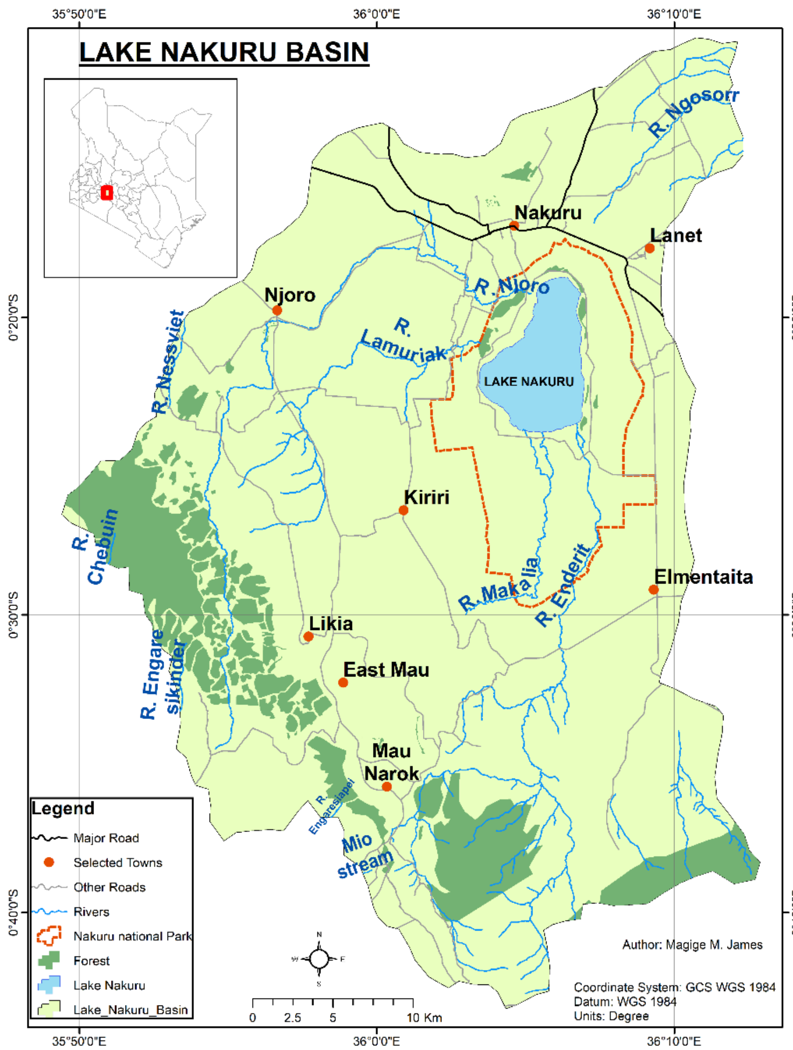

Figure 3.1: Lake Nakuru Basin Location

3.1.2 Physical set-up

Within the basin there are five main rivers namely Ngosur River, Lamudhiak River, Makalia River, Njoro River and Nderit River which all feed Lake Nakuru that is surrounded by a National Park that covers 90 square miles. These rivers originate from the Eastern Mau. There is no river that drains out of lake Nakuru as water loss is due to evaporation. The highest point of the basin is 3085 metres and the lowest point is 1720 metres above sea level as shown in Figure 3.2.

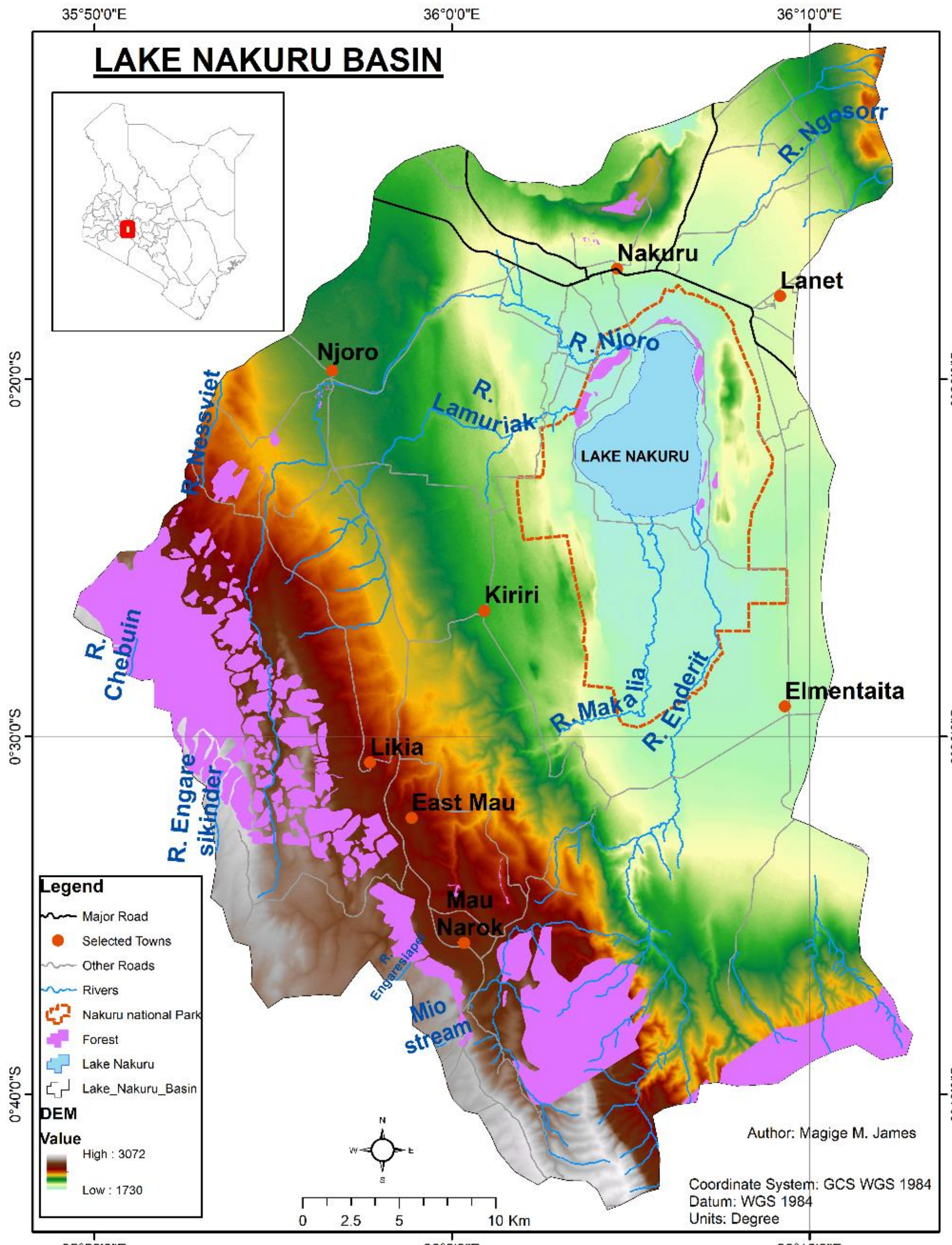

Figure 3.2: Lake Nakuru Basin Digital Elevation Model

3.1.3 Ecological conditions

The lake Nakuru catchment forested areas consists of the Eburru, Eastern Mau and Dondori forests. Eburru forest that covers 8,736 ha, serves as a habitat of indigenous tress species while Dondori forest covers an area of 6,956 ha. Eastern Mau forest forms part of the Mau Complex, consists of plantations, thickets of bamboo and indigenous forest. Since the gazettement of the Lake as a national Park in 1968, the protection of the park has conserved various endangered species including the famous Black Rhino. The lake had a high population of lesser flamingo which has since left due to declining food concentration in the lake's water as a result of water level rise. Cyanophyte, which often occurs as a unialgal bloom is the basis of a simple food chain in the lake. This can support a big number of Lesser flamingo and the fish that support a number of secondary consumers in Nakuru City (UNDP, 2021). The lakeshore is mainly covered by alkaline mud, marsh and sedge that gives way to grassland and a belt of *Acacia* woodland. Euphorbia forest and scrub covers the Rocky hillsides on the park's eastern side.

3.1.4 Land use land cover

Since the precolonial era, Lake Nakuru basin LULC has changed rapidly. The area used to be covered by vegetation and wildlife with less settlement. The forested areas were characterized with indigenous tress species. The rift valley floors were dominated by shift cultivation, pastoralism and settlement by the Ogiek who were bee keepers, hunters and gatherers. With the coming of British in Kenya, the demand for timber from trees and settling in the fertile lands increased. Settlement schemes such as Bagaria, Gichobo, Naishi, and keriri were established on large -scale farms that were initially owned by the Whites. This was as a result of the continuous pressure to allocate land to the landless in 1980s. The large-scale farms were sub divided into small plots and allocated to individuals (Nakuru County, 2018).

Due to increased population demand for land also increased in 1990s, resulting to illegal forest encroachment and logging for settlement, cultivations and fuel. As a result of population growth, the lake basin has also experienced increased human settlement that has led to rapid urban growth. In 2020, the catchment was estimated to have 2.2 million people. 400,000 people were estimated to be living in Nakuru town municipality and the rest in the small towns, marketplaces and rural areas (Nakuru County, 2018).

3.2 Data

The data used in this study consist of rainfall, temperature (annual avg) at yearly time series from the year 1990 to 2020 from Kenya Meteorological Department, 12.5m Digital Elevation model (DEM) from Joint Research Center for European Union, Lake Nakuru Watershed data from WRA and Landsat satellite photos from the USGS official website (http://glovis.usgs.gov) between 1990 and 2020 as shown in Table 3.1 and 3.2 . It has been reported that these sensors have great spectral and temporal resolutions, as well as high spatial resolution. It has a 28.5, 30 and 30m resolution for each VNIR multispectral band. All photos were shot between July and December to guarantee the best possible level of greenery in the region.

Table 3.1: Datasets, source and description

Datasets	**Source**	**Description/Format**
12.5m Digital Elevation Model (DEM)	Joint Research Center for European Union (JRC)	Tiff
Buildings, Roads and powerline	OpenStreetMap (OSM)	Shapefiles
Kenya Counties	Humdata.org	Shapefiles
Satellite Multispectral Images	USGS official website (http://glovis.usgs.gov).	Landsat satellite images (1990, 2000, 2010 and 2020)
1990 to 2020 Temperature and Precipitation	Kenya Meteorological Department	CSV

Table 3.2: List of Multispectral Landsat Images Downloaded

1. LC08_L1TP_168061_20200921_20190326_01_T1
2. LE07_L1TP_168061_20100821_20170213_01_T1
3. LT05_L1TP_168061_20000715_20161024_01_T1
4. LT05_L1TP_168061_19901225_20170213_01_T1

3.3 Methodology

The three objectives of this study were achieved using the methodology highlighted in the methodology flow chart in Figure 3.3.

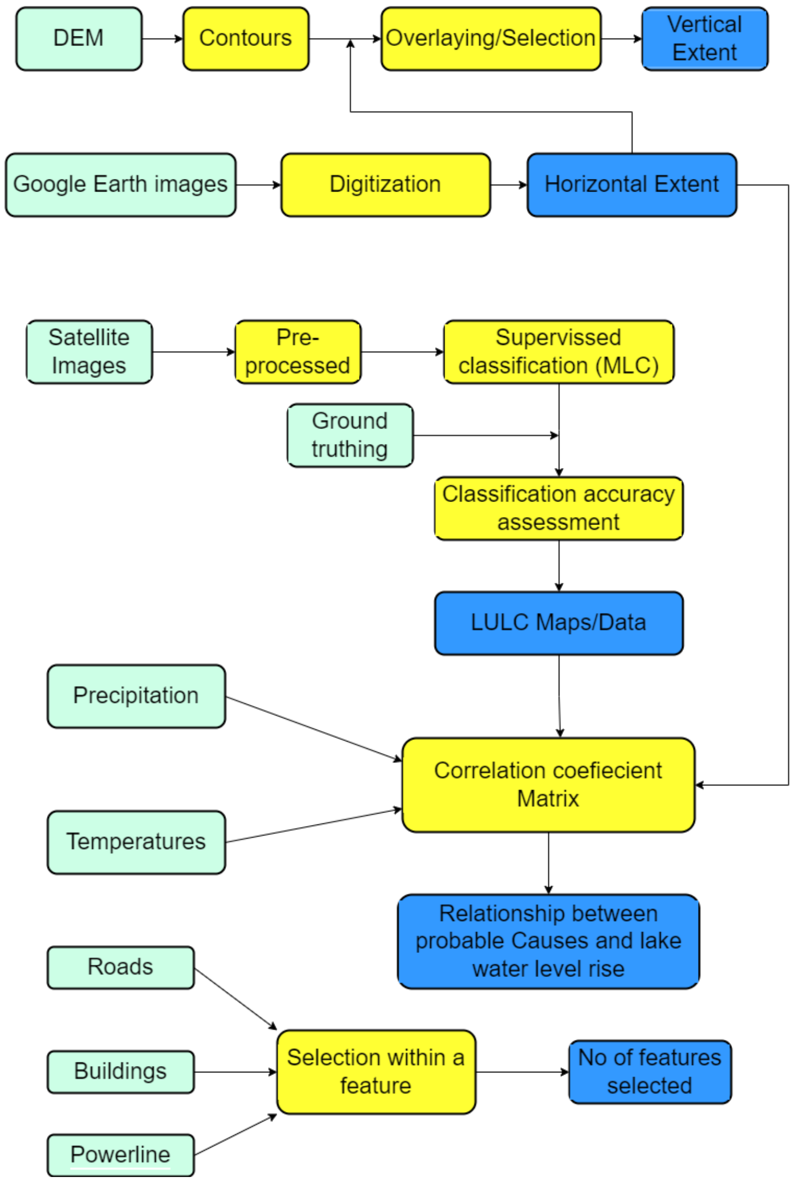

Figure 3.3: Flow chart Methodology

3.3.1 Lake extent

3.3.1.1 Vertical extent of the lake

Using the 12.5 m Digital elevation model (DEM) from Joint Research Center for European Union, a 10m contour line of the Lake Nakuru watershed has been created and the digitized horizontal water level extent of the lake for the 4 years overlaid. These helped us identify the contour lines that are along or very close to the different horizontal water level extent in the lake for the 4 yeas. This has then showed us the contour line difference hence the vertical extent of the water level in the lake between 1990 and 2020.

3.3.1.2 Horizontal extent of the lake

The surface area of the lake (horizontal extent) was derived from digitizing the lake extent using the time series high resolution images on google earth for the year 1990, 2000, 2010 and 2020. This helped us get the polygons of the lake for the four years that was used to compute the area in Km^2. The difference in area was also computed using ArcMap 10.5.1.

3.3.2 Land use land cover changes

3.3.2.1 Image Pre-processing and Classification

The Landsat images were pre-processed individually using Google Earth Engine and ArcGIS 10.8.1. The less than 10% cloud cover zipped Landsat TM/ETM+/OLI downloaded from USGSS and stored in the DATA/RAW data directory was processed and converted into a Tiff file. To guarantee data compatibility and facilitate the use of this data in other applications, six bands (Red, Green, Blue, Near Infrared, Shortwave Infrared 1 and Short Waves Infrared 2) in each year satellite image, were layer stacked, and mosaicked. The digital number (DN) values of the output was then converted to top-of-atmosphere (TOA) reflectance. The data was then calibrated to a common radiometric scale. A subset of the study area from each image was created. To achieve better supervised classification accuracy, the subsets were enhanced using histogram equalization method before classification. The subset images and the DEM, were georeferenced to a common projection coordinate system

The projected subset images were clustered and pixels allocated to classes (Shalaby & Tateishi, 2007) leading to defined spectral classes. Using maximum likelihood algorithm (MLC)a supervised classification was performed, generating seven LULC classes (forests, water bodies, grasslands, settlements, agriculture, barelands and shrubs). The classified images were then segmented and the shapefiles used to produce LULC maps and also to produce the areas of each classes in square kilometers for the four years.

3.3.2.2 Classification accuracy assessment

To know how accurate is our supervised classification we divided the number of successfully categorized pixels by the total number of validations sets in that class (Congalton, 2005). We compared 50 ground-truthed GPS coordinates (historical Google Earth photographs) to what was classified on each of the four images to determine the correctness of each of the seven land use classifications we've developed.

3.3.3 Relationship between probable causes and water level rise

The land-use land cover results, temperature and precipitation variations (independent variables) and the water level rise (dependent variable) for 4 years has been used to create a correlation coefficient matrix between the variable. This has helped us find out the relationship between the LULC changes, temperatures, precipitation and water level rise in Lake Nakuru.

3.3.4 Infrastructural development affected

Using the historical Google earth images between 1990 and 2020, all the development features (Roads, Buildings and Powerline) within the lake were digitized and some downloaded from OpenStreetMap platform. Using ArcMap 10.5.1 software, the Key Mark-up Language (KML) file have been converted to shapefiles, and a proximity analysis that enables suitable site, feature or event selection, respectively was done. Proximity analysis used the horizontal extent of the lake in 2020 to compute and determine its spatial relationship in distance with its neighbours (Roads, Buildings and Powerline) thus enabling us to select by location, the features that are within the horizontal water level extent of the year 2020.

4 RESULTS AND DISCUSSIONS

In order to see the "natural colour" of our area of study for easy image interpretation, a band combination of 321 on the layer stacked images was done and a 4-epoch map generated. With this band combination, ground features such as unhealthy vegetation is brown and yellow, healthy vegetation are green, roads are grey, recently cleared fields are very light, and shorelines are white, which is same as the appearance in the human visual system. This band combination is used for urban monitoring. This enabled us to visualize the extent of the lake Nakuru between 1990 and 2020 as shown in Figure 4.1.

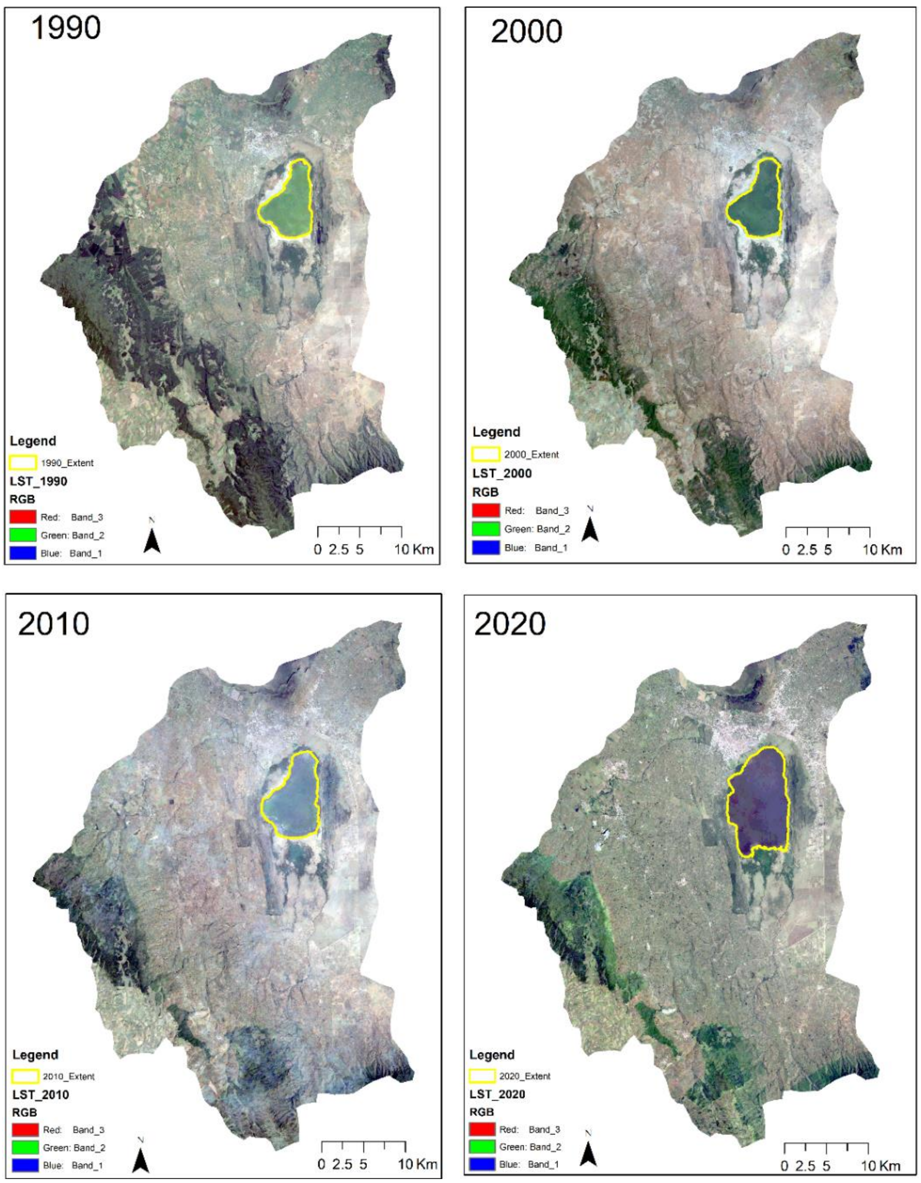

Figure 4.1: Landsat Images with 321 bands combination (Natural colour)

A 543-band combination, just like the 4 5 1 combination has been used in this study as shown in Figure 4.2 to provide us with a great amount of information and color contrast. Healthy vegetation are bright green and soils are mauve. This band combination uses TM 5, that has the most agricultural information. This combination is helpful for vegetation monitoring and studies.

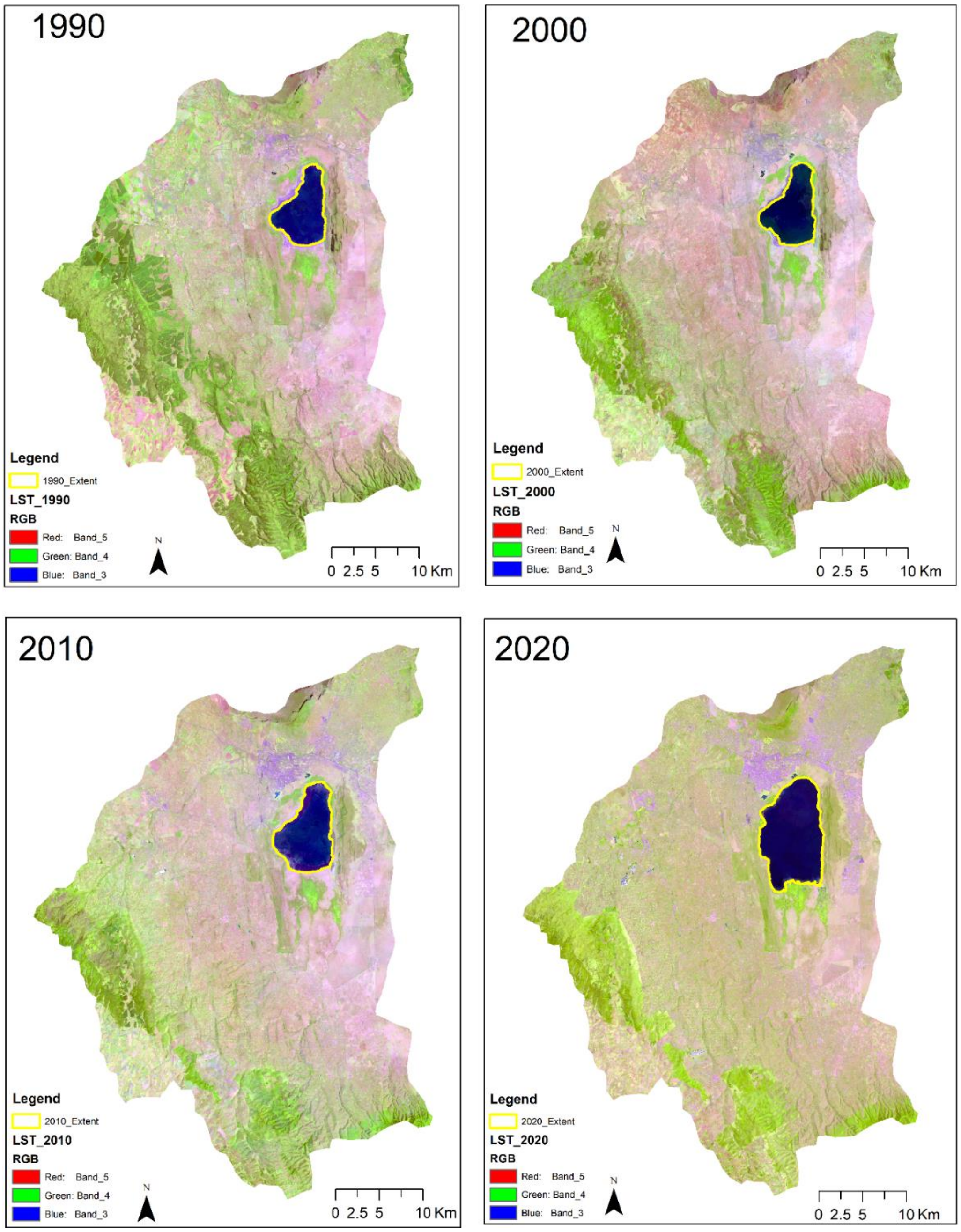

Figure 4.2: Landsat Images with 543 bands combination

4.1 Lake Extent

4.1.1 Vertical extent

The 2 metres interval contour lines of the lake Nakuru extent was generated using ArcGIS and overlaid on the Landsat images for the 4 years. The results showered that for the year 1990 the lake extent was overlaying on the 1759m contour line, in 2000 the extent was overlaying on the 1759.5m contour line, in 2010 it was overlaying on the 1760m contour line and in 2020 it was on the 1768 contour line. These results show that the vertical extent of the lake Nakuru has increased by 9 metres from 1990 to 2020, with an alarming increase of 8 metres above sea level between 2010 and 2020 as shown in Figure 4.3 and 4.4.

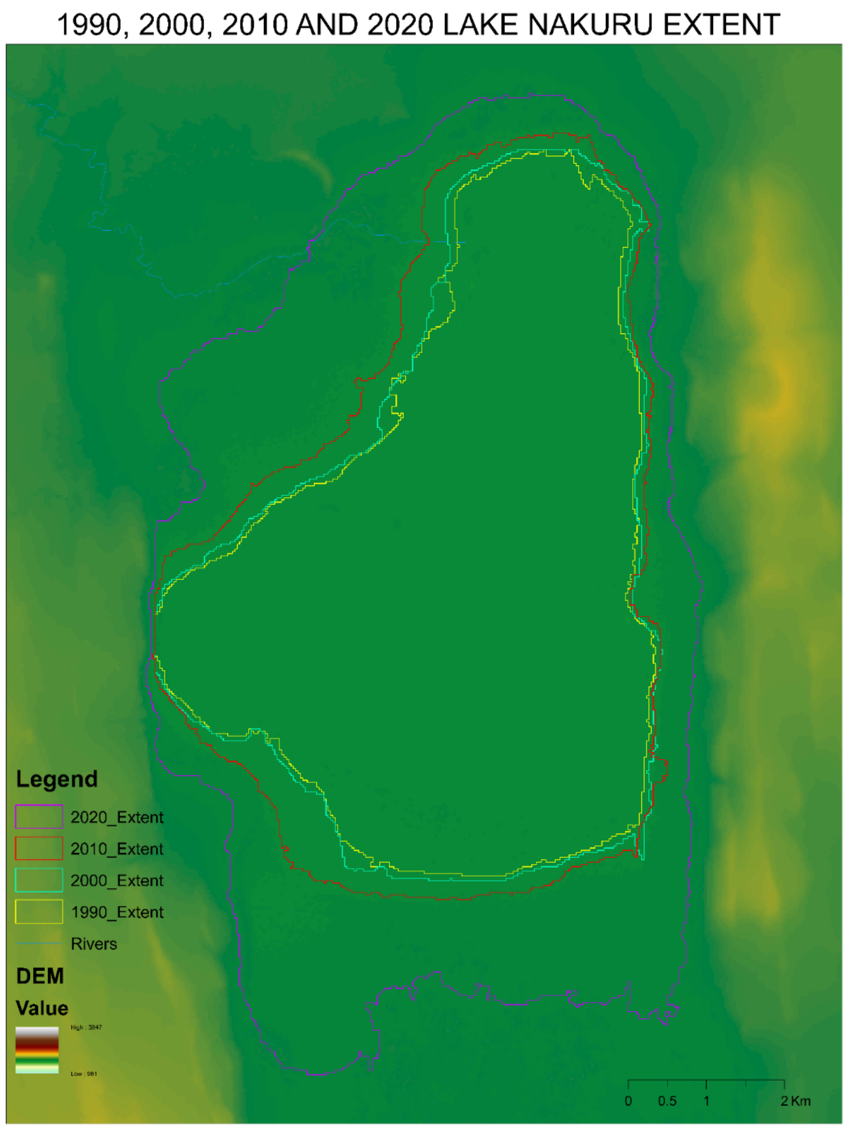

Figure 4.3: Lake Nakuru vertical extent between 1990 to 2020

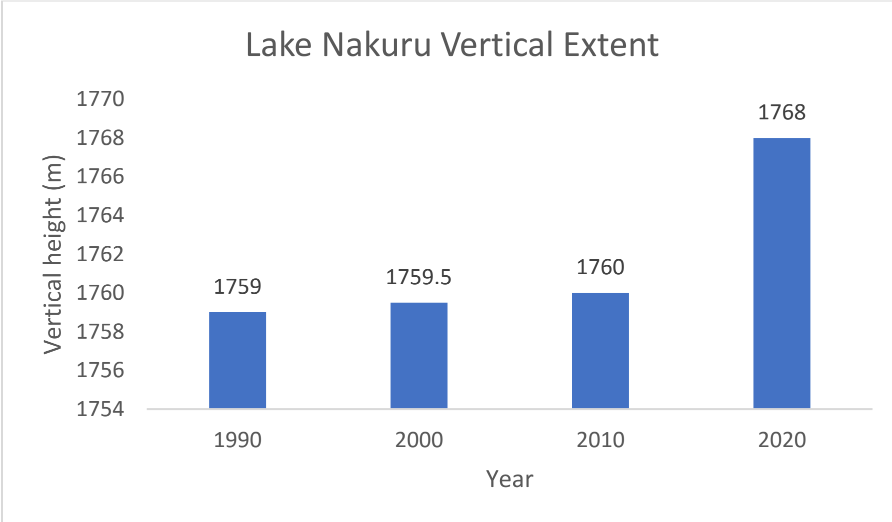

Figure 4.4: Vertical extent of lake Nakuru

4.1.2 Horizontal extent

There have been talks and research on whether the surface area of the lake has been increasing or decreasing over time. The analysis from the supervised classification on our study area has showed us that the lake surface area has been increasing from 35.60 Km^2 in 1990 to 67.07 Km^2 in 2020 which is a 31.47 Km^2 (88.4%). There was an alarming increase in the surface area of the lake between 2010 to 2020 from 42.76 Km^2 to 67.07 Km^2 which is a 24.31 Km^2 (56.9%) as shown in Figure 4.5 and 4.6. This horizontal increase has affected the socio ecological and biodiversity in and around the lake.

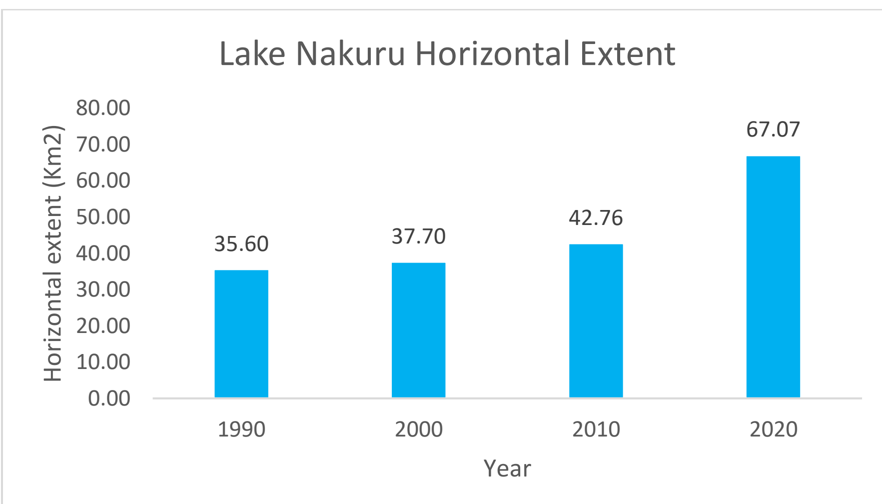

Figure 4.5: Horizontal extent of lake Nakuru

1990, 2000, 2010 AND 2020 LAKE NAKURU EXTENT

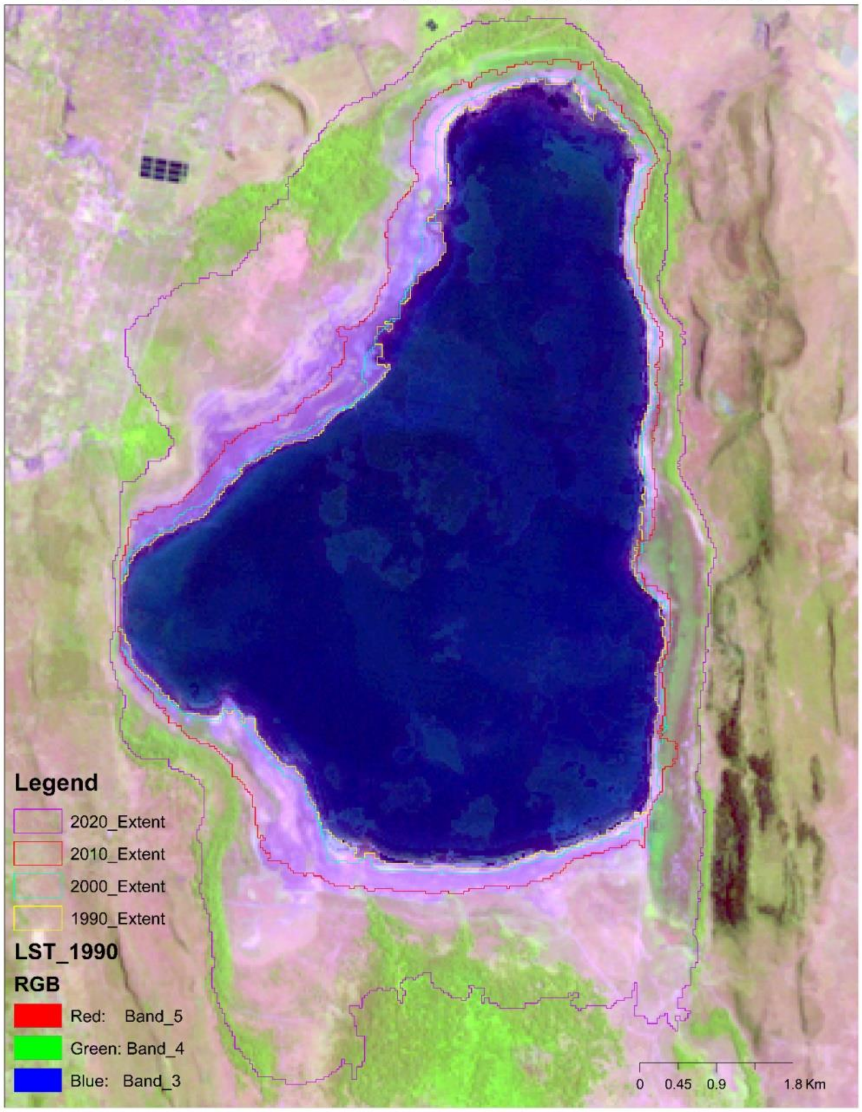

Figure 4.6: Lake Nakuru horizontal extent between 1990 to 2020

For the last 3 decades, Lake Nakuru just like any other rift valley lake has experienced tremendous water extent increase. The vertical extent has increased by 9 metres above see level as of 2020 compared to 1990. This finding can be supported by a similar study done by IPAD-USAID on the rift valley lakes, that shows that in late 2020, Lake Nakuru vertical extent was at 1767 metres above see level, and has since then been reducing as shown in Figure 4.7. The horizontal extent has equally increased by 31.47 Km^2 (88.4%) which is almost double its size in 1990. The water increase has had more effects on the Western and north Western side as well as the Southern part because of its gentle slope. The water extent went beyond the Lake Nakuru National park causing massive destruction on the biodiversity, roads, buildings, and powerline. People and animals have been displaced and some have lost their lives.

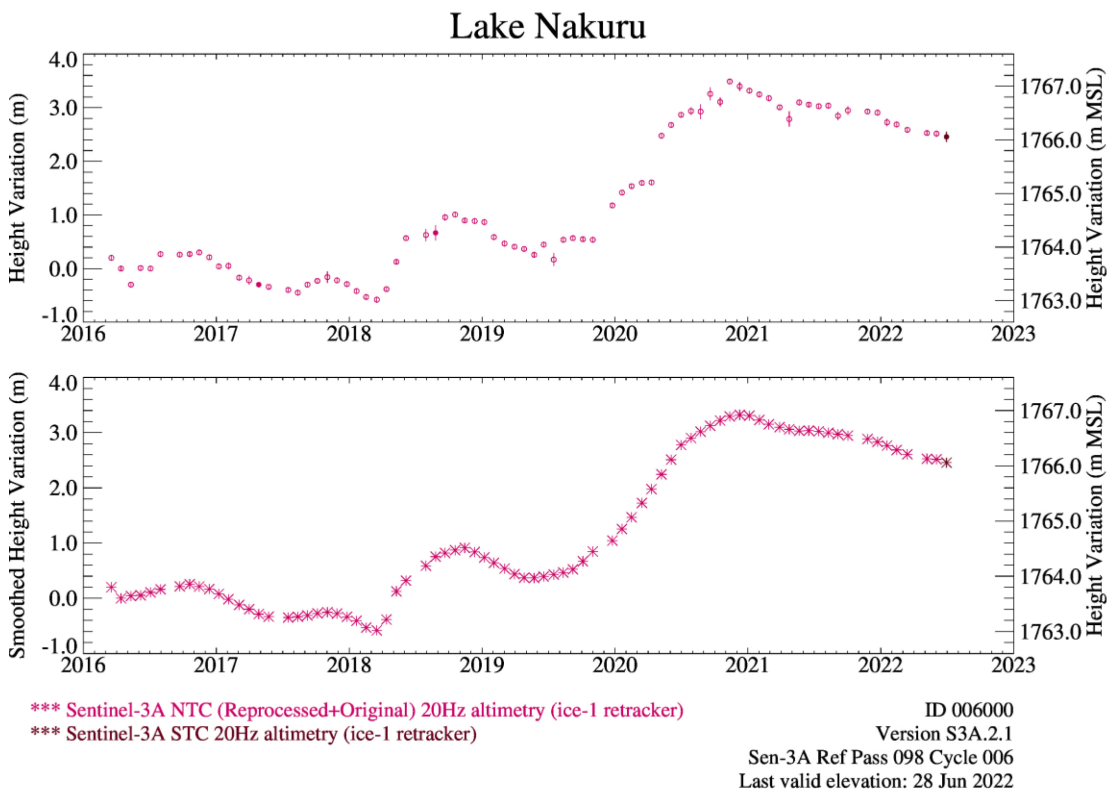

Figure 4.7: Lake Nakuru (006000) Height Variations from Altimetry

4.2 Relationship between probable causes and water level rise

4.2.1 LULC changes

The 541-band combination shown in Figure 4.8 helped us to do a pixel based supervised classification using seven classes namely: Agriculture, Bare lands, Built-up, Forest, Grassland, Shrubs and Waterbody which each class assigned 50 signature points in each year of interest.

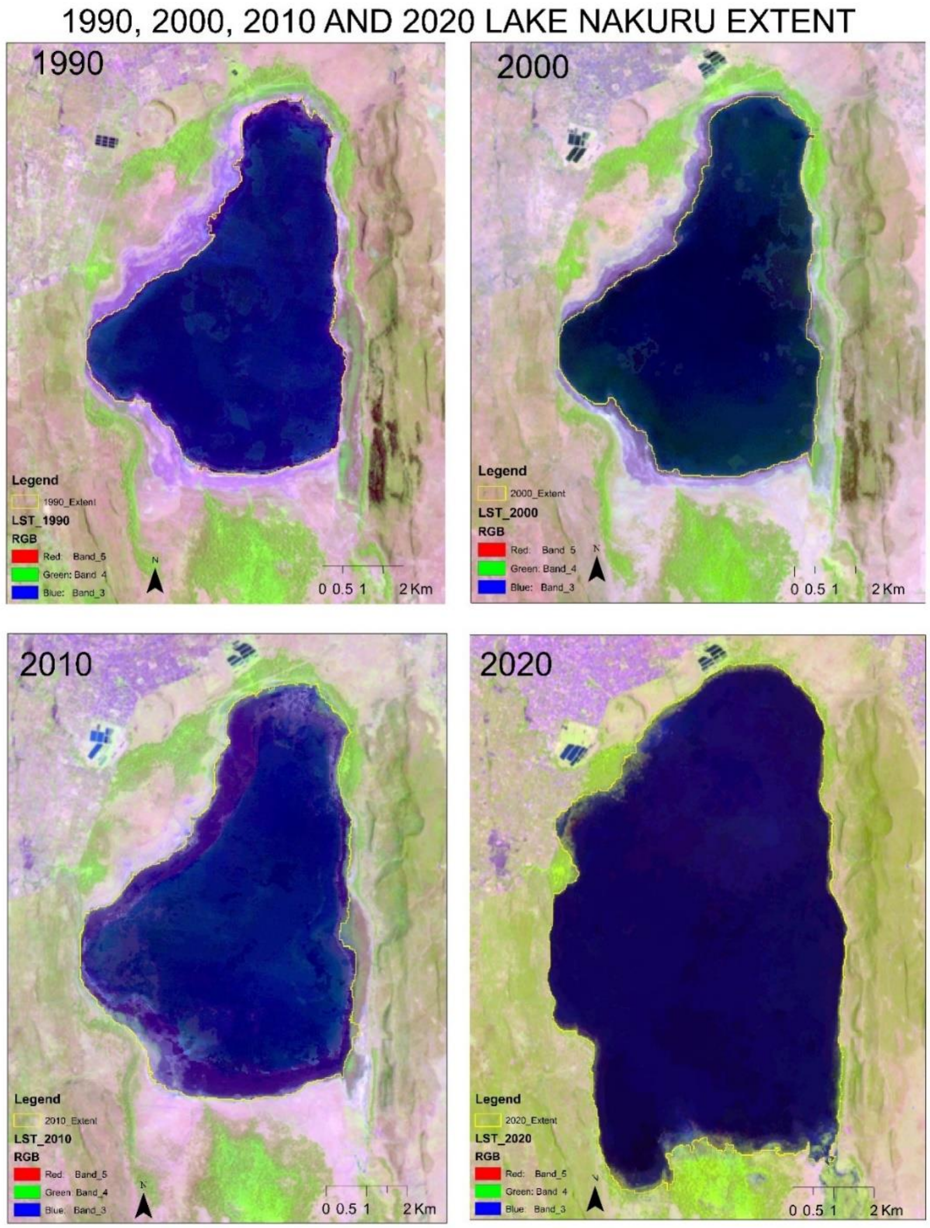

Figure 4.8: Horizontal extent of lake Nakuru between 1990 and 2020

4.2.1.1 Supervised classification

The analysis from supervised classification shows that human activities within the lake basin have been increasing over the years, leading to an effect on the water level rise in Lake Nakuru. Agriculture/farming has increased from 702.65 Km^2 in 1990 to 975.05 Km^2 in 2020 (38.8%). Built-up has been increasing from 17.35 Km^2 in 1990 to 99.71 Km^2 in 2020 (474%). Waterbody has also increased from 35.60 Km^2 in 1990 to 67.07 Km^2 in 2020 (88.4%). Shrubs have increased from 122.61 Km^2 in 1990 to 134.50 Km^2 in 2020 (9.8%). Barelands has decreased from 11.09 Km^2 in 1990 to 3.84 Km^2 in 2020 (63.6%). Forest has been decreasing from 376.52 Km^2 in 1990 to 154.53 Km^2 in 2020 (59.04%). Grassland has decreased from 302.51 Km^2 in 1990 to 133.08 Km^2 in 2020 (55.96%) as shown in Figure 4.9 and Table 4.1.

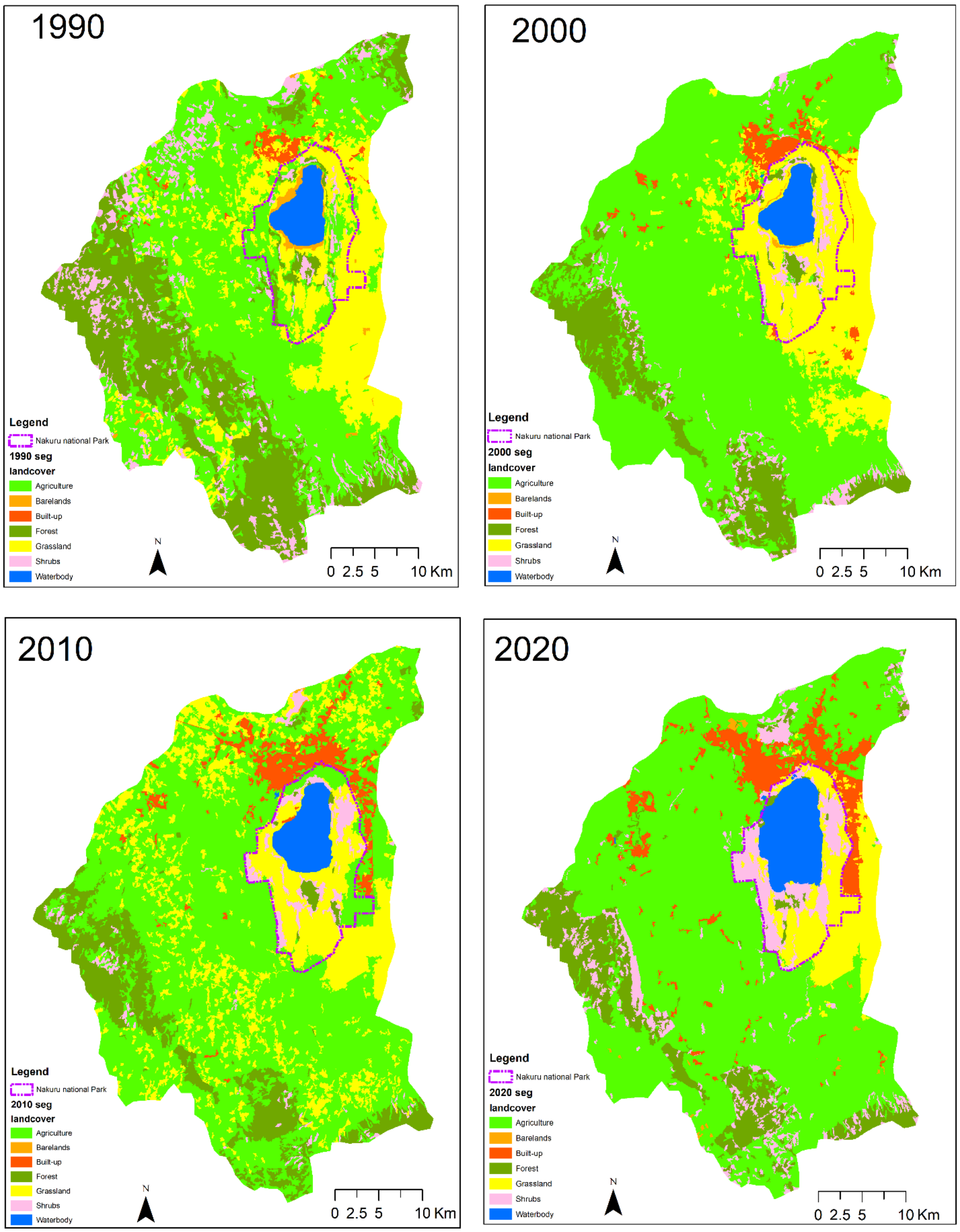

Figure 4.9: Land use Landcover changes between 1990 and 2020

Table 4.1: Land use landcover changes between 1990 and 2020

Land use	1990	2000	2010	2020	% Change
Built-up	17.35	40.19	65.25	99.71	475%
Waterbody	35.6	37.7	42.76	67.07	88%
Agriculture	702.65	957.41	931.3	975.05	39%
Shrubs	122.61	65.14	46.4	134.5	10%
Grassland	302.51	291.19	314.22	133.08	-56%
Forest	376.52	174.48	167.65	154.53	-59%
Barelands	11.09	1.97	0.5	3.84	-65%

4.2.1.2 Classification accuracy assessment

To ensure the accuracy of our supervised classification, the 50 signatures in each class in each year is compared with the classified image to ascertain if it is accurately classified by the softwares as shown in Figure 4.10. The result generally shows that the classification accuracy was 78.8%, with Waterbody 94.5%, Forest 84% and Built-up 82% having the highest accuracy and Grasslands 70%, Shrubs 73% and Agriculture 73.5 have the lowest accuracy as shown in Table 4.2.

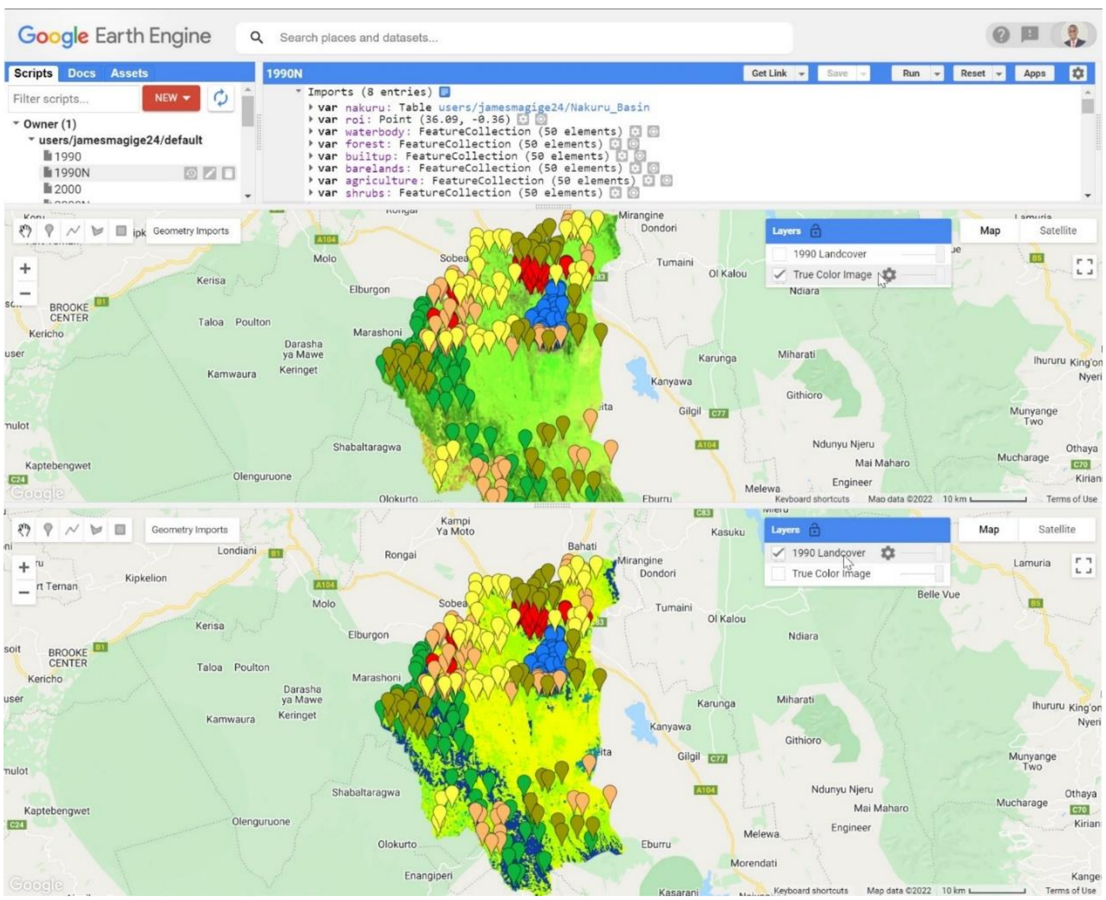

Figure 4.10: Accuracy assessment on Google Earth

Table 4.2: Land use Landcover Accuracy assessment

Land use	1990	2000	2010	2020	Average	% Accuracy
Agriculture	38	34	38	37	36.75	73.5%
Barelands	39	35	37	38	37.25	74.5%
Built-up	39	43	40	42	41	82.0%
Forest	42	41	43	42	42	84.0%
Grassland	38	35	34	33	35	70.0%
Shrubs	35	39	38	34	36.5	73.0%
Waterbody	47	48	46	48	47.25	94.5%
Average	39.71429	39.28571	39.42857	39.14286	39.39286	78.8%
% Accuracy	79.4%	78.6%	78.9%	78.3%	78.8%	

Human activities/LULC in the lake watershed (increased Agriculture, Barelands, Built-up areas and grasslands as well as decreased forest cover and Shrubs) have an impact on the water level rise in the lake. In terms of the LULC changes in the last 30 years, Built-up areas has experienced the highest land use landcover change of 475% majorly due to high population in the watershed in search of water and arable agricultural land. Followed by Waterbody which has increased by 88%. Agriculture has increased by 39% majorly due to people migrating to watershed areas in search of arable lands. Shrubs have increased by 10 % majorly due to deforestations and agriculture in the watersheds. Barelands have decreased the most by 65%, followed by Forest cover by 59% and lastly Grasslands by 56 %, these is as a result of increased human activities in the watershed.

High population increase has resulted to people cutting down forest for settlements as well as for Agriculture. This has resulted to deforestation, increased settlement as well as increased Agriculture in the watershed. This has resulted to increased barelands and grasslands as well as decreased shrubs. With increased rainfall and temperature in the watershed caused by climate change, the surface run-off has increased and water infiltration has reduced due to increased barelands and decreased vegetation cover. Increased agriculture has resulted to increased water siltation hence when it rains all almost all the water finds it self in the water bodies and with siltation the water level rises.

4.2.2 Annual Temperature and Rainfall

Over the years the temperature and rainfall patterns have fluctuated in the rift valley. For the Lake Nakuru basin, the annual average temperature from 23.37^{0}C in the year 1990 to 24^{0}C in the year 2020 as shown in Figure 4.11. The precipitation has also increased by 950% from 826.79 mm in the year 1990 to 2020 mm in the year 2020, with a massive increase between 2010 and 2020, as shown in Figure 4.12 and Table 4.3.

In the last 30 years, Increased Temperature from 23.37^{0}C in the year 1990 to 24^{0}C in the year 2020 in the watershed as a result of climate change has resulted to increased evaporation in the waterbodies which in return has led to increased precipitation in the area by 950% from 826.79 mm in the year 1990 to 2020 mm in the year 2020. Together with increased LULC/human activities in the basin as a result of increased human population, the watershed ecosystem has been affected resulting to high siltation, high surface run-off as well as less water infiltration. These has resulted to increased water level in the rift valley lakes.

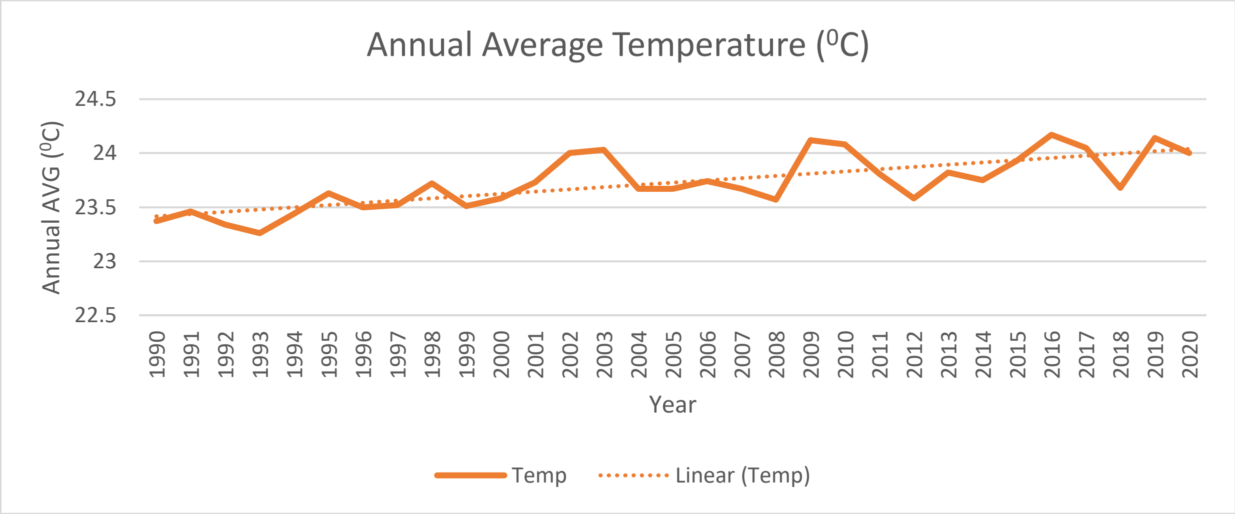

Figure 4.11: Annual Average Temperature (^{0}C)

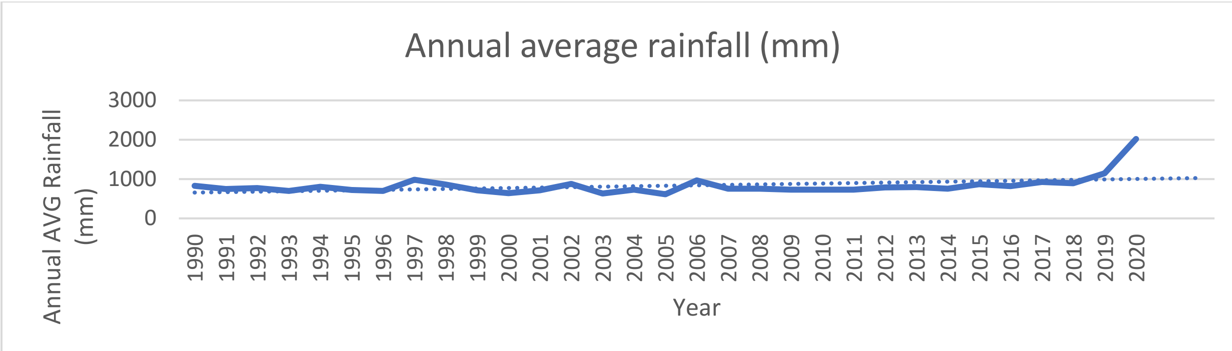

Figure 4.12: Annual average rainfall (mm)

Table 4.3: Temperature and Precipitation changes between 1990 and 2020

Year	1990	2000	2010	2020
Annual average Temperature (^{0}C)	23.37	23.58	24.08	24
Annual average Precipitation (mm)	826.79	644.72	731.05	2020

4.2.3 Correlation Matrix

A correlation Matrix between the Land use Land cover classes, temperatures and precipitation in Lake Nakuru shows that the rising water level has a very strong positive correlation of 0.964327 with the precipitation than any other probable causes, which means an increase in rainfall in the basin results to an increase in water level in Lake Nakuru. This is followed by Built up areas that has a positive correlation of 0.926782 with the lake water level and lastly Temperature has a positive correlation of 0.648903 with the lake water level, Agriculture has 0.550567 and Shrubs has 0.506646. For the negative correlation which results to an increase in water level and a decrease in the probable cause, Grassland areas has a negative correlation of -0.95645, Forest has -0.53461 and lastly Barelands has -0.023755 as shown in Table 4.4 and Figure 4.13.

Out of the six LULC/ Human activities classes, grasslands have the highest correlation (-0.9565) with the rising water levels, possibly because their decrease results to higher surface run-off, high siltation and less soil infiltration. This means that a decrease in the grasslands leads to an increase in the water level. Built-up areas are the second with correlation of (0.9268), which means an increase in built-up-areas results to an increase in waterbody. The class with the least correlation with the waterbody is barelands (-0.2376). In terms of climate change factors, both have a positive correlation, which means an increase in the climate change factors leads to an increase in the water level rise. Precipitation has the highest correlation (0.964327) which also happen to be the highest in all the factors. Followed by Temperature with a positive correlation of (0.6489) which means precipitation has a more direct influence on the water level rise than temperature, even though increased temperature is the cause of rainfall.

Table 4.4: Correlation Matrix

	Year	Agricultur	Barelands	Built-up	Forest	Grassland	Shrubs	Waterbod	Temp (0C) (Annual avg)	Precipitation (mm) (Annual avg)
Year	1	0.802612	-0.63794	0.995127	-0.8209	-0.73442	0.050886	0.885292	0.910551	0.731271
Agriculture	0.802612	1	-0.90658	0.762574	-0.99311	-0.44279	-0.35433	0.550567	0.731149	0.339119
Barelands	-0.63794	-0.90658	1	-0.56408	0.937772	0.056427	0.700448	-0.23755	-0.744252	0.021617
Built-up	0.995127	0.762574	-0.56408	1	-0.7744	-0.79496	0.148912	0.926782	0.873913	0.794961
Forest	-0.8209	-0.99311	0.937772	-0.7744	1	0.39543	0.411767	-0.53461	-0.793323	-0.307924
Grassland	-0.73442	-0.44279	0.056427	-0.79496	0.39543	1	-0.67303	-0.95645	-0.40708	-0.981423
Shrubs	0.050886	-0.35433	0.700448	0.148912	0.411767	-0.67303	1	0.506646	-0.262986	0.716729
Waterbody	0.885292	0.550567	-0.23755	0.926782	-0.53461	-0.95645	0.506646	1	0.648903	0.964327
Temp (0C) (Annual avg)	0.910551	0.731149	-0.74425	0.873913	-0.79332	-0.40708	-0.26299	0.648903	1	0.441991
Precipitation (mm) (Annual avg)	0.731271	0.339119	0.021617	0.794961	-0.30792	-0.98142	0.716729	0.964327	0.441991	1

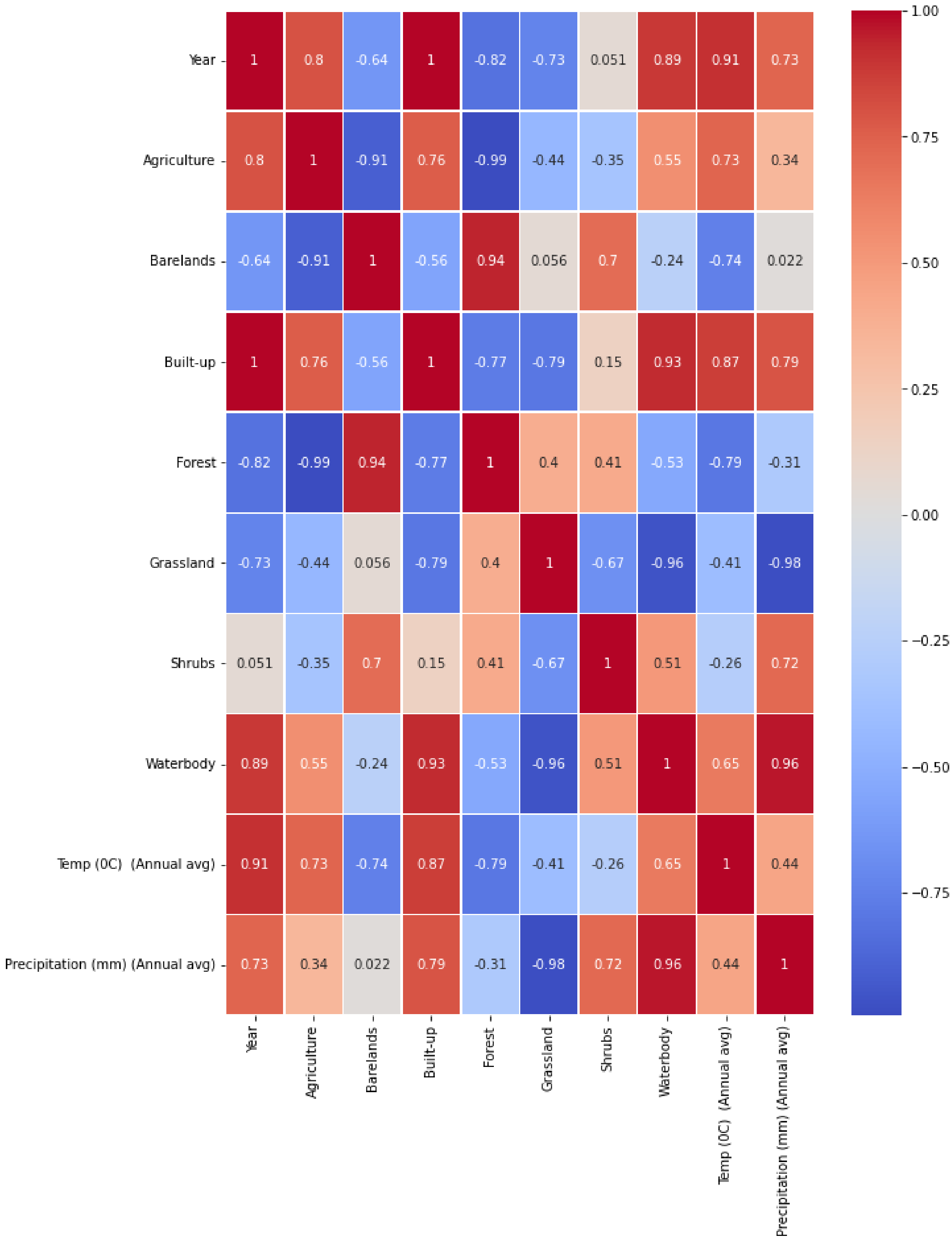

Figure 4.13: Correlation Matrix

4.3 Affected Infrastructure

4.3.1 Building affected

The spatial analysis shows us that 178 building structures at the Mwariki area and the park entrance that have been submerged and destroyed by the rising water level by 2020. This has also resulted to displacement of people, animals and birds around the lake. The 2 parking lots at the entrance has also been submerged as shown in Figure 4.14, 4.15, 4.16. 4.17, 4.18 and 4.19.

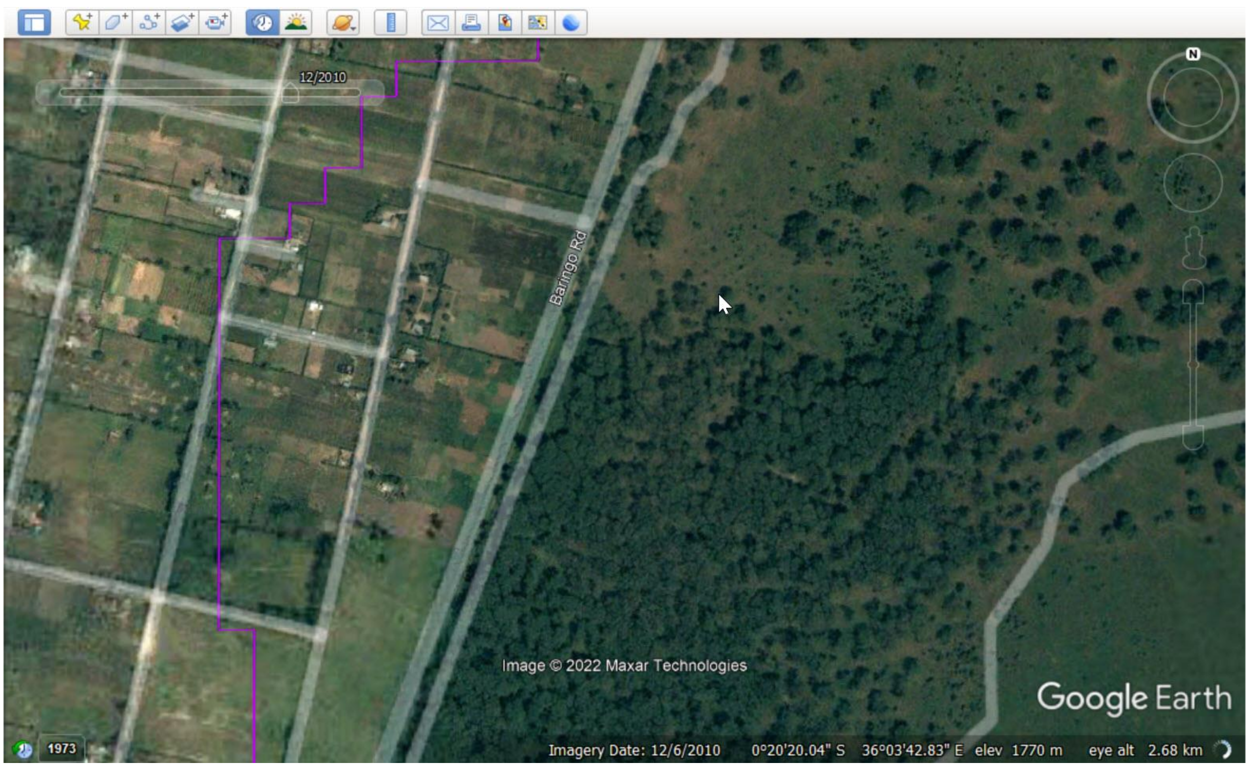

Figure 4.14: Buildings around Mwariki area in 2010

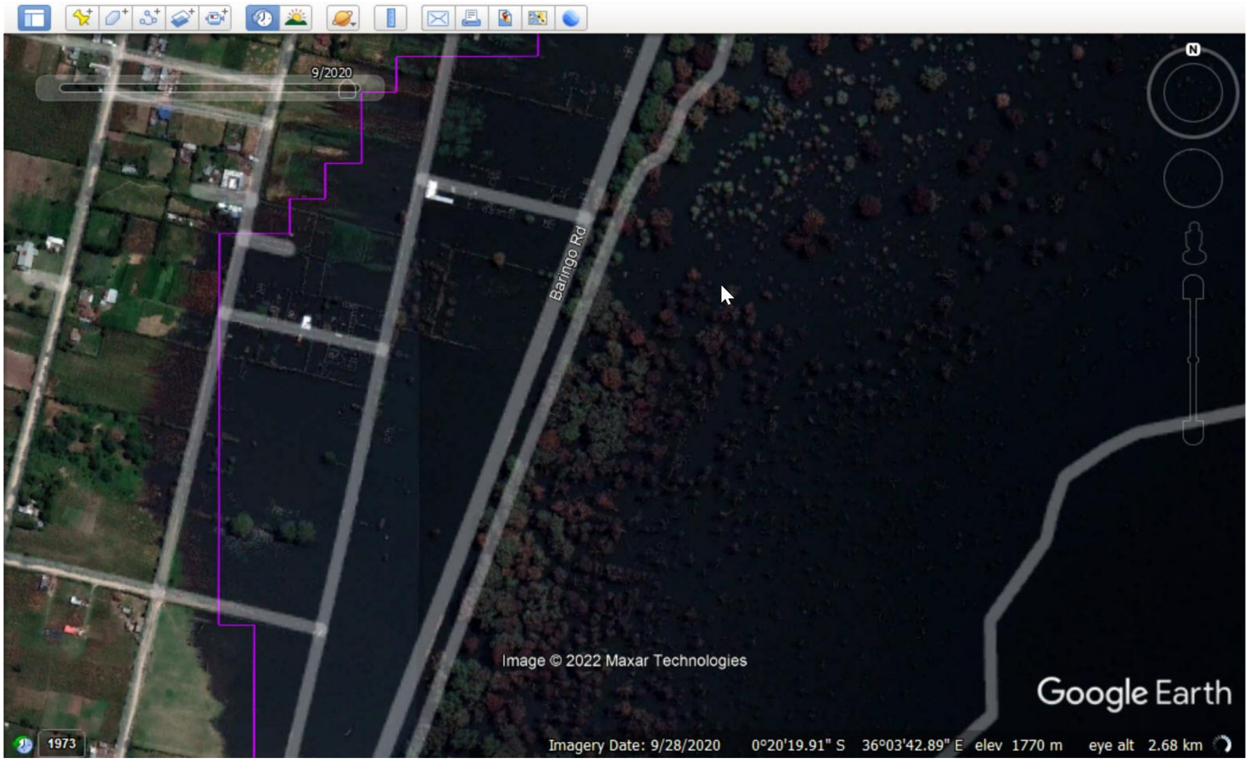

Figure 4.15: Submerged buildings around Mwariki area in 2020

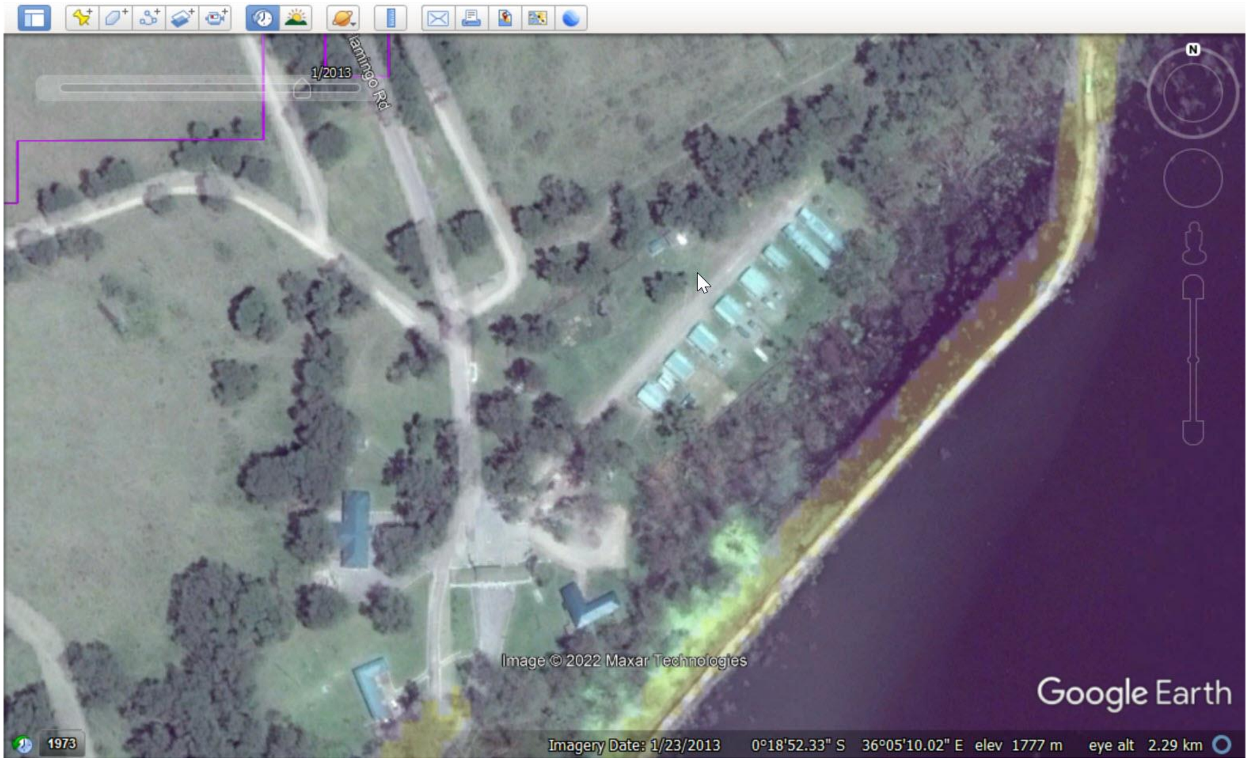

Figure 4.16: Buildings around the park entrance gate area in 2013

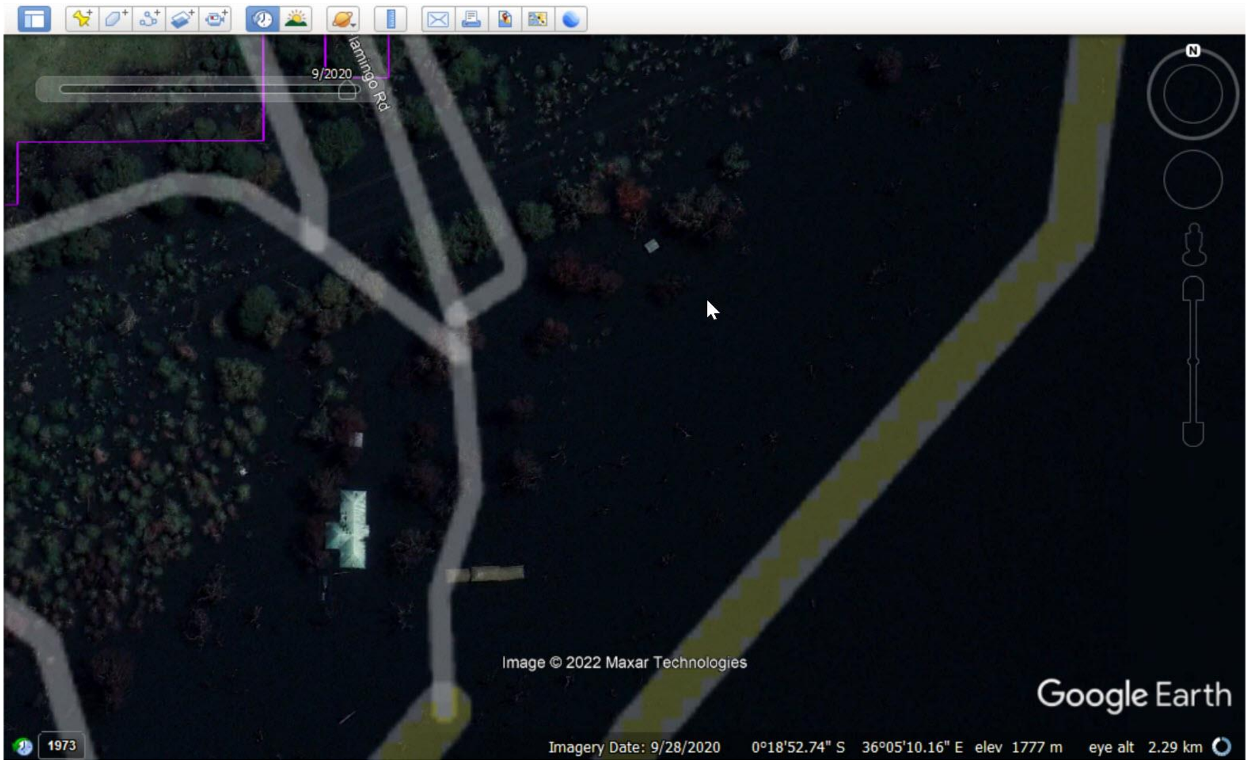

Figure 4.17: Affected buildings around the park entrance gate area in 2020

Figure 4.18: Submerged park entrance gate in 2020

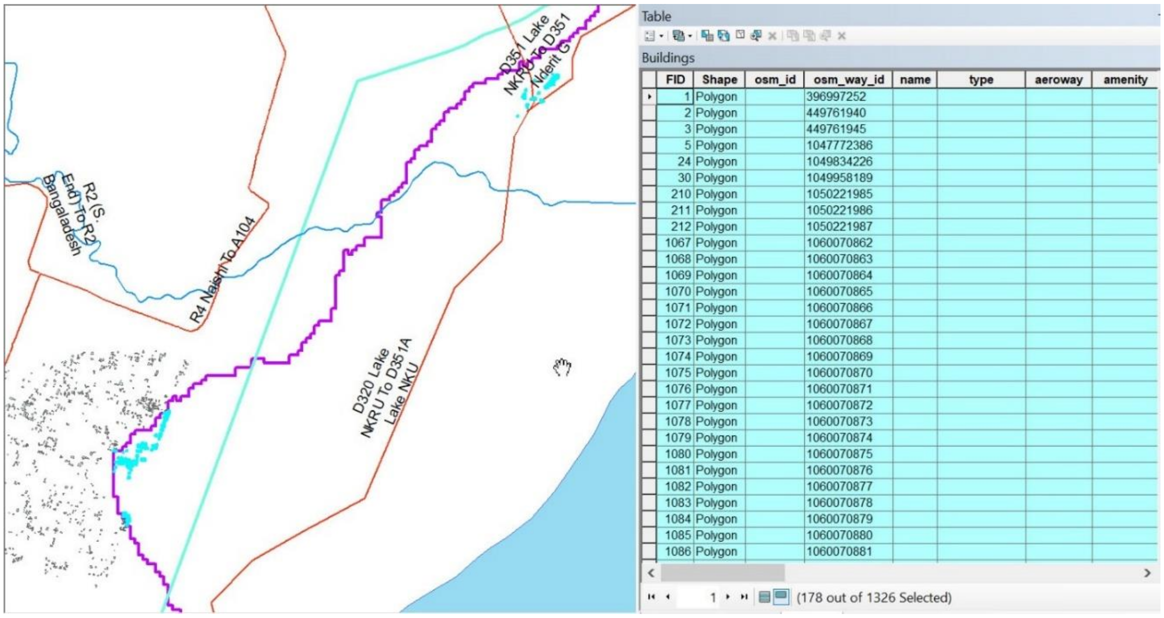

Figure 4.19: Submerged buildings in 2020

4.3.2 Road network affected

The road network which is crucial in the area because of the park, has been dramatically affected and destroyed by the rising water level in Lake Nakuru. From the analysis, 3 KenHA roads have been affected as shown in Figure 4.20. Baringo road near the Mwariki area and Flamingo road to the park entrance has also been submerged. This has affected the people who rely on tourism sector for survival.

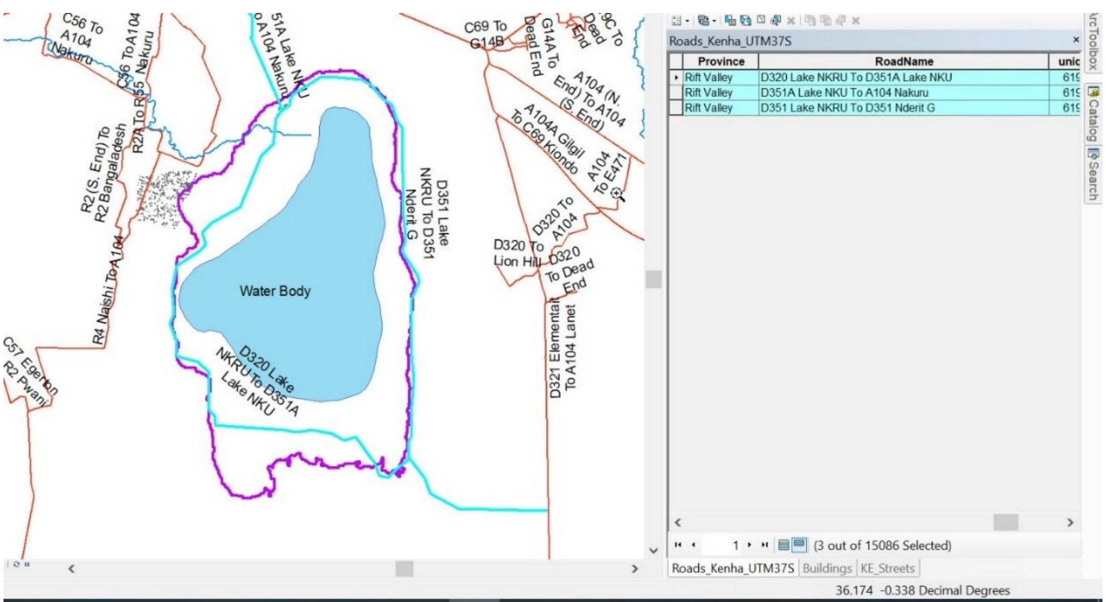

Figure 4.20: Submerged road network in 2020

4.3.3 Powerline affected

The powerline that supplies electricity to the park has also been destroyed by the rising water level, affecting other functionality within the park, as shown in Figure 4.21.

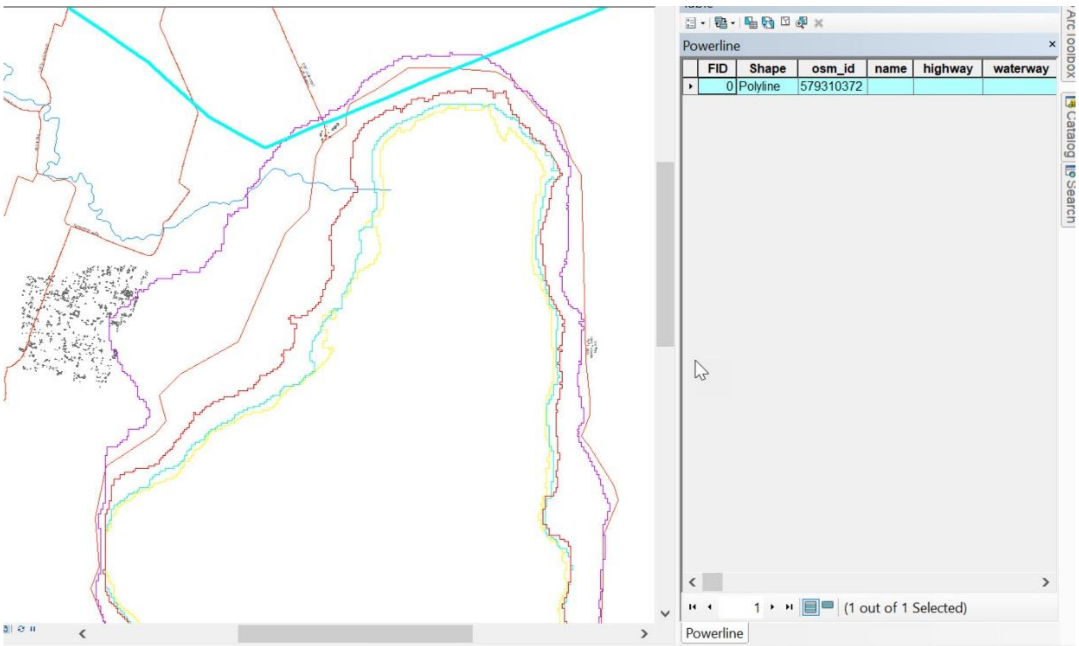

Figure 4.21: Affected powerline in the year 2020

Waterbody increased vertically and horizontally for the last 3 decades due to the increased precipitations, LULC, human activities, and Temperature. Horizontally, the water extent surpassed the Lake Nakuru National park in 2020, resulting to destruction of properties, buildings, powerline and roads. This led to loss of lives, displacement of people and animals more so to the western side, Northern side and the southern of the Lake Nakuru.

4.4 Discussions of the results

For the last 3 decades, Lake Nakuru just like any other rift valley lake has experienced tremendous water extent increase. The vertical extent has increased by 9 metres above see level as of 2020 compared to 1990. This finding can be supported by a similar study done by IPAD-USAID on the rift valley lakes, that shows that in late 2020, Lake Nakuru vertical extent was at 1767 metres above see level, and has since then been reducing due to reduced rainfall in the watershed. The horizontal extent has equally increased by 31.47 Km^2 (88.4%) which is almost double its size in 1990. The water increase has had more effects on the Western and north Western side as well as the Southern part because of its gentle slope. The water extent went beyond the Lake Nakuru National park causing massive destruction on the biodiversity, roads, buildings, and powerline. People and animals have been displaced and some have lost their lives.

Human activities/LULC in the lake watershed (increased Agriculture, Barelands, Built-up areas and grasslands as well as decreased forest cover and Shrubs) have an impact on the water level rise in the lake. In terms of the LULC changes in the last 30 years, Built-up areas has experienced the highest land use landcover change of 475% majorly due to high population in the watershed in search of water and arable agricultural land. Followed by Waterbody which has increased by 88%. Agriculture has increased by 39% majorly due to people migrating to watershed areas in search of arable lands. Shrubs have increased by 10 % majorly due to deforestations and agriculture in the watersheds. Barelands have decreased the most by 65%, followed by Forest cover by 59% and lastly Grasslands by 56 %, these is as a result of increased human activities in the watershed.

Increased Temperature from 23.37^{0}C in the year 1990 to 24^{0}C in the year 2020 in the watershed as a result of climate change has resulted to increased evaporation in the waterbodies which in return has led to increased precipitation in the area by 950% from 826.79 mm in the year 1990 to 2020 mm in the year 2020. Together with increased LULC/human activities in the basin as a result of increased human population, the watershed ecosystem has been affected resulting to high siltation, high surface run-off as well as less water infiltration. These has resulted to increased water level in the rift valley lakes.

Out of the six LULC/ Human activities classes, grasslands have the highest correlation (-0.9565) with the rising water levels, possibly because their decrease results to higher surface run-off, high siltation and less soil infiltration. This means that a decrease in the grasslands leads to an increase in the water level. Built-up areas are the second with correlation of (0.9268), which means an increase in built-up-areas results to an increase in waterbody. The class with the least correlation with the waterbody is barelands (-0.2376). In terms of climate change factors, both have a positive correlation, which means an increase in the climate change factors leads to an increase in the water level rise. Precipitation has the highest correlation (0.964327) which also happen to be the highest in all the factors. Followed by Temperature with a positive correlation of (0.6489) which means precipitation has a more direct influence on the water level rise than temperature, even though increased temperature is the cause of rainfall.

5 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of Key Findings

This study focused on establishing whether LULC changes, Temperatures, and Precipitation affect Lake Nakuru's water level rise. This study provides comparative estimates of changes in seven land-use and cover classes due to increased human activities in the lake basin from 1990, 2000, 2010, and 2020. But before establishing the relationship between the LULC changes, temperatures, precipitations, and the rising water level, it was good to first look at whether the lake has indeed increased vertically and horizontally. Vertically the lake extent has increased by 9 metres from 1759m in 1990 to 1768m in 2020, horizontally the lake extent has increased from 35.60 Km^2 in 1990 to 67.07 Km^2 in 2020 which is a 31.47 Km^2 (88.4%).

Human activities/LULC in the lake watershed (increased Agriculture, Barelands, Built-up areas and grasslands as well as decreased forest cover and Shrubs) have an impact on the water level rise in the lake. In terms of the LULC changes in the last 30 years, Built-up areas has experienced the highest land use landcover change of 475% majorly due to high population in the watershed in search of water and arable agricultural land. Followed by Waterbody which has increased by 88%. Agriculture has increased by 39% majorly due to people migrating to watershed areas in search of arable lands. Shrubs have increased by 10 % majorly due to deforestations and agriculture in the watersheds. Barelands have decreased the most by 65%, followed by Forest cover by 59% and lastly Grasslands by 56 %, these is as a result of increased human activities in the watershed.

Annual mean precipitation has increased by 950% from 826.79 mm in 1990 to 2020, with the massive increase taking place between the year 2010 and 2020. The annual average temperatures have also increased from 23.370C in 1990 to 240C in 2020. Out of the six LULC/ Human activities classes, grasslands have the highest correlation (-0.9565) with the rising water levels, possibly because their decrease results to higher surface run-off, high siltation and less soil infiltration. This means that a decrease in the grasslands leads to an increase in the water level. Built-up areas are the second with correlation of (0.9268), which means an increase in built-up-areas results to an increase in waterbody. The class with the least correlation with the waterbody is barelands (-0.2376). In terms of climate change factors, both have a positive correlation, which means an increase in the climate change factors leads to an increase in the water level rise. Precipitation has the highest correlation (0.964327) which also happen to be the highest in all the factors. Followed by Temperature with a positive correlation of (0.6489) which means precipitation has a more direct influence on the water level rise than temperature, even though increased temperature is the cause of rainfall.

With reference to the main objective, the research found out that there is a relation between LULC changes, temperature, precipitation and the water level rise in the lake. There is a very strong positive correlation (Corr = 0.964327) between precipitation and water level rise. These makes precipitation the main probable cause of water level rise in Lake Nakuru, considering only LULC changes, temperatures and precipitation as the probable causes. 178 building structures around the lake have been destroyed and submerged, 4 Road networks and one powerline have been submerged and destroyed.

5.2 Conclusions

Considering that only LULC changes, temperatures and precipitation as the probable causes of the water level rise in the rift valley lakes in Kenya. High temperatures result to high evaporations in the lakes, which results to high precipitation in the basin. Due to increased human activities such as deforestation, settlement, and agriculture, more surface is exposed. When it rains, there is less water infiltration and higher surface run-off into to the rivers feeding the lakes. This also causes siltation in rivers and lakes which results to water level rising in the lakes. When this water rises it causes flooding which destroyed properties, causes loss human, animals and birds' lives. Flooding also affect the economic and social activities of the region. With the finding in this study, human activities within the basin should be closely monitored to avoid further mess. The concept of sustainable development in the lake basin must be pursued in principle and in practice and must be applied in politics, as well as farming until the idea becomes accepted and integrated in our collective thinking and wisdom.

5.3 Recommendations

Since the study only focused on only LULC changes, temperatures and precipitation as the probable causes of the water level rise in the rift valley lakes, we recommend that all other probable causes of the water level rise such us, active tectonic and change in weather patterns should be considered. A much higher resolution DEM and Satellite Images should be used for more accurate results. We also recommend that a research to identify the most appropriate contour line to be used to create buffer zone along the lake be done to avoid future impacts of flooding since the water level has gone beyond the Lake Nakuru national park boundary as of the year 2020. Strong institutions such as Lake Nakuru Catchment Management Center should be established to sustainably manage the forests/woodlands in the area for both development and conservation. Since forests/ woodlands continue to be converted to other land-uses (e.g. Agriculture and Built-up), while socio-economic disparities keep increasing, there is a need for continuous monitoring of forest and the surrounding areas as well as increased human activity. The forested areas should be mapped and buffer zones created to help create boundary and thus preventing people from cutting trees in the forest.

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