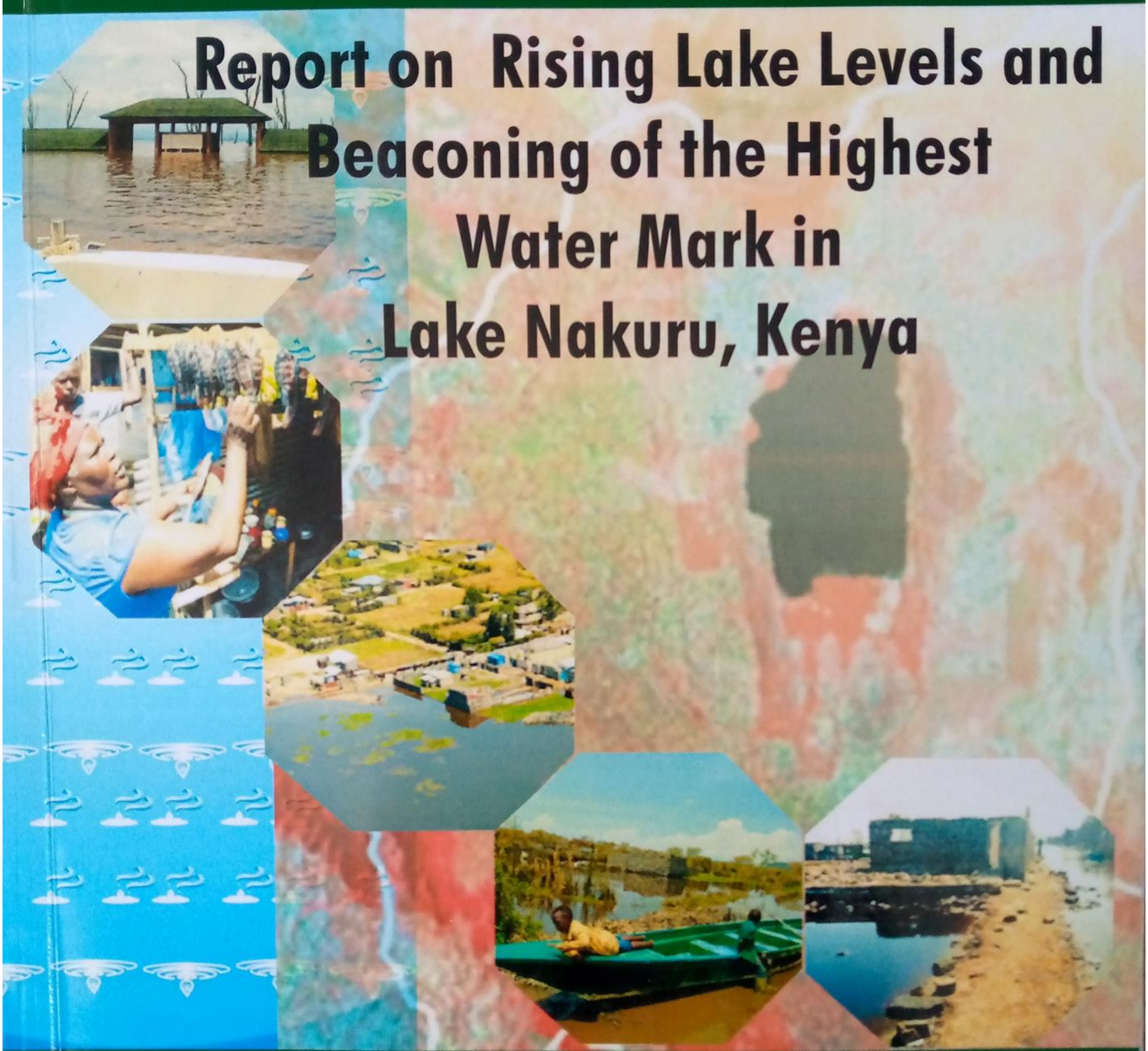
REPUBLIC OF KENYA

COUNTY GOVERNMENT OF NAKURU

DEPARTMENT OF WATER, ENVIRONMENT, ENERGY AND NATURAL RESOURCES

Report on Rising Lake Levels and Beaconing of the Highest Water Mark in Lake Nakuru, Kenya



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LIST OF ABBREVIATIONS

CBO	Community Based Organization
DO	Direct Observation
DRSRS	Department Of Resource Surveys And Remote Sensing
ENSO	El-Nino Southern Oscillation
FGD	Focus Group Discussions
GIS	Geographical Information System
Ha	Hectares
IOD	Indian Ocean Dipole
ITCZ	Intertropical Convergence Zone
KALRO	Kenya Agricultural Livestock Research Organization
KEFRI	Kenya Forest Research Institute
KFS	Kenya Forest Service
KII	Key Informants Interviews
Km^2	Kilometres Squared
KMD	Kenya Meteorological Department
KWS	Kenya Wildlife Service
KWTA	Kenya Water Towers Agency
ILBM	Integrated Lake Basin Management
LULC	Land Use & Land Cover
M asl	Meters Above Sea Level
MEF	Ministry of Environment and Forestry
MW	Megawatts
NAWASSCO	Nakuru Water and Sanitation Services Company Limited
NDOC	National Disaster Operations Centre
NEMA	National Environment Management Authority
SMEs	Small- Medium Enterprises
WRA	Water Resources Authority
WRUAs	Water Resources User Association

ACKNOWLEDGEMENTS

We acknowledge the steering role performed by the Governor County Government of Nakuru, H.E. Hon. Lee Kinyanjui in identifying the need to undertake this study, for appointing the taskforce members and for providing the necessary logistics required to undertake the study.

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EXECUTIVE SUMMARY

Since September 2010, the water level in Lake Nakuru and seven other Rift Valley lakes has risen to extraordinary levels. The lake level rise has led to the submergence of nearly all the riparian land and displacement of thousands of people. Infrastructure such as roads, settlements, social amenities, grazing land, farmland, fish landing and processing facilities, electricity lines, water supply structures and wildlife habitats have been destroyed leading to significant loss of livelihoods and biodiversity. There have been increased human wildlife conflicts occasioned by shrunk habitats and stress both on animals and humans.

It is on the basis of these major concerns that the Governor Nakuru County, H.E. Hon. Lee Kinyanjui constituted a Multi-Agency Technical Team to assess the impacts of Rising Water Levels, Flood Related Implications and Riparian Zone Beaconing in Lake Nakuru.

Lake Nakuru (36^0 05' E, 00^0 24' S); lies at an altitude of 1758 m above mean sea level at the lowest point of a catchment basin of approximately 1800 km^2. Lake Nakuru measured approximately 43 km^2 in December 2010 and 68km^2 as of June 2021 respectively. This represents an increase of 25km^2 (36.8%) within ten years. The changes in lake area were calculated based on various water level rise scenarios using the SWAT model. To calculate water surface areas at different water rise levels, GIS tools were used to accurately delineate the Lake Nakuru boundary as of June 2021 as the baseline year. In order to undertake simulation and determine the impact of the rising water levels of Lake Nakuru, satellite imagery, Alos Palsar Digital Elevation Models (DEM) with 12.5m resolution and a digitized Lake Nakuru boundary as of June, 2021 were analysed using remote sensing and GIS software.

Based on the 0.7m water level rise per year, an interval of two (2) years was used and therefore projection was done at 1.4m, 2.8m, 4.2m,5.6m and 7m respectively with the base year being 2021(June) and water level estimated at 9.2m during this year. Consequently, the simulation was therefore projected for the years 2023, 2025, 2027 and 2029 in order to assess the level of impact around the lake.

Land-use/ land cover changes within Lake Nakuru catchment were assessed and the spatial dimensions of satellite images were evaluated. Landsat-7 satellite images with 30m spatial resolution covering Lake Nakuru Catchment area for the years 1990, 2000, 2010 and 2019 were downloaded from the United States Geological Survey (USGS) Earth explorer website. The images were processed using ERDAS 2016, a remote sensing software.

To establish the direct and indirect socio-economic impacts of flooding, a total of 100 households were sampled in the four settlements adjacent to the Lake Nakuru National Park. Additional information on the impacts on infrastructure, human/wildlife conflicts, tourism and biodiversity were obtained from Kenya Wildlife Service. A total of 677 families were affected and entailed; 325 households at Barut East sub-location of Barut Ward, 352 households in Mwariki area. In Parkview sub-location in Barut location, about 70 Hectares of land has been submerged within the village. As a result, the local community suffered from psychological trauma and stress as well as low/weak coping mechanism for special groups like PWDs, older persons etc. The affected households were depending on relatives, well-wishers and friends at their new settlements to obtain food.

The rise in lake levels has resulted in capital expenditures of over Ksh. 160 million (in construction of new roads, fences, buildings and other infrastructure) as reported by KWS –Lake Nakuru National

Park. The rise in lake levels has affected the riparian ecosystem, displaced wildlife, road network, staff houses, office blocks, main gate, electric fences and campsites etc. Lake Nakuru National Park has recorded increased cases of human/wildlife conflicts. The lake flood waters have inundated the lower sections of the Old Town Sewage Treatment Plant (STP) and this may compromise Nakuru City's capacity to treat wastewater if the situation continues.

The results reveal a complex interplay of hydro-meteorological variables due to climate change that have led to increased moisture availability as seen in the rainfall data and discharge of the rivers feeding Lake Nakuru, land use land use changes which have increasingly added to the siltation of the lake as seen in the sediment load in the rivers, possible seismic activities etc. The main causes are summarized as follows:

1. The study shows that the extraordinary rise in lake water levels is mainly caused by a strong response to the enhanced rainfall during the 2010-2020 periods. The results of 12-month and 24-month analysis indicate successive moderately wet to severely wet 12- and 24-month periods from 2010 onwards;

2. Increased river flow has led to increased water levels in Lake Nakuru. There has been increased water supply due to increased runoff brought about by changes in land use practices. Discharge analysis from 2FC19 shows that there is a clear streamflow response to the precipitation occurring in the catchment. The first peak flow occurs in May a month after peak rainfall while the second peak flow coincides with that of rain in the month of August.

3. The land use/ land cover maps indicate a significant reduction of the forest cover within the basin from 2001 when 35,000 Hectares was excised to allow for human settlement. The encroachment to forest land for agriculture and other development has led to stripping off the terrains of important forest cover that played the role of reducing runoff and subsequently soil erosion by playing an important role of arresting the eroded soil, leading to increased siltation and sedimentation in Lake Nakuru.

4. Sediment deposition with the layer thickness varies from 0 m to 0.7 m (maximum) and the total sediment storage capacity of 24,191,688.67 m^3. This implies that the sediment occupy 8.37% of the lake storage capacity due to the different activities in the watershed typically inadequate waste disposal systems in the urban watersheds, and increased land use and land cover changes. The severity of land degradation due to anthropogenic threats has resulted in higher rainfall runoff from land, and less percolation into the groundwater systems, leading to larger volumes of water flowing directly and rapidly from the land surface into the lake.

5. Geological controls are also thought to play a role in the current surge of Rift Valley lakes. The entire rift system consists of discrete rift basins which are mechanically linked by zones of rift oblique faulting. The KWTA Taskforce (2015) study shows that significant seismic activities were recorded from 2010-2014 in Kenya with most activities being maximum in 2010-2011.The increased seismic activities could have triggered increased erosion and subsequent siltation that could have led to the rise in the lake levels. Seismic activities could also trigger flow of water into the lakes from other aquifer systems through fractures formed. However, more studies need to be undertaken. This increase in seismic activities coincided with the very wet period and the rise in the lake water levels.

6. Analysis of changes in ground water levels indicates a rise of about 8 m (from 62.7 to 54.4m) in the Water Rest Levels in the Baharini borehole between 2010 and 2021, showing that groundwater has been rising in response to the increased rainfall. An increase in groundwater level is also evident in St Mary's and Kabatini boreholes and indication of supersaturation of ground water aquifers around Lake Nakuru basin.

The key recommendations are as follows:

1. In the short-term, there should be immediate provision of humanitarian assistance to the affected households with food and non-food items as well as incentives, subsidies, and cash transfers to enable them to cope with the crisis. This includes food, shelter and shelter kits, emergency health services, health and nutrition, provision of portable water, hygiene, and sanitation facilities as well as psycho-social support which is urgently required in the immediate phase.

2. In the short-medium term, the Lake Nakuru riparian area should be clearly marked and beacons installed along the highest watermark. However, the work on Lake Nakuru need to be concluded as per set bench marks by re-doing a more refined LULC analysis within the lake catchment using medium/high resolution satellite imageries and high precision DEM for accurate simulation of the water level rise overflows over time. Consequently, a 5m resolution DEM shall be required.

3. A more accurate socio-economic study using a high-resolution satellite imagery of about 50cm is required to accurately map the affected households, infrastructure and other amenities that may be impacted by lake water level rise in the worst case scenario. A comprehensive field ground truthing coupled with satellite image field validation is essential. This will provide the County and National Government with the requisite spatial data for possible planning of the compensation and resettlement of the affected community by evacuating them from the area marked as riparian zone. This will also enable KWS to expand the park boundary and create a buffer zone between the park and the human settlements.

4. The County and National Government should promote Integrated Lake Basin Management (ILBM) as a strategy to provide an integrated framework for the sustainable management and use of Lake Basin resources through informing policies, strategies, plans, projects and programmes, as well as to guide coordinated agency actions. ILBM incorporates lakes and river basins and their associated wetlands as well as the entire scope of the biophysical, socioeconomic and governance aspects, while fully incorporating Integrated Water Resources Management (IWRM) and Integrated River Basin Management (IRBM) principles and approaches, to ensure that there is a balance between conservation and development.

5. Similar scientific study should be replicated in the remaining four lakes in Nakuru County, focusing on land use/land cover, as well as Water Balance studies using High Resolution Images (5m) to inform establishment of the riparian/ highest water mark under the worst-case scenarios in the history of the lakes to help in clearly defining and demarcating the lake boundaries. This should include bathymetric studies to determine the depth to lakebed and sediment topography.

1.0 INTRODUCTION

Lake Nakuru (36^0 05' E, 00^0 24' S); lies at an altitude of 1756 m above mean sea level at the lowest point of a catchment basin of approximately 1800 km^2. In the north, the catchment is bounded by Menengai Caldera, in the North East Bahati highlands, in the west by the Mau Escarpment, in the South by the Eburru and in the east, by a gentle ridge between Lake Nakuru and Elementaita. The lake is surrounded by a number of hills, which include the Lion hill (1780-2040m), Neylan (1870-1920m), Hyrax (1800-1840m) and Honey Moon (1800-1840m asl).

Lake Nakuru lies about 2km to the South of Nakuru City and forms the centrepiece of Lake Nakuru National Park. The Park was designated as Kenya's first Ramsar site (Wetland of international importance) in 1992 and a UNESCO World Heritage Site in 2011 because of its outstanding universal value. In addition, Lake Nakuru was recognized as an Important Bird Area site number KE049 (Birdlife, 2017a, b, c) on account of the numbers and diversity of birds, including many rare and endangered species. The lake has been variously described as "*the lake of a million flamingos*" and is bedrock to the areas' tourism. Congregations of more than 1.5 million Lesser Flamingos have been counted at Lakes Nakuru.

Due to its settings on the floor of the Kenyan Rift Valley Lake Nakuru does not have a surface outlet and thus functions as sink for pollutants arising from human activities in the Nakuru City as well as an intensively cultivated agricultural farmland in the catchment basin. At current rates the population of Nakuru City is estimated to grow from the present 500,000 to over 1,000,000 within the coming 20 years.

The lake is recharged by six rivers namely; Njoro, Makalia, Nderit, Ngosur, Naishi and Lamudiak as well as groundwater, surface runoff and direct rainfall. The rivers and streams have flow that is highly variable even within a single season- a response to the annual and inter-annual pattern of rainfall. Major threats include runoff and siltation, sedimentation, solid waste, waste water pollution, urban encroachment, farming as well as land cover and land use changes.

The water levels at Lake Nakuru levels aren't unprecedented, but can be termed as extraordinary. Evidence suggests that from 8,000-10,000 years ago, two large freshwater lakes occurred in the Naivasha-Nakuru area. The Northern one "Greater Nakuru" had a surface area of 700km^2 and a depth of 180m (McCall, 1957). At that time, the current lakes covered a much wider area referred to as the Pleistocene lakes. Recent history shows significant lake level rise in 1901, 1963 and presently since 2013. Lake Nakuru is recorded to have dried up almost completely in 1933, 1939, 1947, 1961, 1968, as well as from 1995 to mid-1997.

The rise in water levels in Lake Nakuru and several Central Rift Valley lakes in Kenya has generated significant interest and concern among scientists and lake basin managers in the past decade. Onywere *et al*. (2013) were the first to describe the phenomena of lake level rises, including detailed descriptions of the affected lake properties. Building on these findings, Gichuru and Waithaka (2015) and Moturi (2015) focused their analyses on the trends of Lake Nakuru water surface variations between 1984 and 2013, concluding that no direct correlation between rainfall and changes in the lake surface area could be found.

The Physiographic Assessment of Mau Ecosystem Study on the Rise of Water Levels in Lakes Nakuru and Elementaita among other findings concludes that the rise in lake water levels was likely caused mainly by the enhanced rainfall during the 2010-2013 period (KWTA, 2015).

The most recent study is the Rising Water Levels within the Great Rift Valley Lakes, the Turkwel Gorge Dam and Lake Victoria among other significant findings concludes that the main reason for the rising water levels is climate change with mounting evidence from the level of rainfall in the catchment areas as documented at the various rainfall gauging stations (Ministry of Environment and Forestry, 2021).

Since May 2010, the lake level has been rising from an annual average level of 0.7 meters to the highest level of approximately 10.5 meters recorded in June-July 2020 (Kiogora *et al*., 2020). This has resulted in a significant increase in lake area from 43.3 km^2 in 2012 to the highest lake area of 70 km^2 recorded in April 2020 consequently, inundating about 26.6 km^2 of the park area.

The rising water levels have flooded large sections of Mwariki settlement. It is on this basis that H.E. Governor Lee Kinyanjui called upon a Team of Experts to constitute a Technical Taskforce to carry out an Assessment of the Rising Water Levels, Flood Related Implications and Riparian Zone Beaconing in Lake Nakuru.

This report outlines five (5) main areas covering introduction, methodology and data collection, key findings, conclusions and recommendations.

2.0 PROJECT SCOPE AND OBJECTIVES

The overall objective of the study was to carry out an Assessment of the Rising Water Levels, Flood Related Implications and Riparian Zone Beaconing in Lake Nakuru.

The scope of the analysis involved assessing the hydrological variations and trends, climatic variations and trends (Rainfall and, Evaporation), hydro-geological dynamics, groundwater, lake level trend analysis, bathymetry & sedimentation rates, seismic dynamics, land use/ land cover changes and socio-economic impacts.

The specific objectives are as follows: -

1. To develop GIS Maps on Land use / Land cover changes from 1990, 2000, 2010 and 2021 to assess levels of catchment degradation in Lake Nakuru Basin.
2. To develop GIS maps marking the Highest Watermarks for L. Nakuru using recent High-Resolution images & Global Navigation Satellite System (GNSS) Reflectometry Technology.
3. To undertake Water Balance Modelling using SWAT tools to determine Lake Nakuru Depth-Volume-Surface area relationship establish the highest watermark as well as suggest likely reasons for the current high-water levels in the lake.
4. To establish the lake boundary, beaconing the riparian zone based on the highest watermark in the worst case scenario and prepare an inventory of the affected and vulnerable households from rising lake waters.
5. To conduct a socio-economic study of the affected local communities.

3.0 METHODOLOGY

The task was to carry out an Assessment of the Rising Water Levels, Flood Related Implications and Riparian Zone Beaconing in Lake Nakuru. To achieve this, the changes in lake area were calculated based on various water level rise scenarios. To calculate water surface areas at different water rise levels, GIS tools were used to accurately delineate the Lake Nakuru boundary as of June 2021 as the baseline year.

In order to undertake simulation and determine the impact of the rising water levels of Lake Nakuru, satellite imagery, Alos Palsar Digital Elevation Models (DEM) with 12.5m resolution and a digitized Lake Nakuru boundary as of June, 2021 were analysed using remote sensing and GIS software.

The land-use/land cover change within Lake Nakuru catchment was assessed using the spatial dimension of satellite images. The spatial dimension of remote sensing images as assessed by image texture contains information on local spatial structure and variability of land-cover categories, and can raise land-use classification accuracies in heterogeneous urban landscapes. Landsat-7 satellite images with 30m spatial resolution covering Lake Nakuru Catchment area for the years 1990, 2000, 2010 and 2021 were downloaded from the United States Geological Survey (USGS) website. The images were processed using ERDAS 2016, a remote sensing software. The selected bands were layer stacked to form a multiband false colour image. Supervised image classification was performed to derive LULC maps and statistics for each target year. During image classification, seven (7) classes including Forestland, Open grassland, Cropland, Open Water, Vegetated wetland, Settlements and Wooded grassland were adopted.

Hydrological and geo-hydrological data was used in setting up a lake water balance model that aims to estimate future lake level scenarios. The Soil & Water Assessment Tool (SWAT) was adopted for this work. SWAT is a small watershed to river basin-scale model used to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change.

The socio-economic impacts assessed by administering 100 questionnaires in households adjacent to the park. Focused Group Discussions (FDGs) were conducted targeting special interest groups including youths, local leaders, and women, among others. Key informant interviews were carried out with administrative officials of various subsectors, political leaders, and non-governmental organizations working in the area. Additional information on the impacts on infrastructure, human/wildlife conflicts, tourism and biodiversity was obtained from Kenya Wildlife Service.

4.0 Data availability and Analysis

This section provides a summary of the hydrological and meteorological data collected for the Lake Nakuru Water Balance Model. Rainfall data was obtained from five (5) stations, namely Nakuru MET, Soysambu Estate, Egerton University, Water Resources Authority (Nakuru Town) and Sururu Forest Station. The team also reviewed the KWTA Taskforce report (2017) and obtained recent data from the other stations within the lake basin including; Njoro Plant Breeding Research

Centre, Kenana Farm, Menengai Farm, Technology Farm, Ng'era Fancy Farm, Dundori FS, Kwetu Farm.

Pan evaporation data was only available from the Nakuru Meteorological station and Egerton University. The obtained data was mainly in paper records and needed time to be digitized before analysis could be carried out.

River flow, groundwater and lake level data was purchased from the Water Resources Authority and FlamingoNet. The team was not able to get recent lake level data since the RGS station in the lake was submerged in 2011. The Database for Hydrological Time Series over Inland Waters (DAHITI) was utilized to describe the surface area, water level and volume variations. DAHITI also uses satellite altimetry to derive water level data from wetlands, reservoirs, and other inland water bodies. The volume variations of DAHITI is calculated based on the combination of water surface area and water level time series. They are free of charge and publicly available on the DAHITI website (https://dahiti.dgfi.tum.de/).

4.1. Meteorological data

The Meteorological data is summarised and analysed below:

4.1.2 Rainfall Data

Initially 19 standard rain gauge stations distributed over the catchment were selected for the study. However, after quality control checks only 10 stations (Fig.1) were acceptable as having relatively consistent rainfall data (ANNEX 1) shows the station numbers, owners and the record period. Trend analysis of the annual rainfall data from Egerton station (1977-2020) was performed. The data shows an increasing trend but this trend is not statistically significant. A break-point analysis was also performed. A statistically significant break-point was identified in 2009. This indicates that the rainfall from 2010 onwards is higher than the rainfall from 2009 backwards. This explains to some extent, why the lake water levels have been rising from 2010 onwards. Further analysis of the data using CLimpact (Climpact (climpact-sci.org)), a software, developed by WMO to determine indices of climate extremes was done.

4.2. KEY FINDINGS

The results of 12-month and 24-month analysis are shown in Figure x. From these graphs, the indices indicate successive moderately wet to severely wet 12- and 24-month periods from 2010 onwards.

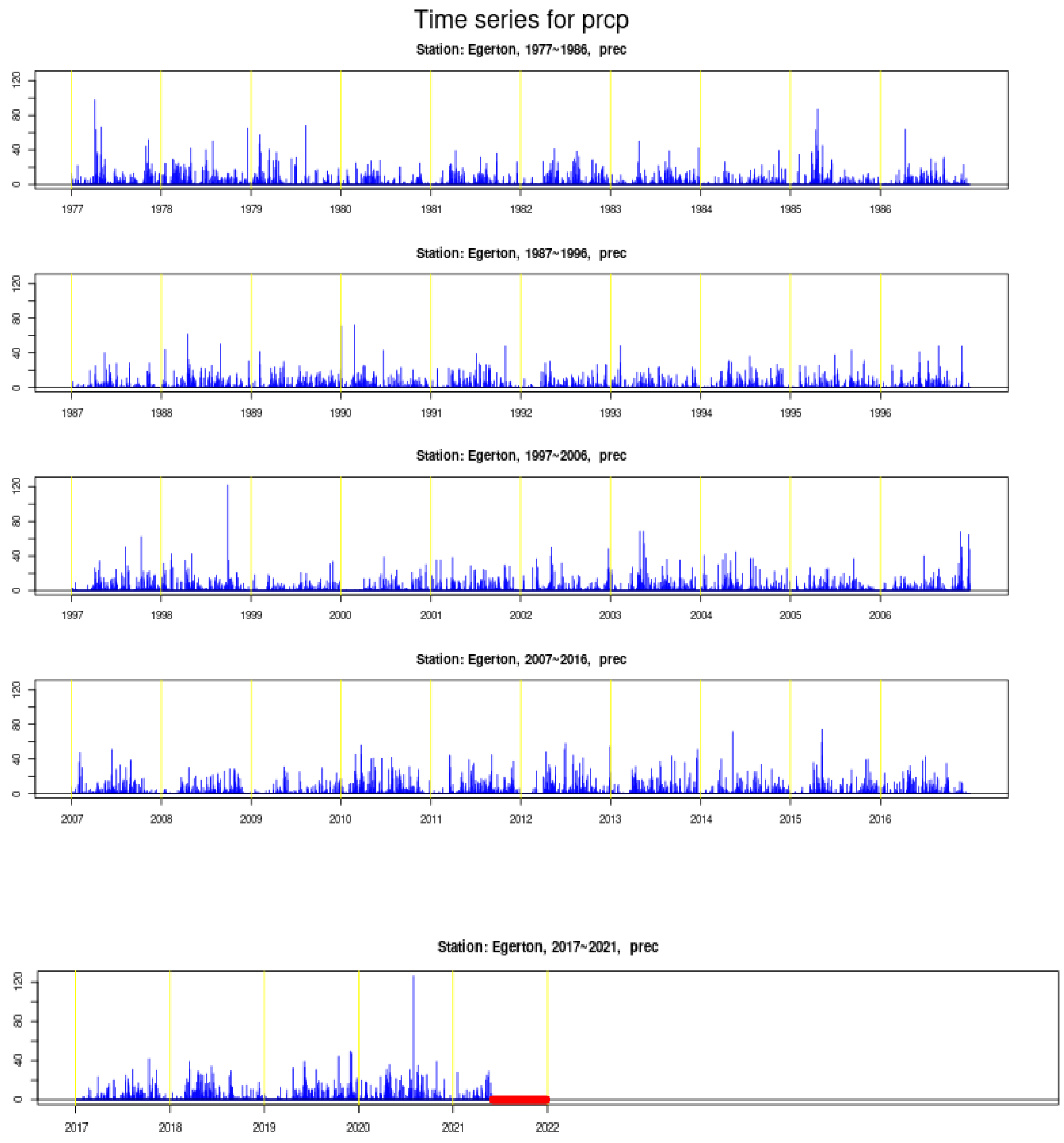


Fig. 1. Daily rainfall data from Egerton University Meteorological Station

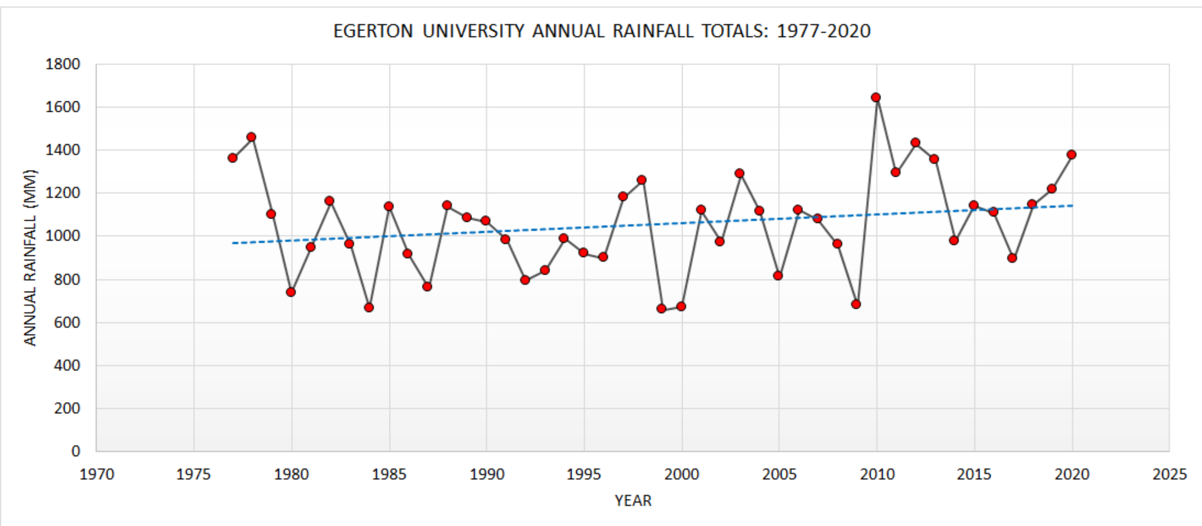
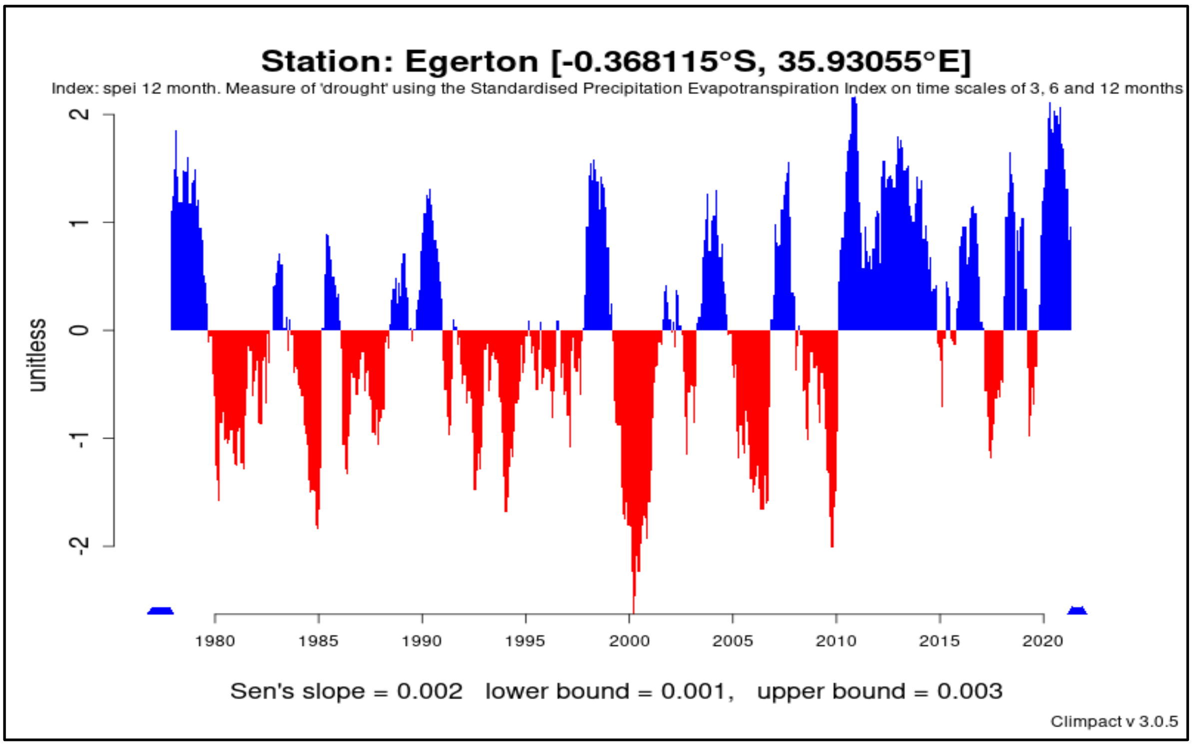


Fig.2 Trend analysis of annual rainfall at Egerton University Met Station



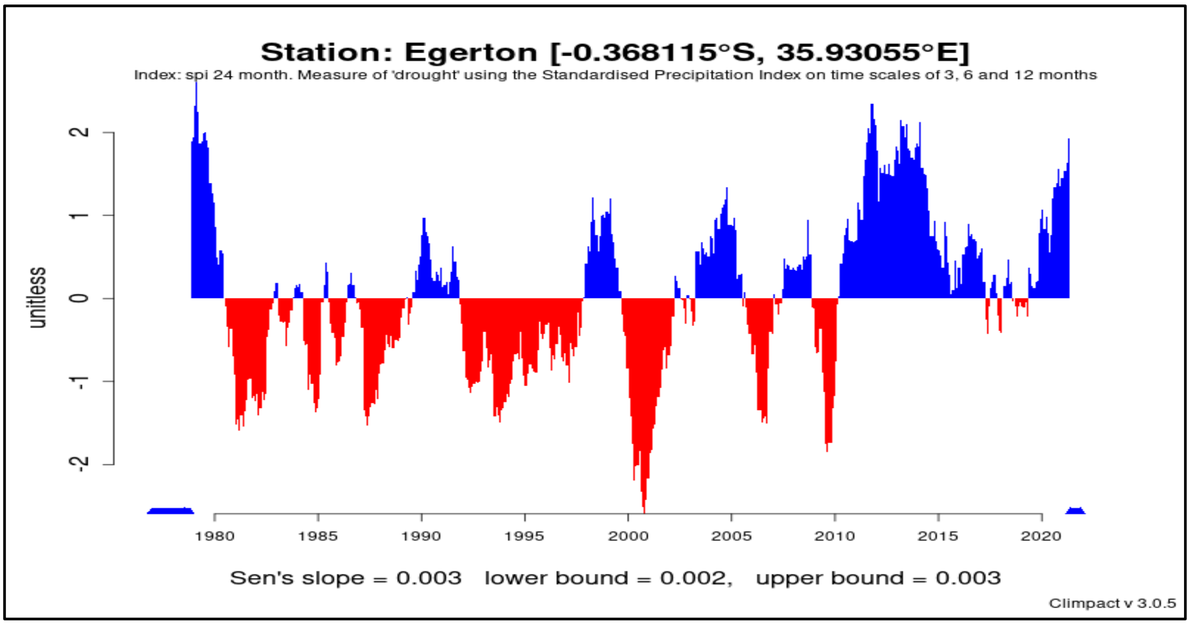


Fig. 3 & 4. 12- and 24-Month Standardised Precipitation Index at Egerton University Met Station

Category	SPI	Probability (%)
Extremely wet	2.00 and above	2.3
Severely wet	1.50–1.99	4.4
Moderately wet	1.00–1.49	9.2
Near normal	−0.99–0.99	68.2
Moderate drought	−1.00 to −1.49	9.2
Severe drought	−1.50 to −1.99	4.4
Extreme drought	−2.00 and less	2.3

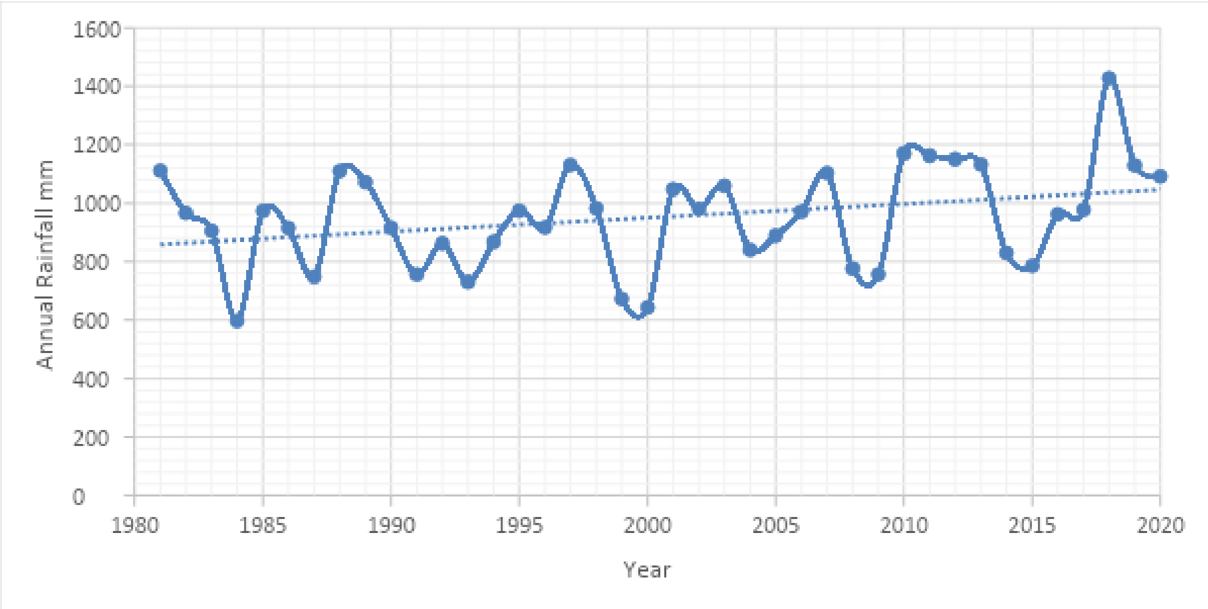


Figure 5: Annual Rainfall at the Water Resources Authority (WRA) Rainfall Station

4.2.1 Evaporation Data

Evaporation data has only been measured at Nakuru Meteorological Station, Egerton University and Lake Nakuru. The dataset is reasonably complete and indicates a two-season pattern of higher evaporation rates from December to March (186-, 186- 194 mm/month, respectively) and lower rates from April to November. (114 -138 mm/ month). Annual averaged value for the available dataset is 1747 mm/year. The data shows a decreasing trend of evaporation.

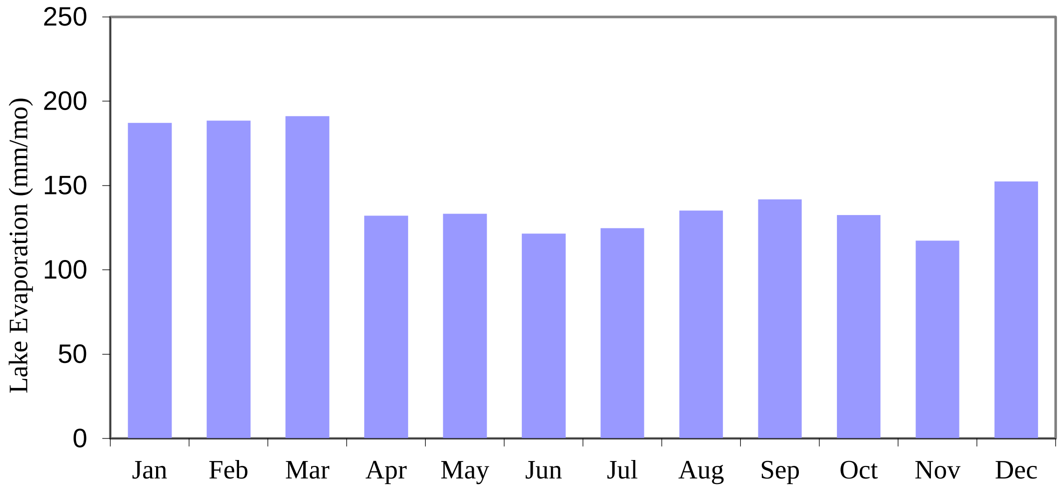


Fig. 6. Mean monthly lake evaporation

4.2.2. Radiation and Temperature Data

Solar radiation and temperature have annual means of 490langleys, and 17°C respectively. The two parameters have their peaks centred on January and September and minima around April.

4.2.3. Hydrological Data

4.2.4 Streamflow

Surface water inflows into Lake Nakuru include Rivers, Njoro, Makalia, Enderit, Naishi, Larmudiac, Ngosur, Baharini springs and Town Sewage, Njoro and several Storm Water Channels. The discharge from surface inflows was historically determined by using metric staff gauges. Unfortunately, data collection, processing, quality checking and recording is irregular and erratic with the loss of some data.

The majority of river gauging stations are not maintained leading to the current situation where out of 13 Gauging Stations (based on field visit to stations which are known by the Water Resource Authority (WRA) only River Njoro RGS 2FC19 is fully functional.

Table 2:Gauged and Ungauged Sub- Watershed Area

Subwtrshd.	Area (km^2)	Area Prop.	Prop. Q (m^3/mo)	Flow Prop.	Prop. Q (m^3/mo)
Ngosur	155.1	1.0	552,000	1.0	552,000
Ungauged:					
Lamudiak	178.5	1.2	635,000	NA	NA
Nderit	556.3	3.6	1,980,000	NA	NA
Lion Hill	24.1	0.16	86,000	NA	NA
Gauged:					
Makalia	311.6	2.0	1,109,000	2.0	1,120,000
Njoro	302.4	1.9	1,076,000	3.4	1,876,000
Total=	*1373*		*4,886,000*		*2,996,000*
Total ungauged=	*759*	*4.9*	2,701,000		
% gauged=	45%				5.4

River Njoro has discharge data records from the year 1941 up-to-date although a number of gaps exist within the period of observation. The River Njoro watershed is the largest and covers an area of about 290 km² with an estimated annual discharge of 4,752 x 10^3 m^3.

These data have been obtained from the two existing staff gauges 2FCO5 located approx. 3km upstream of Egerton main gate and maintained by the WRA. Discharge analysis from 2FC19 shows that there is a clear streamflow response to the precipitation occurring in the catchment. The first peak flow occurs in May a month after peak rainfall while the second peak flow coincides with that of rain in the month of August.

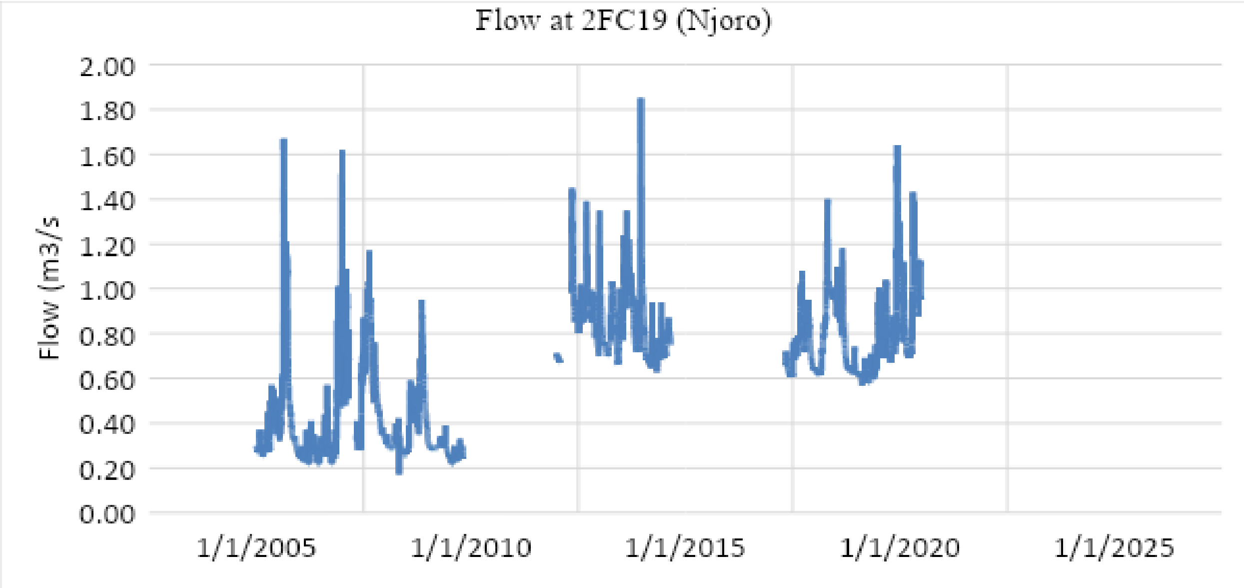


Fig 7: River flow at River Njoro 2FC19

4.2.2 River Makalia, Nderit and Ngosur

River Makalia lying on the South-western side of Lake Nakuru covers 315 km², and has an estimated annual discharge of 1,210 x 10^3 m^3. River Nderit has a catchment area of 520 km² with an annual discharge estimated of 605x10^3m^3. The discharge from River Ngosur (basin area 155 km^2), and River Lamudiak (178km^2) which previously used to disappear underground has not been calculated.

In all the above streams, flow is highly variable even within a single season- a response to the annual and inter-annual pattern of rainfall. The rivers and streams have flow that is highly variable even within a single season- a response to the annual and inter-annual pattern of rainfall.

4.2.5 Lake level data

Records on lake levels are available since 1956 up to date although there are several gaps within the period of observation. The driving phenomenon of lake levels are; seasonal variation, cyclic climatic oscillation and anthropogenic influences. During periods of drought the lake level drops dramatically; the last of such occasions in Lake Nakuru was in 1996. Historical records show that the lake almost completely dried up in 1933, 1939, 1947, 1961, 1968, 1996 and part of 1997.

Due to its setting in a basin without surface outlets, the lake is subject to considerable fluctuations of water level. Lake Nakuru area rose from 40.4 to Km² 68.18 Km², a difference of 28.14 Km² or 70.28%. From estimations made using satellite image analysis, the lake surface area has increased by about 15% in the last two years to about 64Km^2. The increase coincides with the increased rainfall over the lake catchment with the significant increase in area seen in 2018 and 2021. Changes in lake water levels between 2010 and 2021 depict overflows submerging an estimated area of 2,131.56 Ha. This accounts for 39.47% increase of the total surface area.

According to various sources in literature (e.g. Wambui, 2016; Onywere *et al*., 2013), the increase in the lake's surface area from a low area of 31.8 km² in January 2010 to a high of 54.7 km² in Sept. 2013 was caused by an increase in the mean annual precipitation in the period 2009-2014. The KfW Hydrogeological Study further supports the above hypothesis. The level of a lake and any change is affected by the balance total input and total output. Negative balance reduces the water level while positive balance leads to the rise in the water level of the lake. Due gentle slopes at the bottom of the rift valley increase in the Lake Water Levels is manifested in the large area increase of the area covered by volume of the increased water (WRA, 2020).

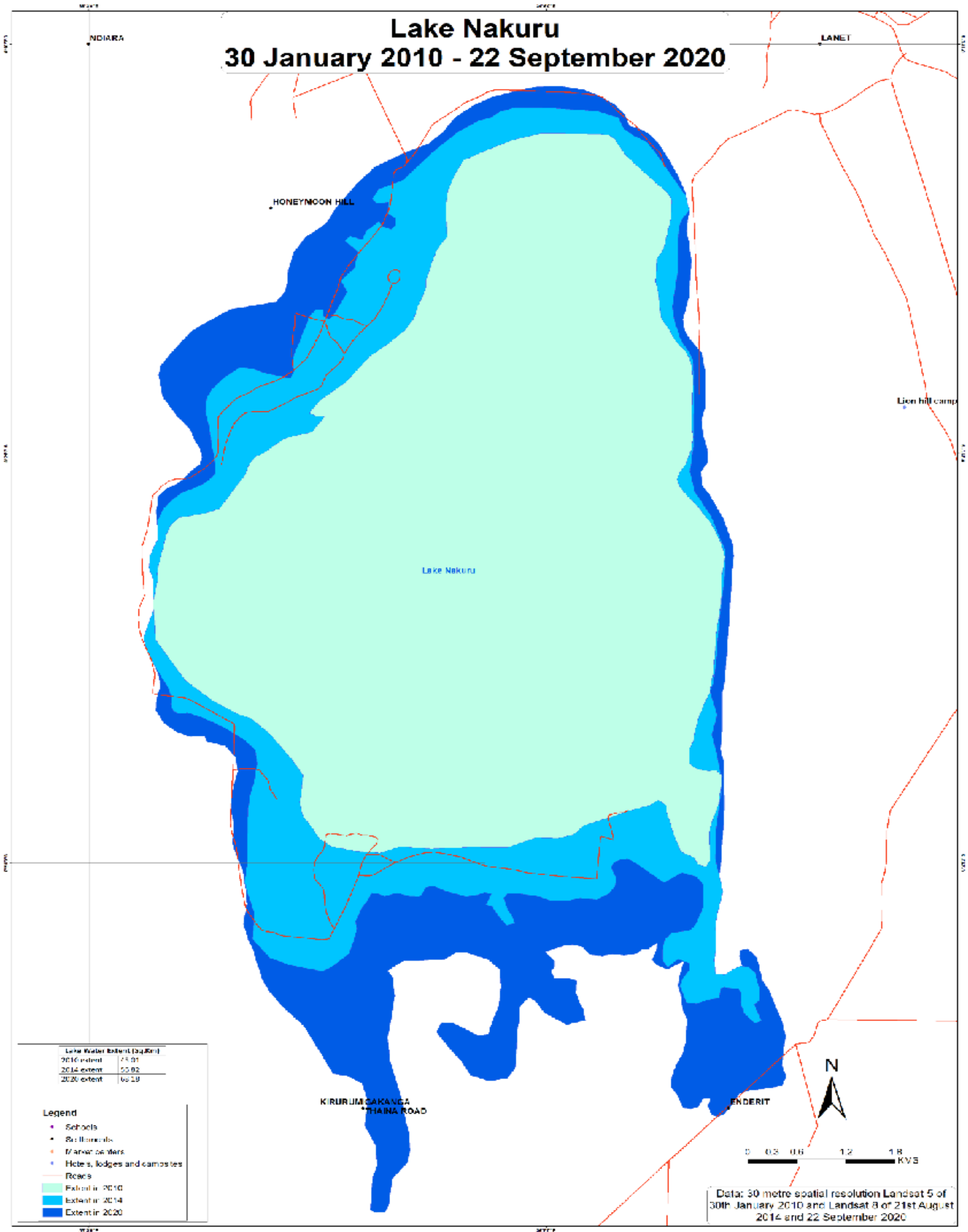


Fig.8: Lake Nakuru Lake Level Changes; 2010-2020

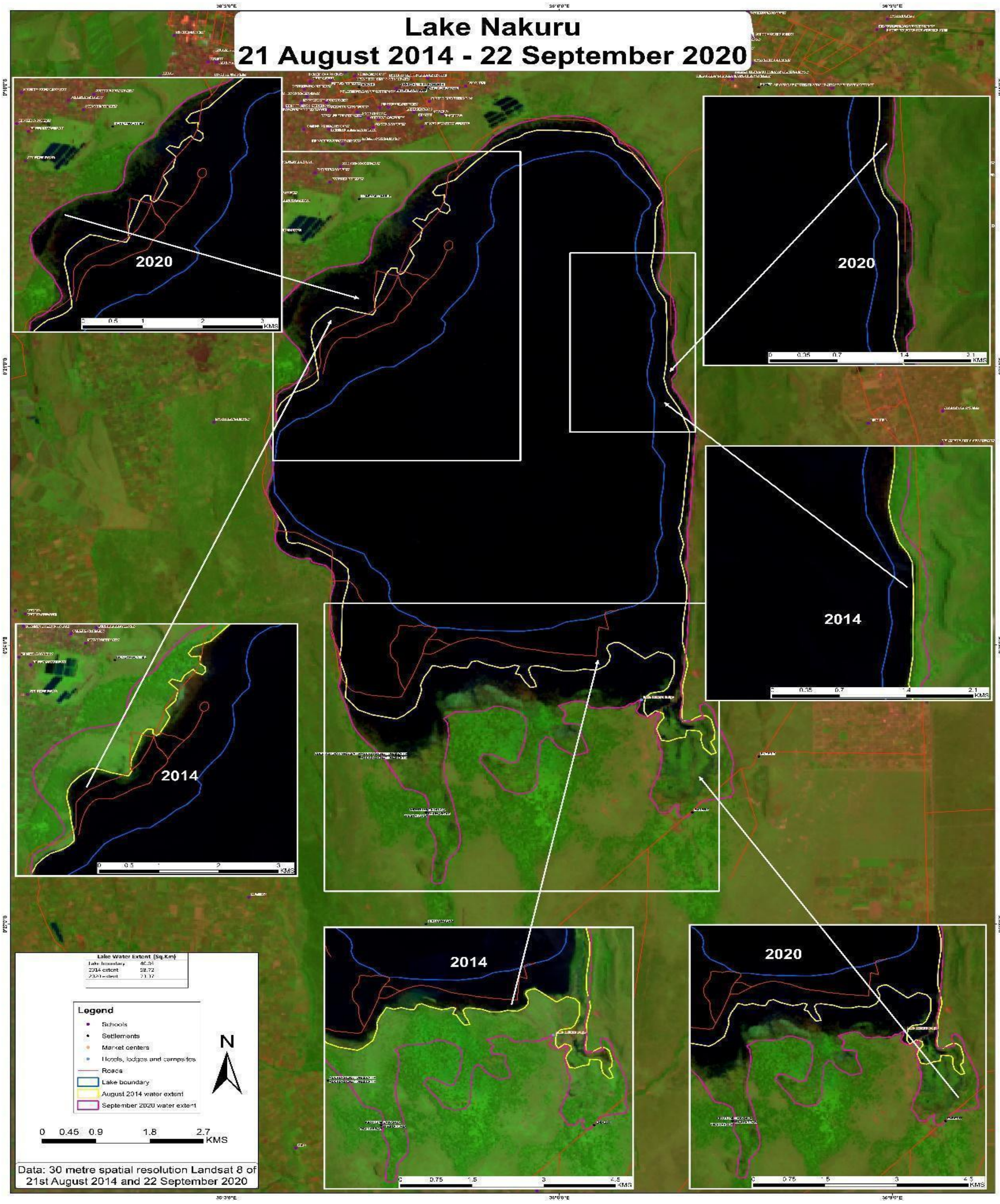


Fig.9: Lake Nakuru Level Change: 2014-2020

4.3 Hydrogeology

The water balances in lake are determined by inflow from direct precipitation, rivers inflows, discharges from groundwater and surface runoff while outflow is by outlet, evaporation and infiltration into groundwater aquifers which are then released through springs (WRA, 2020).

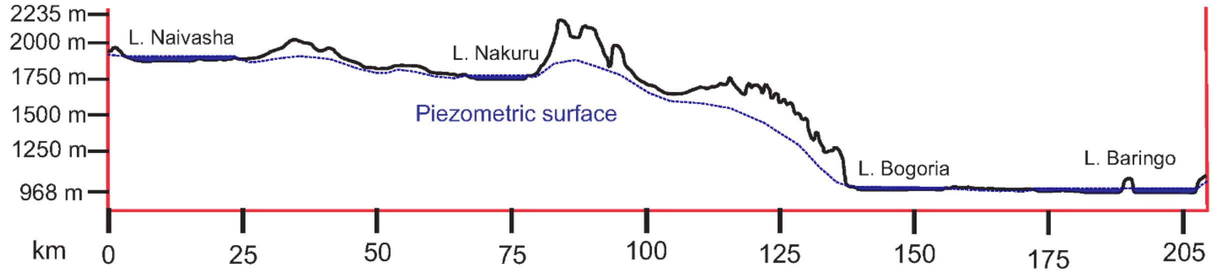


Fig. 10: Groundwater – surface water interaction as illustrated using potentiometric surface and lake levels.

Allen *et al.*, (1989) and Allen & Darling, (1992), through isotopic indication and Piezometric plots suggested that groundwater within the Rift Valley basin of Kenya are recharged by rainwater on the western and eastern flanks of the rift. Becht et al., 2006 through the analysis of natural isotopes demonstrated that groundwater flows from Lake Naivasha to Lake Magadi to the South and to the north on Lake Elementaita, Nakuru and Bogoria.

Mcann (1992) estimated that groundwater inflow of 14 m^3/year and 23 m^3/year into Lake Elementaita and Nakuru are required to maintain the respective lake levels. Becht *et al*., (2006) further concluded that the freshness of lake Naivasha and Baringo are due to and or both surface water overflow or groundwater outflow. The lakes are also interconnected through groundwater flows, hence, when Lake Naivasha levels rises, the downslope lakes levels increases more than Naivasha due to head gradient variation. Currently L. Naivasha has risen by 4 m while Baringo has risen by 12.8 m, a true demonstration of the increased inflow and groundwater flux due to increased head.

4.3.1 Geology

The geology of Lake Nakuru trough consists of a varied series of lava flows and sheets to superficial sediments and volcanic soils. Lava sheets have their origin from fissures associated with the Rift Valley faulting and those associated with the central volcano (Menengai). Pumiceous tuffs and sediments owe their origin to the dust and vitric ash which emanated from explosive episodes of the Menengai caldera (McCall, 1957). The soils in the Lake Nakuru catchment are derived from Tertiary Quaternary volcanic materials, including pyroclastic rocks, and are also associated with alkaline sediments (McCall, 1957).

The drainage classes range from poorly drained, moderately well drained, well drained to excessively drained, with texture ranging from loam, clay to clay loam and structures in the range of moderately strong to strong. The soils therefore tend to be friable, well drained and in some instances shallow (McCall, 1957, JICA, 2008). Soils in the central plains are mainly derived from lacustrine deposits and volcanic ashes. Having developed on sediments, they are grey, deep and poorly drained and slightly calcareous to saline. On the more open grassland plains, the soils are derived from pumice beds and ashes from recent volcanoes and appear to be well drained friable loams to sandy clay loam that support the bulk of grazing land in the park. In the upper parts of the catchment the soils are red, well developed and fertile, formerly supporting dense tropical mountain forests.

The geology of the basin consists predominantly of Quaternary volcanic material characterized by porous pumiceous formations and basaltic intrusions that are weakened by fault lines and scarp zones (Baldgya, 2005; Mainuri, 2005). Volcanic rocks ranging in age from Tertiary through Quaternary to recent and partly comprise pyroclastics. The rocks are predominantly conglomerates, sediments, welded turfs and phonolites on mountains, pumice, basaltic tuffs and black ashes on hills, plateaus, uplands, plains and valleys and alluvium and lacustrine and fluvial sediments derived directly from them (Sombroek, 1992). Rocks that compose the cliffs and rock outcrops are basaltic.

The main geological features (Fig 1.) found around the lake and its fringing wetland includes:

a) The Rift Valley bottom or lowland, composed of trona-impregnated silt overlying gravel, tuffs and diatomaceous silt, in which the Lake Nakuru lies;

b) The escarpments including the foot-slopes and cliffs on the western side of the lake, Mau and Eburru, comprised mostly of pumice tuffs, ignimbrites and welded tuffs with lacustrine sediments;

c) The uplifted Lion Hill range on the eastern side and other hills, composed of faulted phonolitic trachytes;

d) Menengai crater on the northern side of the lake, and;

e) Fault lines that run in a North-South direction.

The recent deposits are superficial deposits ranging from lacustrine, pluvial and alluvial deposits. The alluvial sands include river deposits and outwash fans from hills. Sandy soil are well drained.

4.3.2 Siltation and Sedimentation

The primary source silt is from degraded catchments and poor land use patterns. The volume of the silt that the lake receives per year is the sum of the silt load of the contributing rivers. It has been determined that the rate of siltation is subject to soil erosion rate and land use practices in the catchment. A bathymetric survey done in June 2019 revealed that the maximum water depth is 6.2 m with the total water level coverage area of 59.3 km^2, the total water storage capacity of 64,699,344.54 m^3 and the total shoreline length with 36.20 km. The results of the study show that the lake depth increasing from the shoreline to the middle part of the lake with a maximum depth of 6.2 meters and the water storage of 264,699,344.54 m^3. The sediment deposition with the layer thickness varies from 0 m to 0.7 m (maximum) and the total sediment storage capacity of 24,191,688.67 m^3.

This implies that the sediment occupy 8.37% of the lake storage capacity due to the different activities in the watershed typically inadequate waste disposal systems in the urban watersheds, and increased land use and land cover changes along the River Njoro and Makalia which exhaust the rural watershed with a large amount of eroded soil resulted majorly from deforestation and land sub-division for small-scale agriculture (Parfait *et al*, 2020).

Activities in the catchment such as quarrying, deforestation, road construction and poor cultivation practices among others may have caused increased sediments deposited into the lakes. In addition, increased seismic activities are also known to increase sedimentation in the water bodies.

4.4. Rising Ground Water Levels

Groundwater monitoring wells within the Rift Valley Basin Area are also producing increased groundwater levels. What is observed could be of the lower end since all the monitoring wells are production boreholes. This therefore demonstrates that the observed levels are more dynamic due to abstraction rather than being static water level (WRA, 2020). The location of the three monitoring boreholes by the water service provider (NAWASSCO) is indicated in figure 12.

Groundwater saturation poses eminent threats to lake water levels discharge. There could be a likelihood of potential subsurface groundwater exchange due to saturation resulting in an unbalanced negative moisture budget. The impacts of groundwater saturation within the fault-pathway networks are thought to limit underground out-flow from the lake water body.

Fig 12. Locations of the observation boreholes - Baharini, St Marys and Kabatini

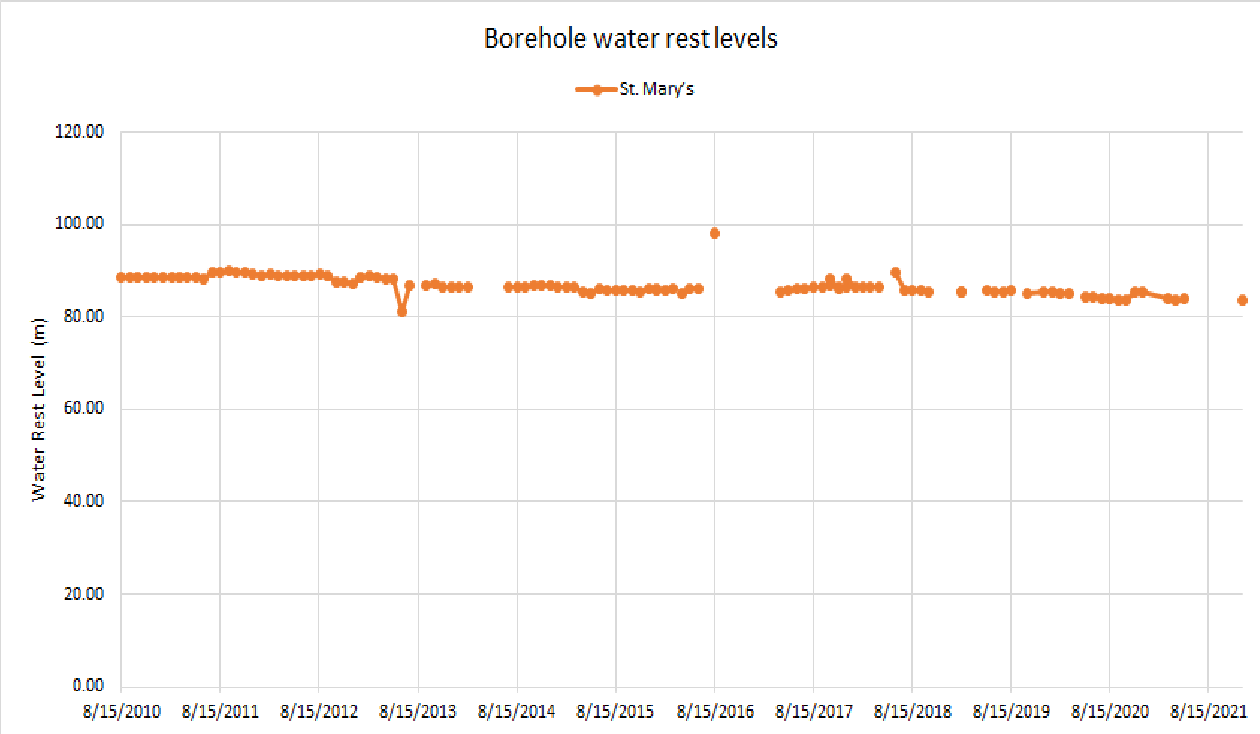


Fig 13. Borehole Water Rest Levels, St Marys observation borehole

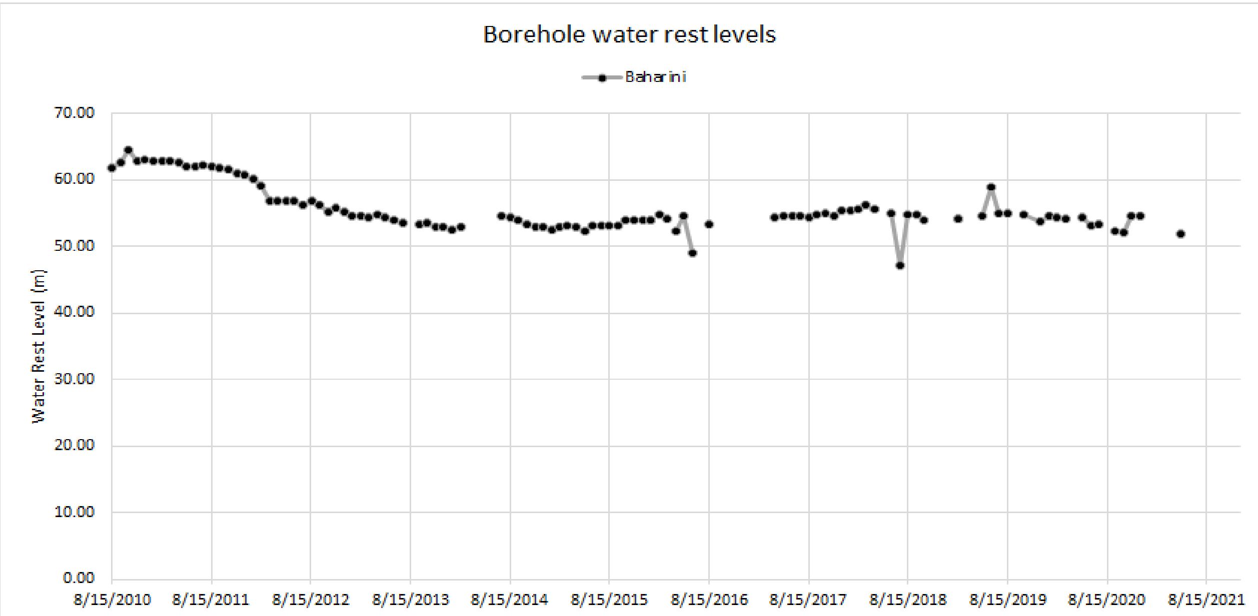


Fig 14. Borehole Water Rest Levels, Baharini observation borehole

Analysis of changes in water levels indicates a rise of about 8 m (from 62.7 to 54.4m) in the water rest levels in Baharini borehole between 2010 and 2021, showing that groundwater has been rising in response to the increased rainfall. An increase in groundwater level is also evident in St Mary's and Kabatini boreholes (Fig 12.)

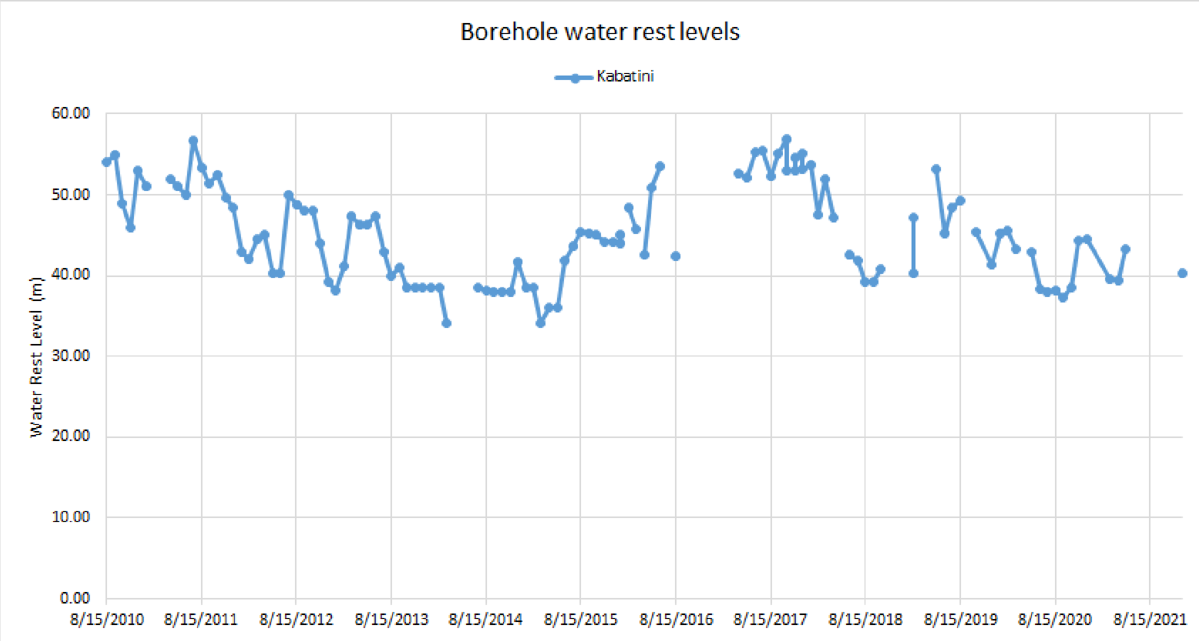


Fig 15. Borehole Water Rest Levels, Kabatini observation borehole

5.0 WATER BALANCE MODELLING

The application of computer-based watershed models to Lake Nakuru basin would allow water managers to test the implications of land use change, changes in the management of land, climate change, water pollution and construction of water abstraction or water storage infrastructure on the water resource. Computer models provide a laboratory where decision makers can explore a range of options and that would not be possible in a physical environment.

The issue of concern here is the rising lake level which has left land, property and natural habitats inundated with serious implications on the economy and livelihoods of affected communities. Well calibrated watershed models could shed light on the causes of these changes and what management interventions can achieve to mitigate these changes. There are several watershed models available and the most suitable one has to be chosen carefully considering the goal, the resources and expertise at hand.

Lake Nakuru basin has an area of 1480 km^2 and is fed by the rivers Ngosur, Nderit, Makalia and Njoro (Figue 17). It has no surface outlet but may be receiving water underground from Lake Naivasha and Elementeita which are higher in elevation and discharging water towards Lake Bogoria and Baringo which are lower in elevation. Lake Nakuru Basin has a minimum elevation of 1759 masl (the approximate level of the lake bed), a maximum elevation of 3072 masl and a mean elevation of 2196 masl.

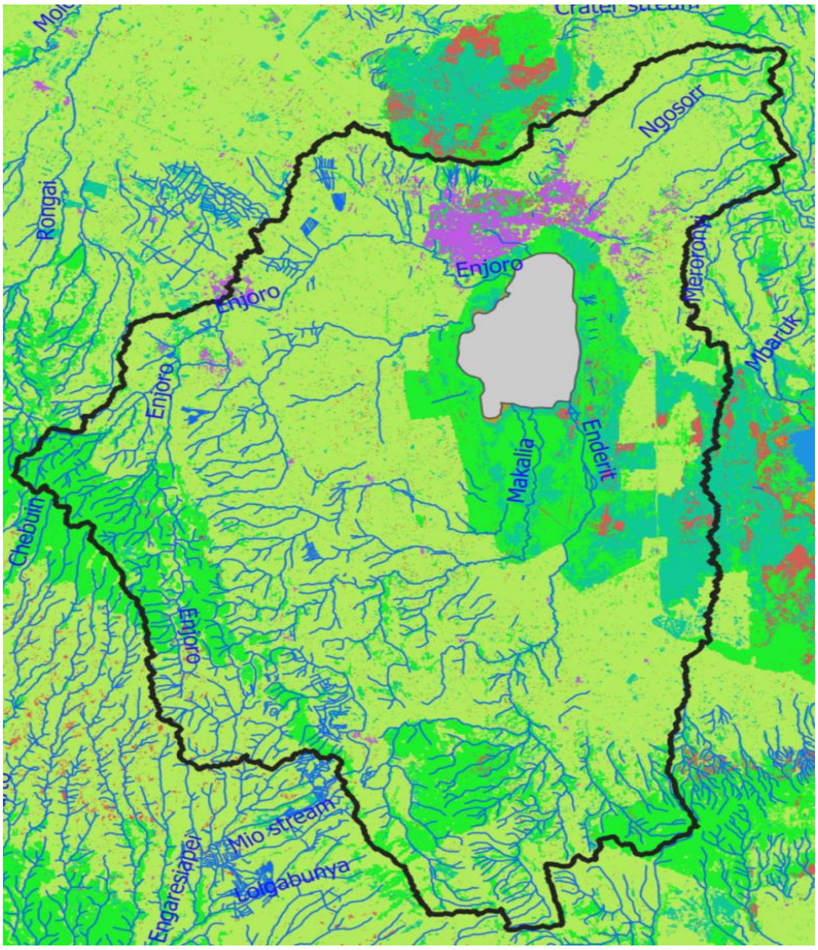


Figure 18: Lake Nakuru basin and the rivers feeding the lake

5.1 Selected Hydrological Model and configuration of the Basin

The Soil & Water Assessment Tool (SWAT) was adopted for water balance modelling. SWAT is a small watershed to river basin-scale model used to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. It is a free software and it runs in a GIS environment such as ArcGIS or QGIS. SWAT is able to simulate the hydrology, soil erosion and nutrient and chemical transport from agricultural watersheds. The Lake Basin was subdivided into three regions: Njoro, Makalia-Nderit and Ngosur-Baharini-Urban (Figure 19). This is because running SWAT for the entire basin was very slow and time consuming. Each of the regions contributed surface runoff directly to the lake and this formed the input of the lake water balance model which was done in Excel.

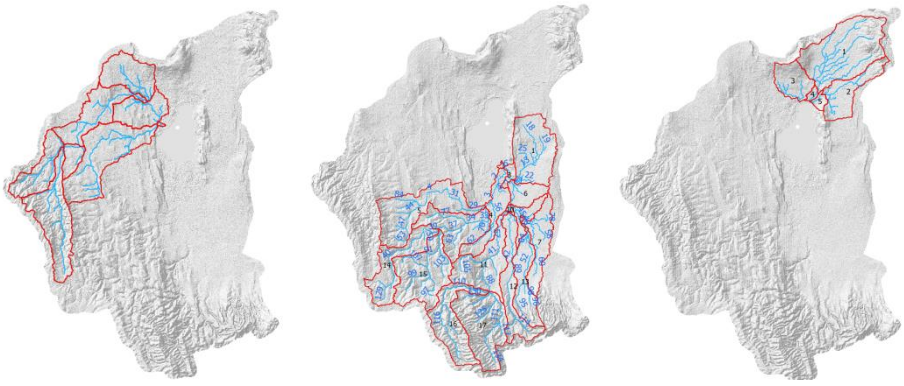


Figure 19: The three regions making up Lake Nakuru Basin (a) Njoro (b) Makalia-Nderit and (c) Ngosur-Baharini

5.2 Input data required by SWAT

SWAT model was set up with the following datasets:-

- QSWAT+ Version 2.0.6 running on QGIS Version 3.16.7 was used for hydrological modelling.
- 12.5 m ALOS PALSAR DEM obtained from https://asf.alaska.edu/data-sets/derived-data-sets/alos-palsar-rtc/alos-palsar-radiometric-terrain-correction/ and used for defining the slope, the streams, drainage network and sub-basins.

- Daily Rainfall data from CHIRPS from https://www.chc.ucsb.edu/data/chirps. This data was downloaded in the form of 5.5x5.5 km resolution grids covering the African continent and running from 1981 to 2020. Time series point data for 35 locations (Figure 1), well distributed over the Lake Nakuru Basin were extracted using the Statistical Computing Package R. The data from CHIRPS was compared with ground station data and where necessary it was moderated so that the annual totals matched the ground station data. This was only possible for locations like Nakuru Met and Egerton University where high quality data was available. From previous studies, CHIRPS rainfall data has been found to be of sufficient quality for water balance studies.
- Kenya Sentinel2 20X20 m resolution Land Use Land Cover data was obtained from http://geoportal.rcmrd.org/. The Land Cover Map is shown in Figure 2.
- The Soil and Terrain Database for Kenya (KENSOTER), version 2.0 digital soil map and associated soil parameter database was used. This was accessed fom https://data.isric.org/ . The soil map was used to prepare the user soil table for SWAT+. The soil map is shown in Figure 3.
- FAO's WAPOR Actual Evapotranspiration data downloaded from https://wapor.apps.fao.org/home/WAPOR_2/1 was used to calibrated the actual evapotranspiration results obtained from SWAT.
- Streamflow data for Njoro River RGS 2FC16 at Egerton University was also used for calibration.

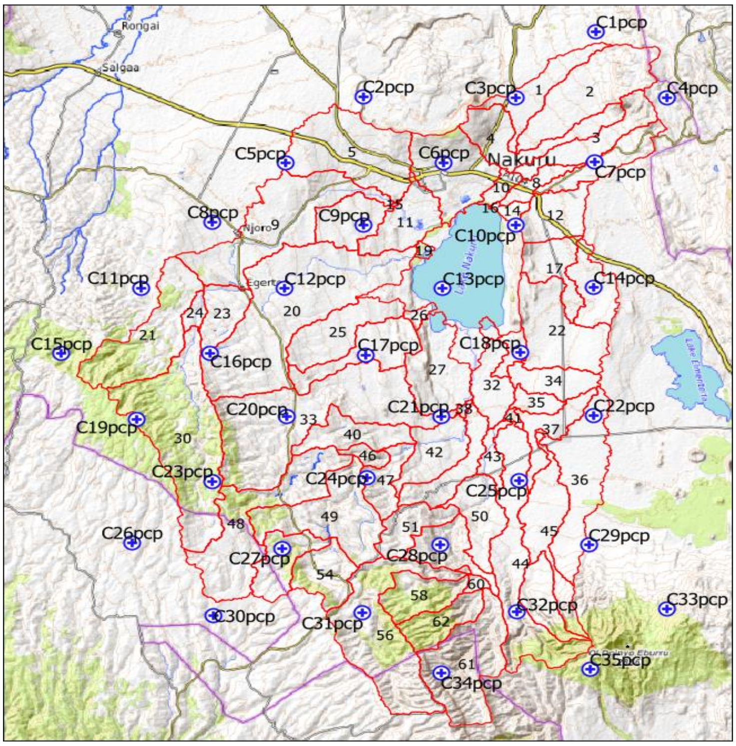


Figure 20: Location of the 35 CHIRPS rainfall stations extracted from the continental gridded datasets

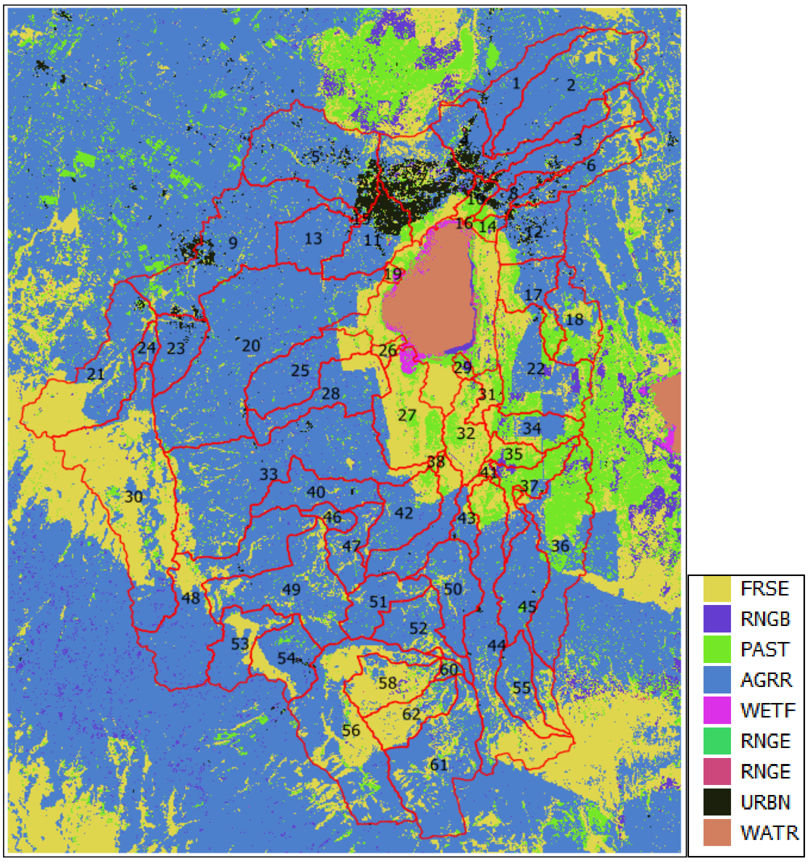


Figure 21: The SWAT land cover classes used for Lake Nakuru Basin (FRSE=Forest, RNGB/RNGE = Rangeland, PAST= Grassland, AGRR = Agricultural Land, WETF= Wetlands, URBAN = Urban and WATR=Water

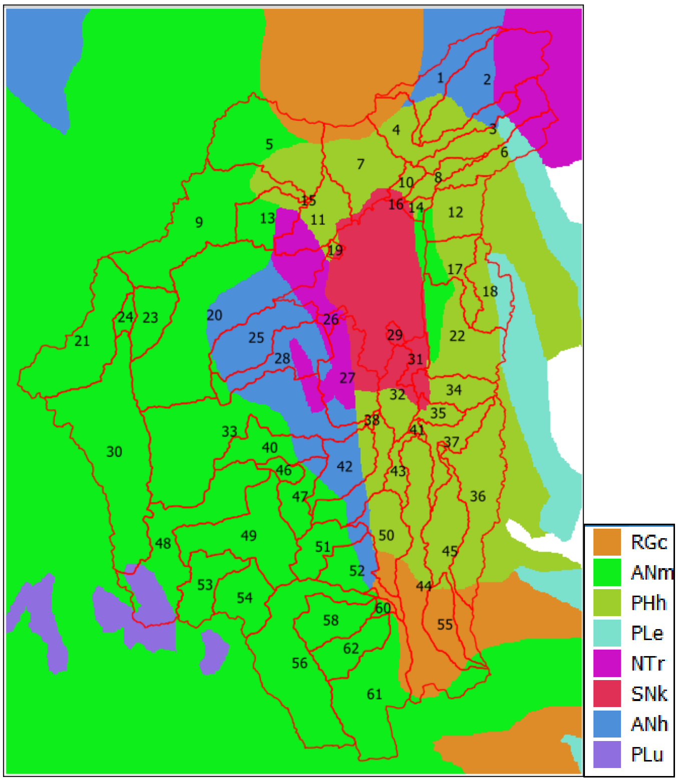
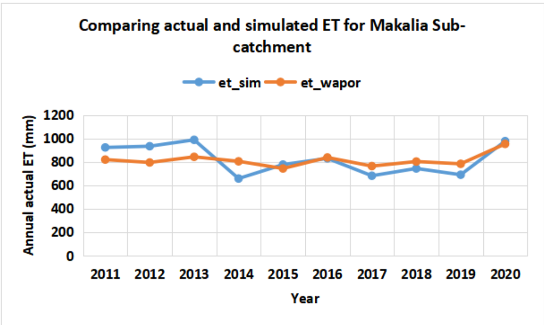
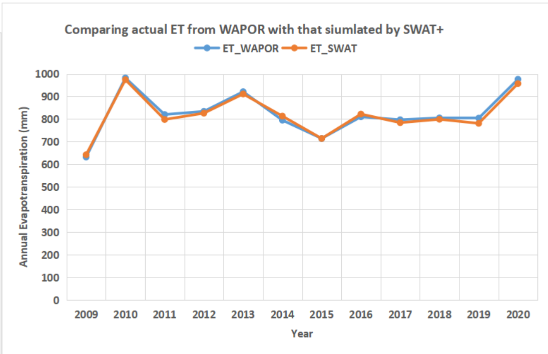


Figure 22: Soil Map with the FAO Codes (RGc=Regosols, ANm/ANh = Andosols, PHh=Phaeozems, NTr = Nitisols, SNk = Solonetz , PLu= Planosols)

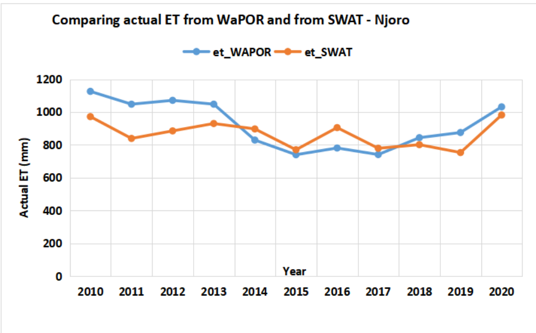
5.3 Calibration of SWAT model

The important components of the long term water balance of a catchment are precipitation P, Water Yield, W and Actual Evapotranspiration, E. These terms can all be expressed in units of water depth. To calibrate the water balance simulated by SWAT, the actual ET data from WaPOR was compared with that simulated by SWAT. The model parameters that alter actual ET were varied until the best fit was found (Figure 22). When P and E are fixed, the balance is Water Yield (or river flow). The results of the water balance modelling are shown in Table 2 and 3.





a. Makalia-Nderit…………………………………………………..(b) Ngosur - Baharini - Urban



(c) Njoro catchment

Figure 23: Calibration of SWAT model using the actual evapotranspiration data from WaPOR

Table 3 Proportions of the water balance based on CHIRPS rainfall data from 1982-2020

Ratio	NJORO 1982-2020	NJORO 1982-2009	NJORO 2010-2020	NGOSUR_BAHARINI_URBAN 1982-2020	MAKALIA-NDERIT 1982-2020
Streamflow/Precipitation	0.19	0.15	0.26	0.18	0.19
Baseflow/Total Flow	0.28	0.29	0.26	0.16	0.58
Surface Runoff/Total Flow	0.72	0.71	0.74	0.84	0.42
Percolation/Precipitation	0.09	0.08	0.11	0.04	0.15
Deep Recharge/Precipitation	0.02	0.02	0.01	0.03	0.02
ET/Precipitation	0.75	0.78	0.66	0.77	0.72

Table 4 Water balance of the three major regions forming Lake Nakuru Basin

	Precipitation (mm)	Actual ET (mm)	Water Yield (mm)
Njoro	1109	827	178
Makalia-Nderit	988	711	120
Ngosur-Baharini-Urban	1051	811	197

5.4 Lake Water Balance 1994 to 2020

A monthly time step lake water balance equation of the form shown below was adopted:

$$V_{t+1} - V_t = (SW_{in} - SW_{out}) + Q_{STW} + (P_l - E_l) + (GW_{in} - GW_{out})$$

Where

SW_{in} / SW_{out} = inflow from surface water bodies sorrounding the lake,

QSTW is flow from the sewage treatment works

P_l = precipitation on the lake

E_l = Evaporation from the lake

GW_{in} / GW_{out} = Groundwater flow into and out of the lake

Of these terms, the GW remains the most challenging component to estimate. Earlier studies by Becht *et al* (2006) and McAnn (1972) pointed out that Lake Nakuru has a net annual groundwater inflow of 24 and 23 million cubic meters. In this study, all the runoff from the sub-basins in Figure 18 was allowed to flow into the lake and the lake level and water surface area varied in accordance with the HVA-curves of the lake (Figure 23). The GW outflow from the lake was set as a fraction of the surface water inflows. It was found that a value of 0.835 produced the best fit as shown in Figure 24.

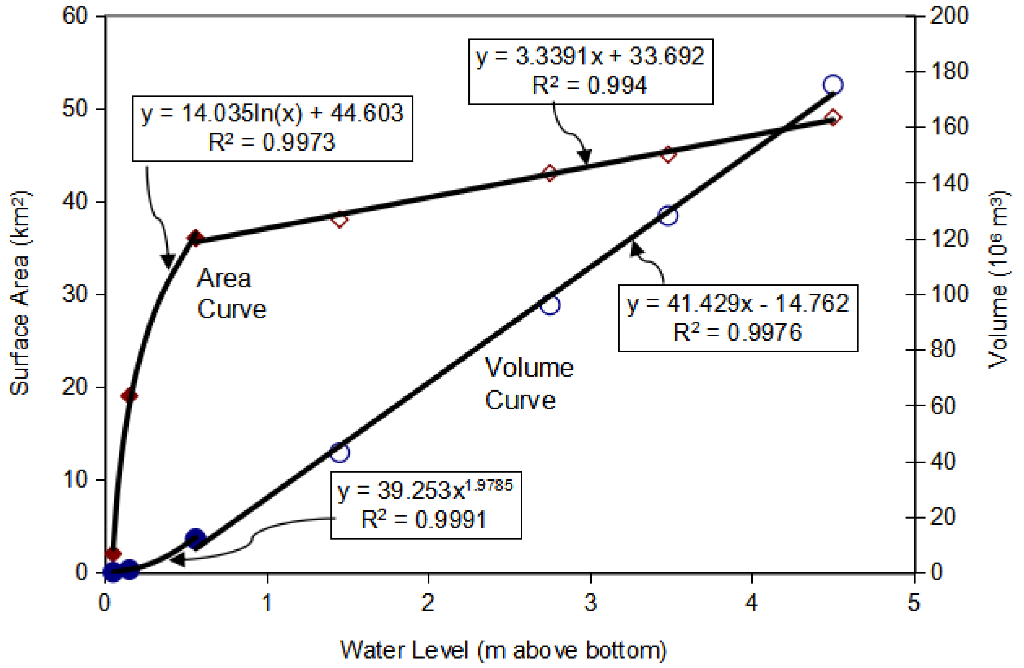


Figure: 24: Height Volume Area (HVA) curves of Lake Nakuru

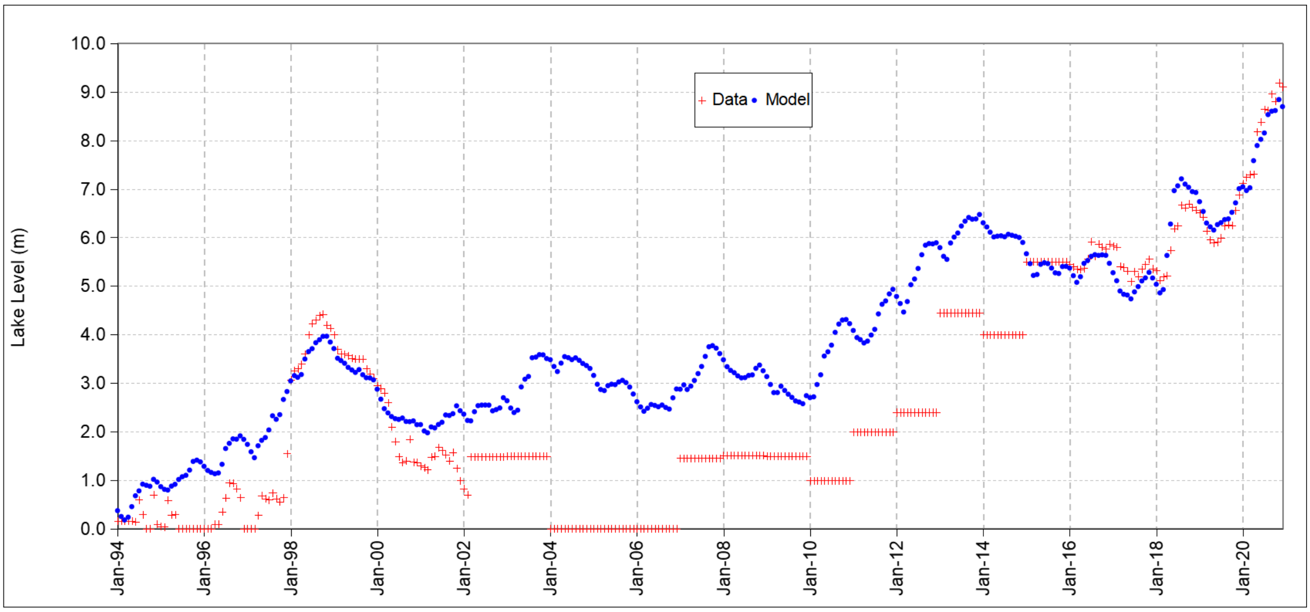


Figure 24: Water balance of Lake Nakuru from 1994 to 2020 based on the outputs from SWAT

5.5 Frequency analysis of lake water levels

The mean annual lake water levels (Figure 25) fitted a log-normal distribution as shown in Figure 26. Based on this graph, the extrapolated lake levels at return periods of 50 to 500 years are shown in Table 5.

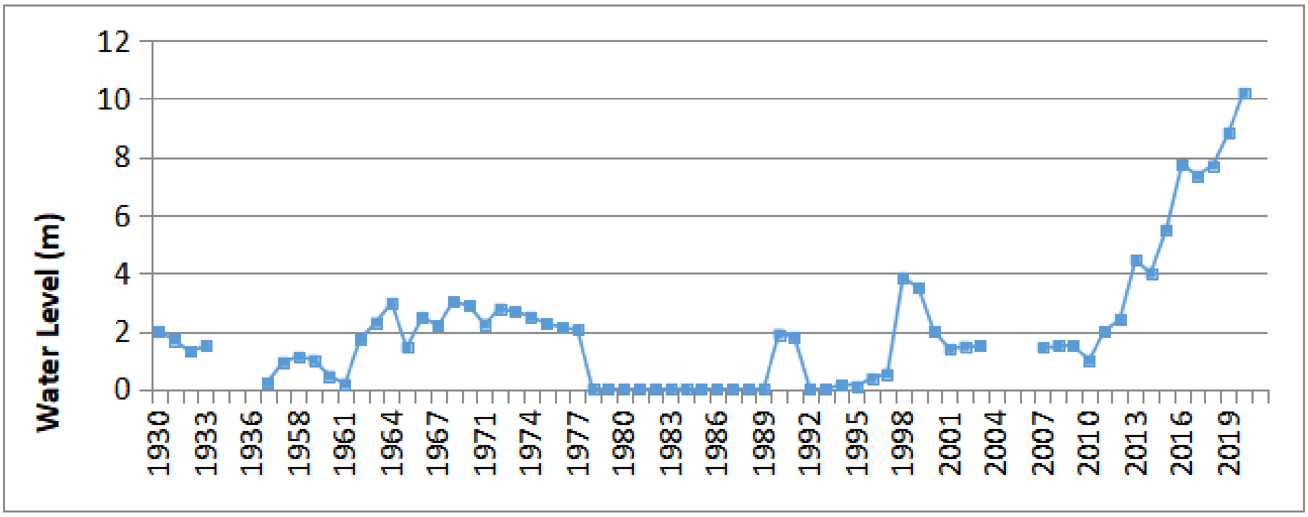


Figure 25: Time series of lake water levels

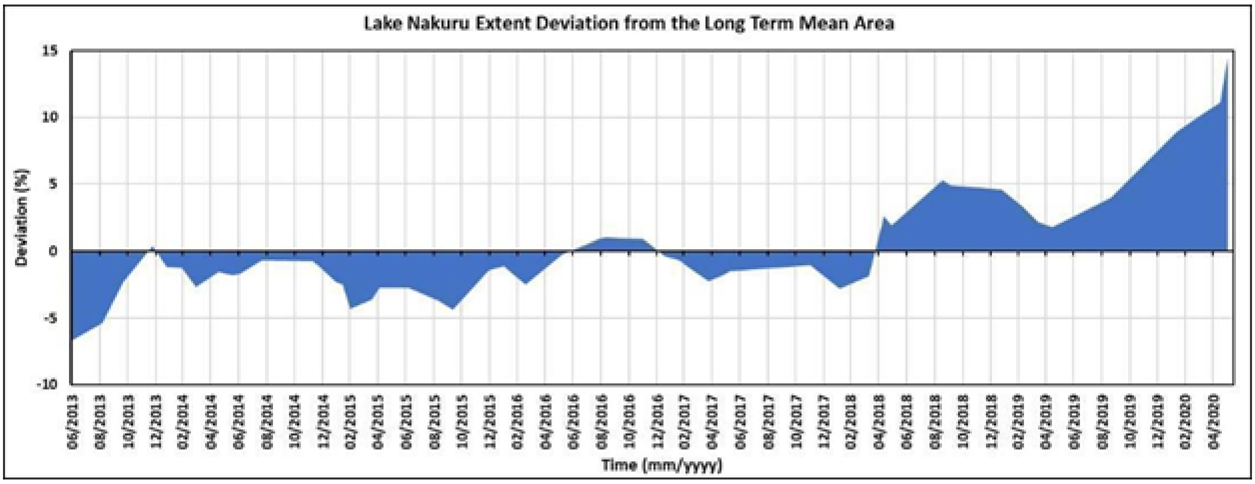


Fig. 26: Lake Nakuru Spatial Extent Deviation from Long-Term Mean.

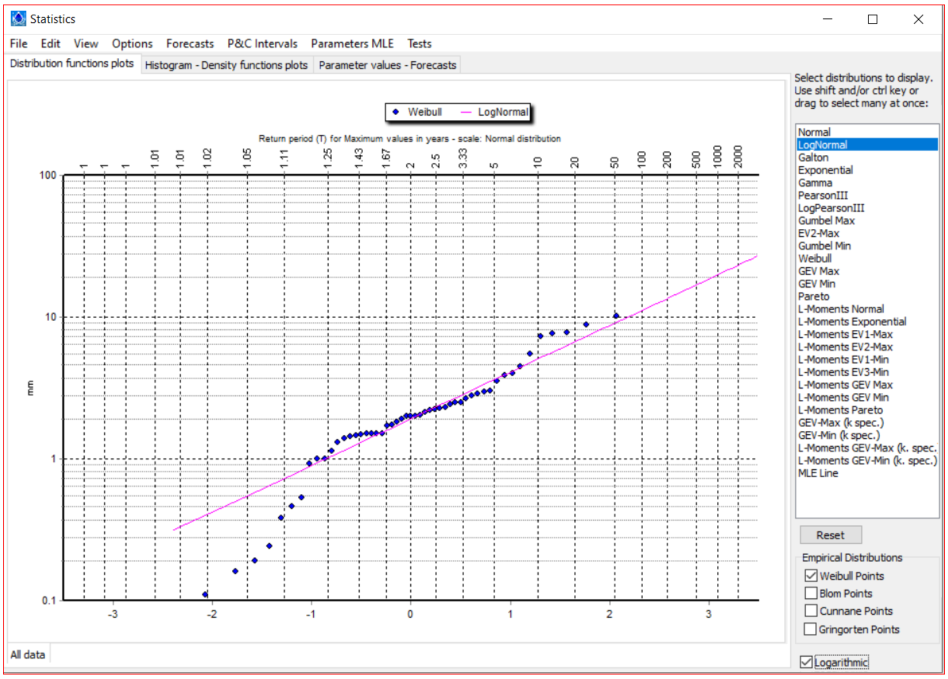


Figure 27: The frequency distribution of mean annual lake levels

Table 5 Lake water levels for different return periods

Return period T (yrs)	Lake Level H (m)	**Elevation (masl)** Zero level = 1757.9 masl
50	9.07	1767
100	11.15	1769
200	13.17	1771
300	14.94	1773
400	16.04	1774
500	16.93	1775

5.6 Boundaries of the lake

Figure 27 and 28 show the areas that are most likely to be inundated if the lake continues to get more water. The areas affected are to the S and NW. The NW area has developed properties that would be affected by water, Although the property owners may not be asked to move, they should be made aware that they inhabit areas that may be flooded at some time in the future. They may be asked to develop their plots with this fact in mind. Looking at the topography in these two maps, it is clear that the limits of the lake run along a series of hills and perhaps point to the fact that these areas may have been under the influence of the lake at some time in the past.

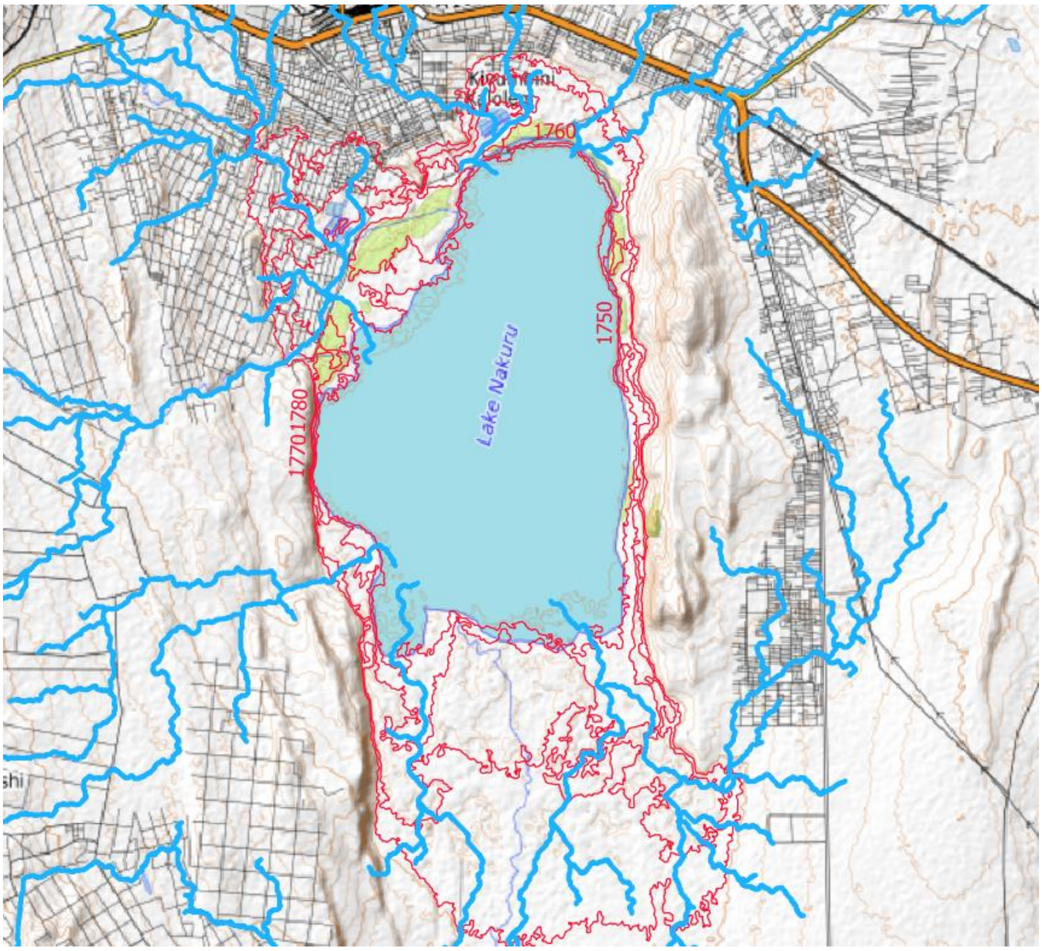


Figure 27: The 500 year flood mark limits showing the 1750, 1760,1770 and 1780 contour lines in red

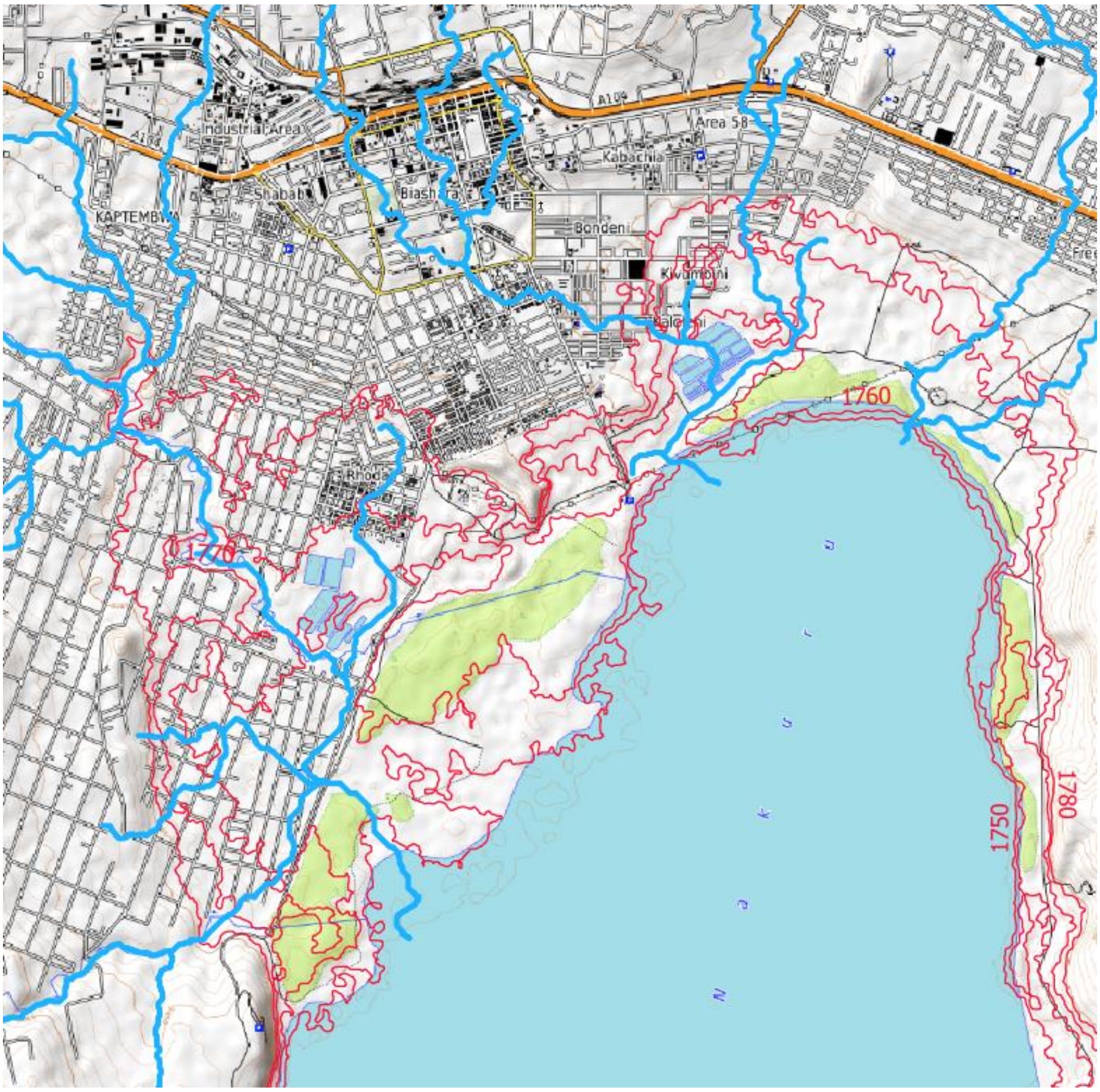


Figure 28: Areas covered by the 500 year flood mark limit of the lake, the outermost line is 1780 m contour line showing areas on the north-west side of the lake that are susceptible to future flooding

6.0 LANDUSE/ LANDCOVER CHANGES

Land use/Land Cover changes have a significant influence on the hydrological & Geological response. These changes are usually induced by human activities and require accurate mapping to understand the Hydrological & Geological pattern of the region under study.

Remote sensing techniques have been valuable in mapping urban land-use pattern as well as data sources which aid in GIS analysis and modeling of urban growth and land-use changes. These data characteristics are necessary for land-use monitoring, which is an essential element of socio-ecological studies and general understanding of its impact on water resources.

In order to assess the land-use within Lake Nakuru catchment, it is best to evaluate the spatial dimension of satellite images. The spatial dimension of remote sensing images as assessed by image texture contains information on local spatial structure and variability of land-cover categories, and can raise land-use classification accuracies in heterogeneous urban landscapes.

During image classification, seven (7) classes were adopted. These included Forestland, Open grassland, Cropland, Open water, Vegetated wetland, Settlements and Wooded grassland respectively.

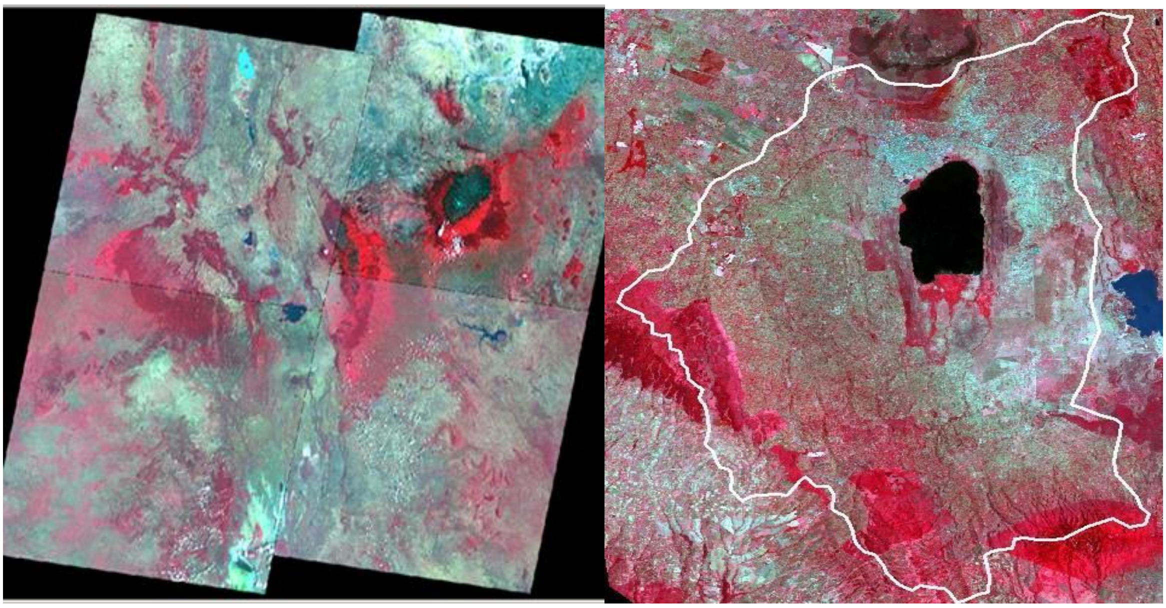


Figure 29 : Landsat satellite image scenes covering Lake Nakuru Catchment area

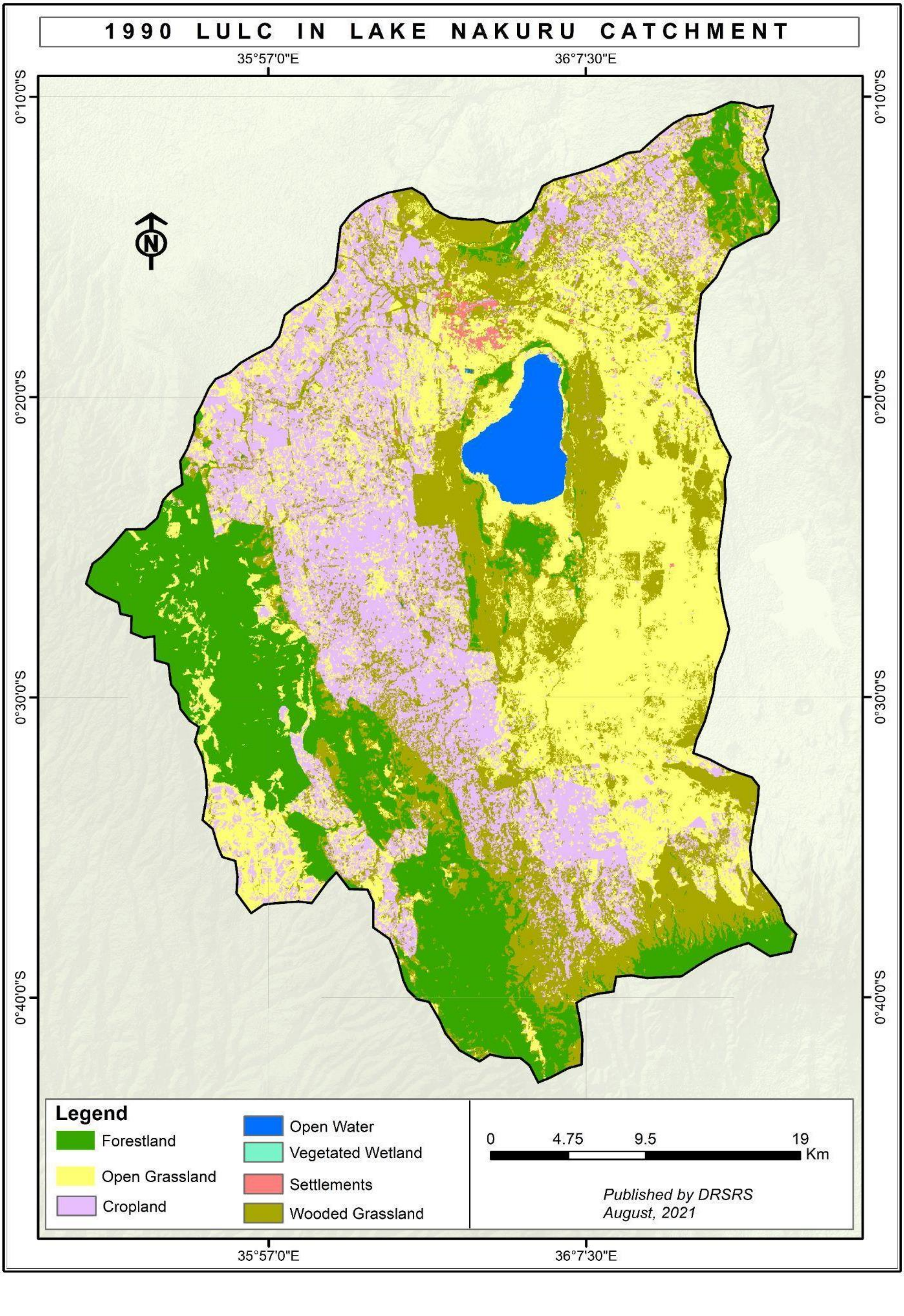


Figure 30 : Land use/Land Cover types in 1990 within Lake Nakuru Catchment

From satellite image analysis for 1990, open grassland covered a large area of the lake catchment representing about 31% of the total area (156,429ha).Other major LULC classes included wooded grassland at 24% and Cropland at 23%. The forest cover remained intact, covering about 19% (30,118.41ha) of the total catchment area. Open water within the catchment occupied about 2% of the total area in 1990.

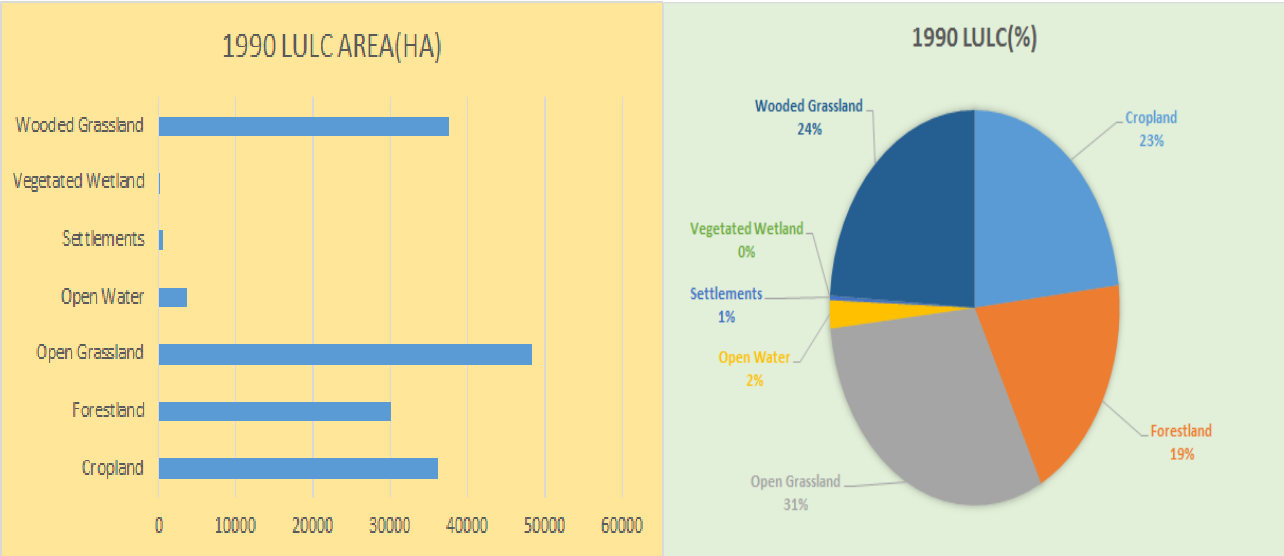


Figure. 31: Graphs showing Landuse/ Landcover Pattern in 1990

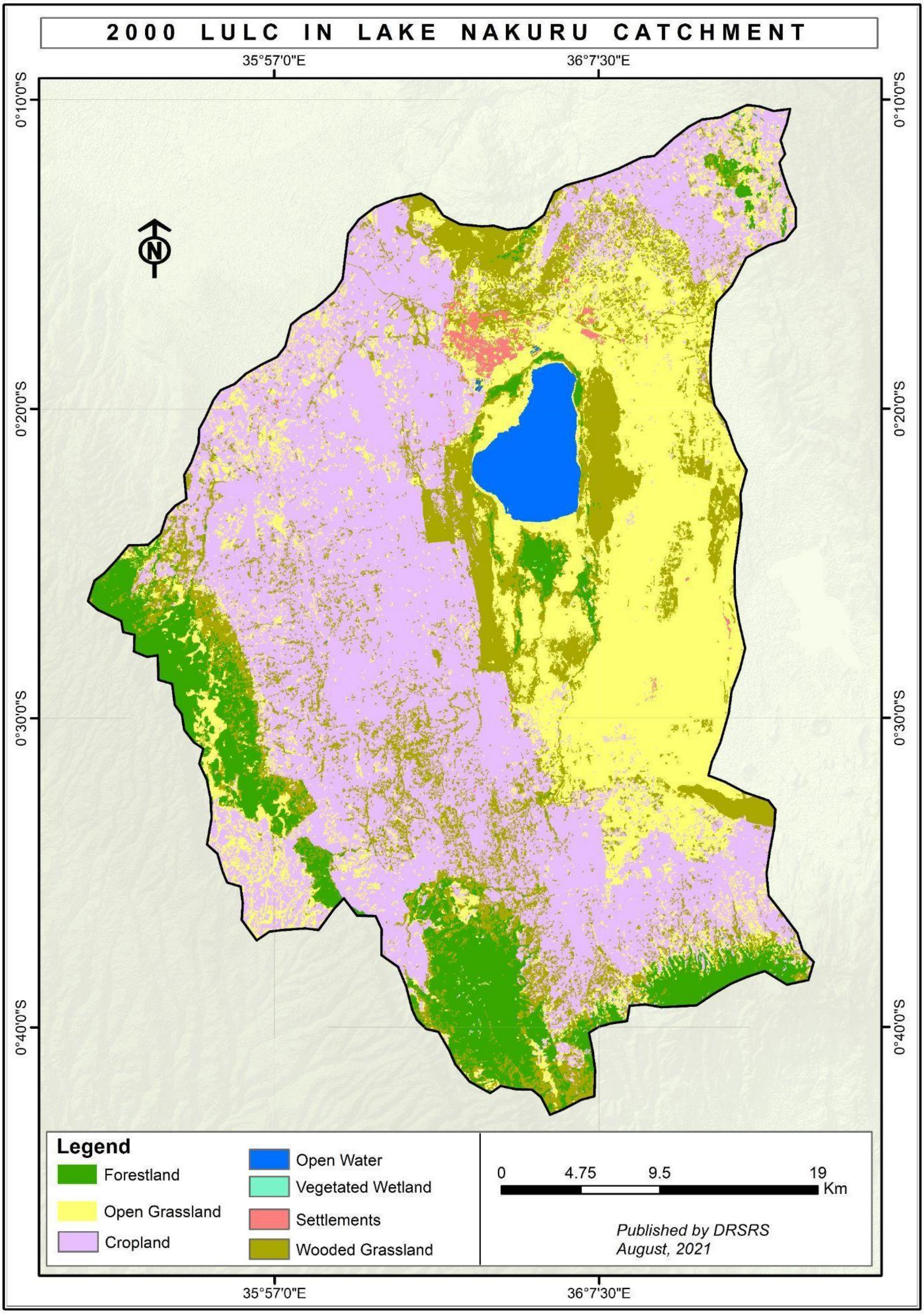


Figure 32: Land use/Land Cover types in 2000 within Lake Nakuru Catchment

In 2000, land use / land cover patterns changed drastically with cropland occupying about 42% of the total catchment area, open grassland 28% and wooded grassland 17% respectively. The analysis does not indicate any significant increase in water surface area between 1990 and 2000. A slight increase of about 3991.05 ha is recorded.

On the other hand, the area under forest land declined significantly in 2000 from 30,118.41ha in 1990 to 14,946.84ha in 2000.This represents about a 9.6% decrease in forest cover between the two periods. The 2001 excision of about 35,000ha in Eastern Mau forest block are responsible for the forest loss in the Lake Nakuru catchment.

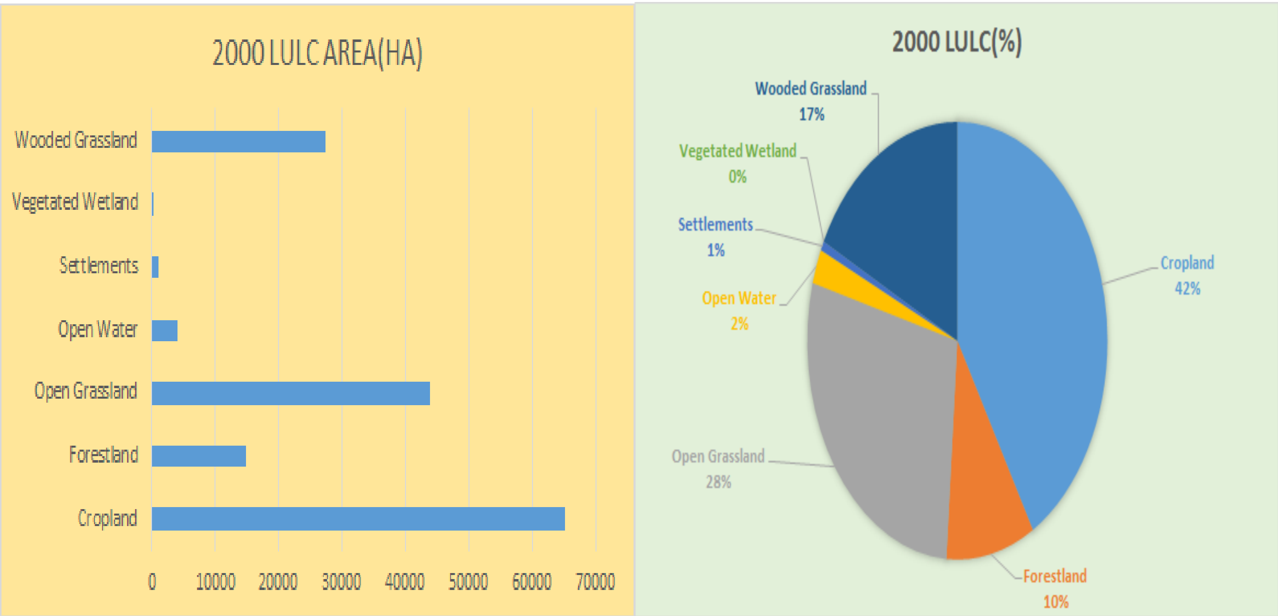


Fig 21: Graphs showing LULC pattern in 2000

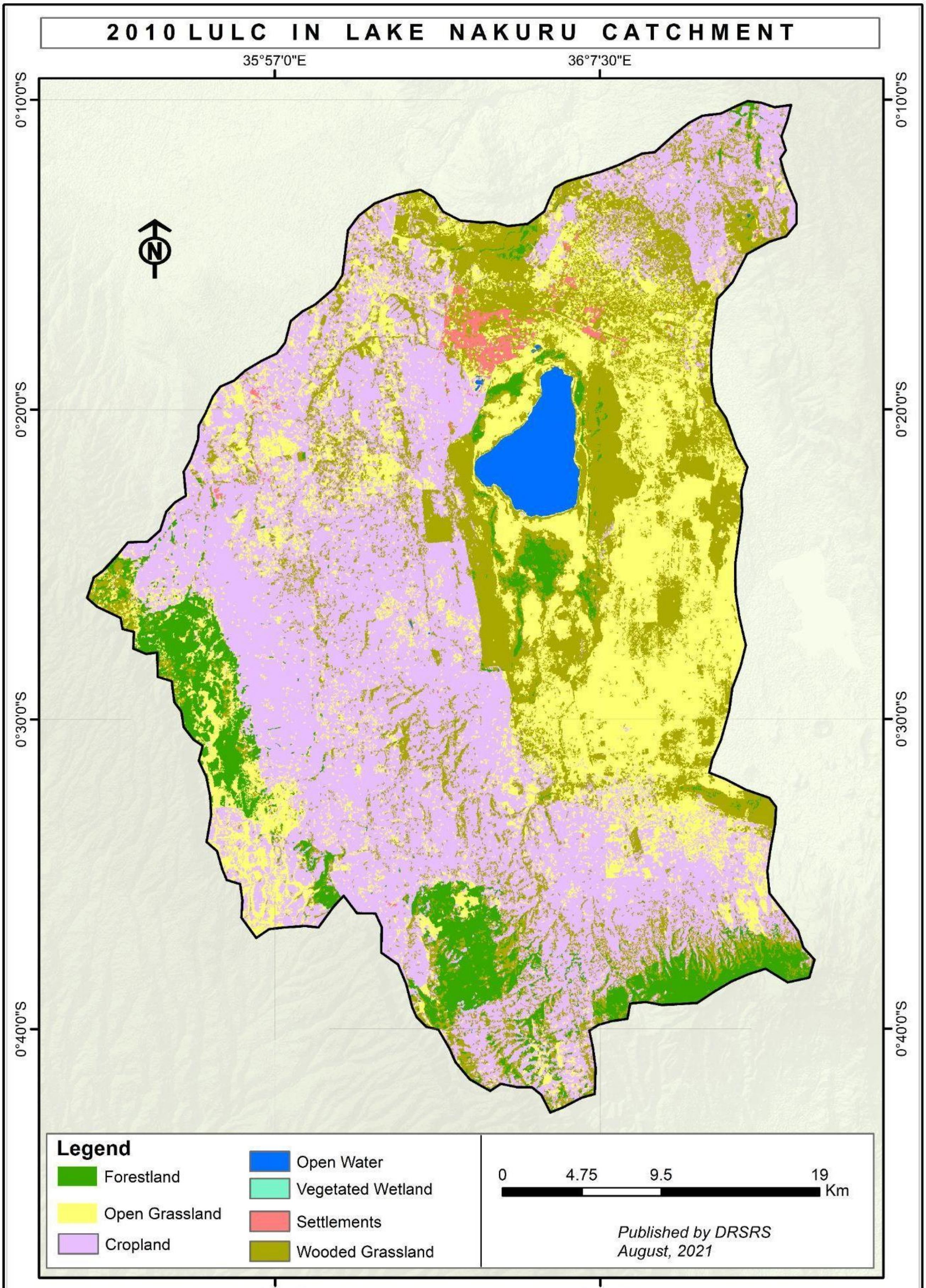


Fig 22 : Land use/Land Cover types in 2010 within Lake Nakuru Catchment

The area under crop land and forestland remained constant in 2010 with cropland declining slightly by only 0.1%. Results from the analysis further indicate a noticeable increase in the area under settlement by about 0.4% from 1,064.07ha in 2000 to 1,712.09ha in 2010.

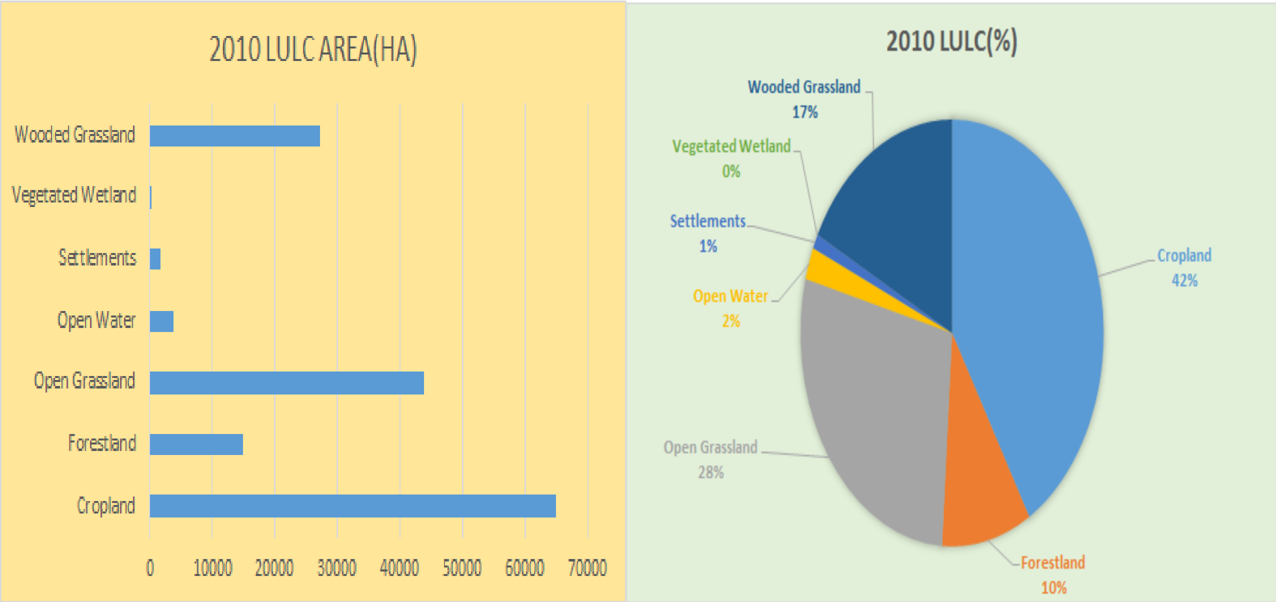


Fig. 23: Graphs showing Landuse/Landcover Pattern in 2010

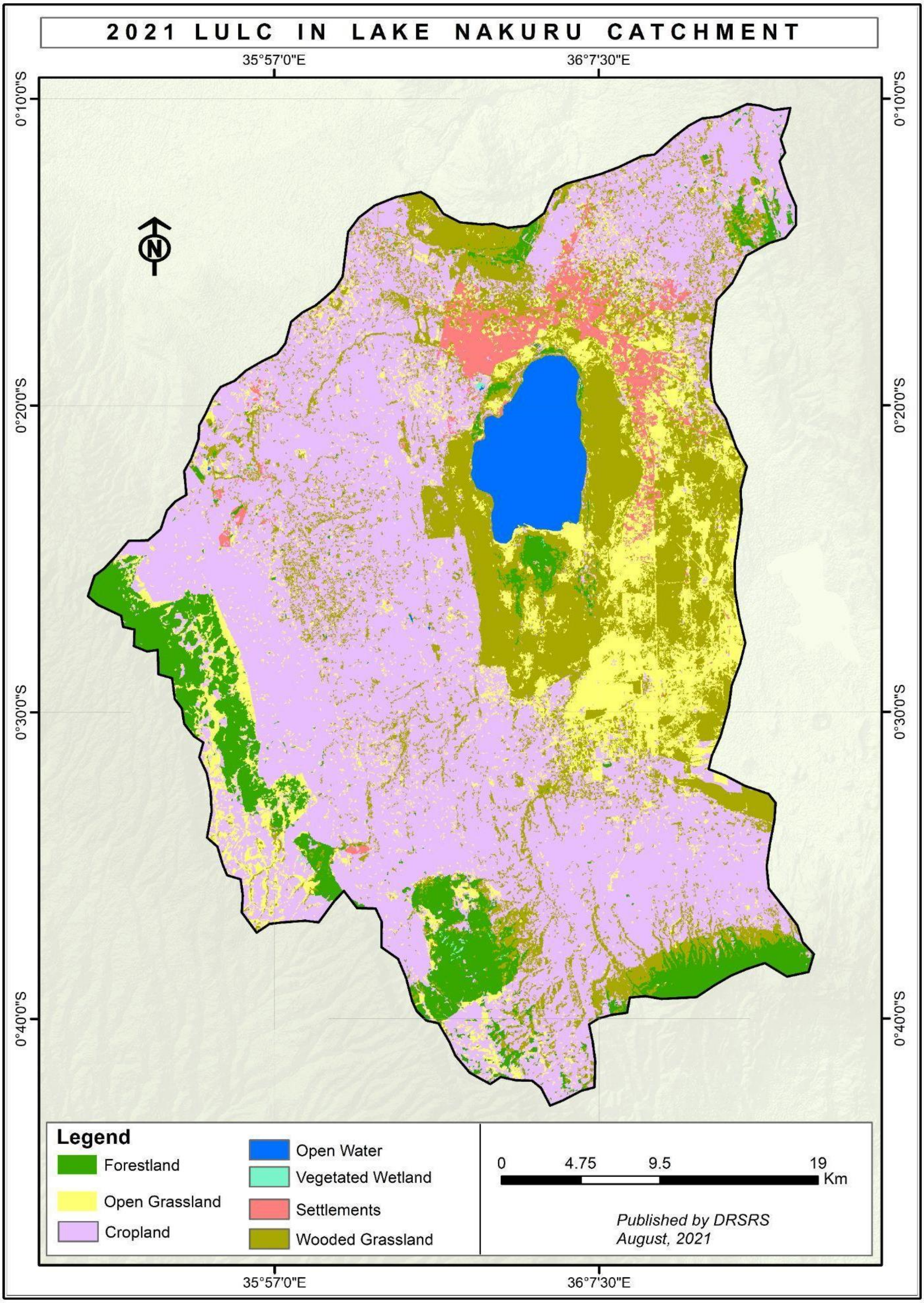


Fig. 24 : Land use/Land Cover types in 2021 within Lake Nakuru Catchment

All the Land use/land cover classes recorded significant change in area as observed from the 2021 satellite image analysis. The area under open water within the basin increased by about 3% from 3,788.09ha in 2010 to 5,404.41ha in 2021.This is evidently shown by the rising water levels in the Rift valley region which covers Lake Nakuru.

Area under crop land increased by about 10.1% from 6,4925.81ha in 2010 to 80,660.16ha in 2021.The Forest cover within the lake catchment declined by about 1.8% from 14,946.81ha in 2010 to about 12,206.07ha in 2021. Open grassland however, declined drastically between the two epochs, recording a 15% decrease from 43,828.54ha in 2010 to 20,371.59ha in 2021.

The area under settlements increased by about 1.9% in 2021 recording an increase in area of about 4,709.07ha as compared to 1,712.09ha in 2010.

Wooded grassland on the other hand increased in area from 17.4% recorded in 2010 to 21.1% in 2021.

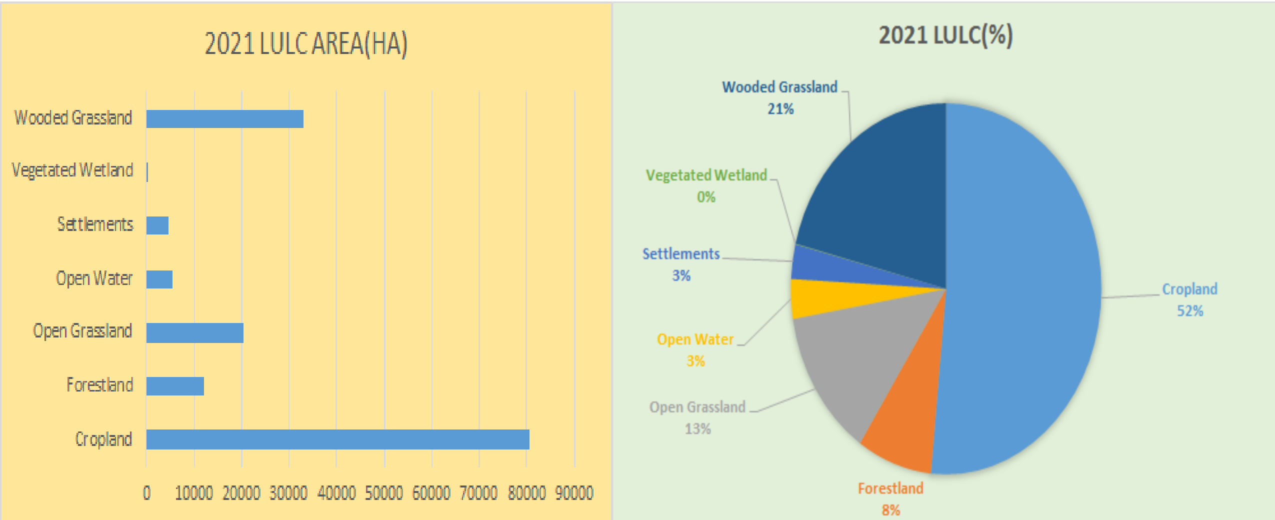


Fig. 25: Graphs showing Landuse/Landcover Pattern in 2021

7.1 Trends in land use/Land Cover Pattern in Lake Nakuru Basin

The case of diminishing forest cover in Mau forest complex cannot be dissociated from the history of human occupation in the region. The present Lake Nakuru basin lies in what was until the late 19th Century, the sprawling Maasai grazing country. The Maasai called the area around the lake "*Angata Nakurru*", or the plain of dust devils.

Prior to Kenya’s independence, most of the land within Lake Nakuru Catchment was occupied by white settlers who owned large tracks of land growing mainly wheat in Njoro, Rongai, Mau, Bahati and Dundori areas. The south eastern parts (including Kiambogo and A.D.C farms) were mainly used for ranching. In 1893 the construction of the Kenya-Uganda Railway began in Mombasa. Upon arrival in Nakuru, the rail crew set up camp and in doing so, established the future agricultural capital of the Rift Valley. Most of the Rift Valley was set aside for the settlement of Europeans and dubbed the *White Highlands*. Hundreds of European colonists followed in the wake of the railway.

Their goal was to set up homes and make a new life, far away from the miseries and restrictions of war torn Europe. Native Kenyans also flocked from different parts of the country to find work on the European owned farms, budding businesses in the towns and the civil service. Others came in from the central areas of Kenya to exploit the newly opened pastures for their livestock thus starting what came to be known as the "squatter problem" which was to escalate into a major conflict between the European settlers and the Africans in the 1950s.

Before long, ranches and large mixed farms sprung up in the area and Nakuru rapidly grew in size. By 1948, the fledgling town supported a population of 17,000 people. Bush and forest were cleared to make room for human habitation, for the cultivation of new cash crops and for grazing highly prized livestock imported from Europe and Australia. Conflict between Europeans and African continued to grow right from the early settlement of the *"White Highlands*" culminating in major unrest of Africans in the 1950s.

The *"White Highlands"* were seen by the Africans as the ultimate prize of independence. The newly created government came under intense pressure to allocate land to the landless. Nakuru area saw a new wave of settlement schemes for indigenous farmers from 1962 to 1967. Settlements initially took place on existing large farms bought from European owners which were sub-divided into smaller, individually owned parcels of land. As the number of settlements increased over the next decade, encroachment into the forest reserves occurred and the thin mantle of protection afforded by the forests in the lakes watershed were gradually eroded.

Between 1970 and 2021, more than 600 square kilometres of forest and land under natural vegetation in the catchment basin of Lake Nakuru has been cleared for cultivation and settlement.The area under natural forest cover within Lake Nakuru basin has reduced from 47% in 1970; 26% in 1986;10% in the year 2000; 9% in 2010 and 8% in 2021.

Table 3: *Table showing Landuse/Landcover changes within Lake Nakuru Catchment between 1990 and 2021*

	1990		2000		2010		2021	
LULC	AREA	% COVER	AREA	% COVER	AREA	% COVER	AREA	% COVER
CROPLAND	36243.81	23.2	65090.34	41.6	64925.81	41.5	80660.16	51.6
FORESTLAND	30118.41	19.3	14946.84	9.6	14946.81	9.6	12206.07	7.8
OPEN GRASSLAND	48322.62	30.9	43928.37	28.1	43828.54	28.0	20371.59	13.0
OPEN	3592.0	2.3	3991.05	2.6	3788.10	2.4	5404.41	3.5

WATER	8							
SETTLEMENTS	569.25	0.4	1064.07	0.7	1712.10	1.1	4709.07	3.0
VEGETATED WETLAND	12.42	0.0	2.52	0.0	2.52	0.0	92.61	0.1
WOODED GRASSLAND	37560.15	24.0	27395.55	17.5	27214.93	17.4	32974.83	21.1
TOTALS	156418.74	100	156418.74	100	156418.80	100	156418.74	100

7.1.1 Cropland

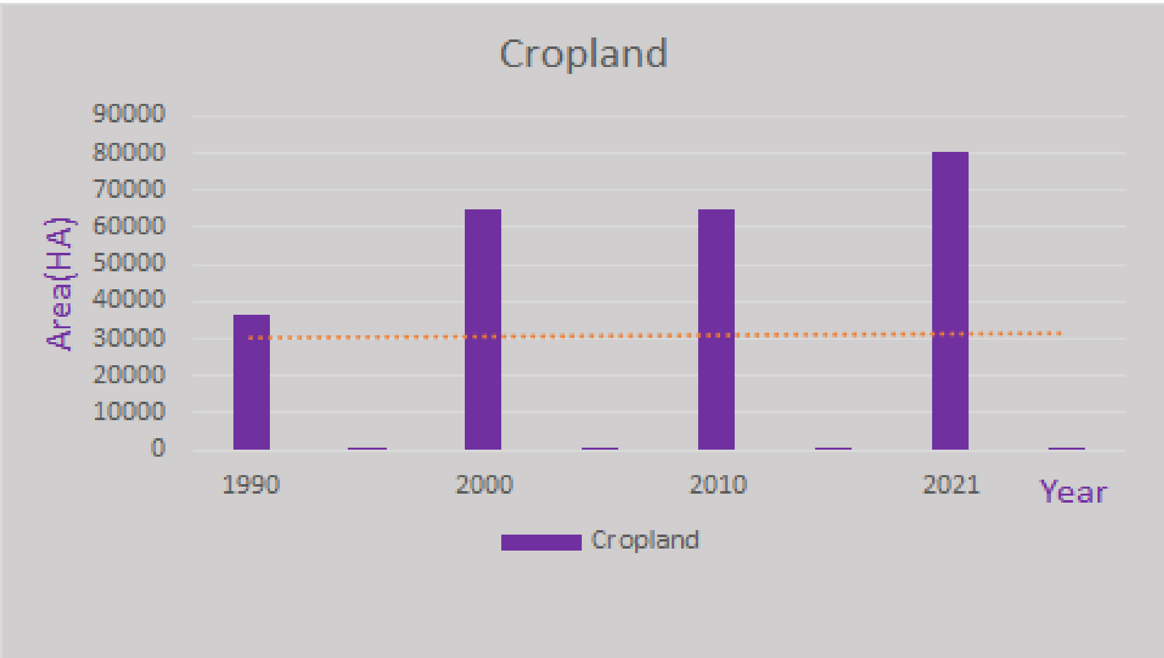


Fig. 26: Graph showing trend in Cropland surface area between 1990 and 2021

7.1.2 Forestland

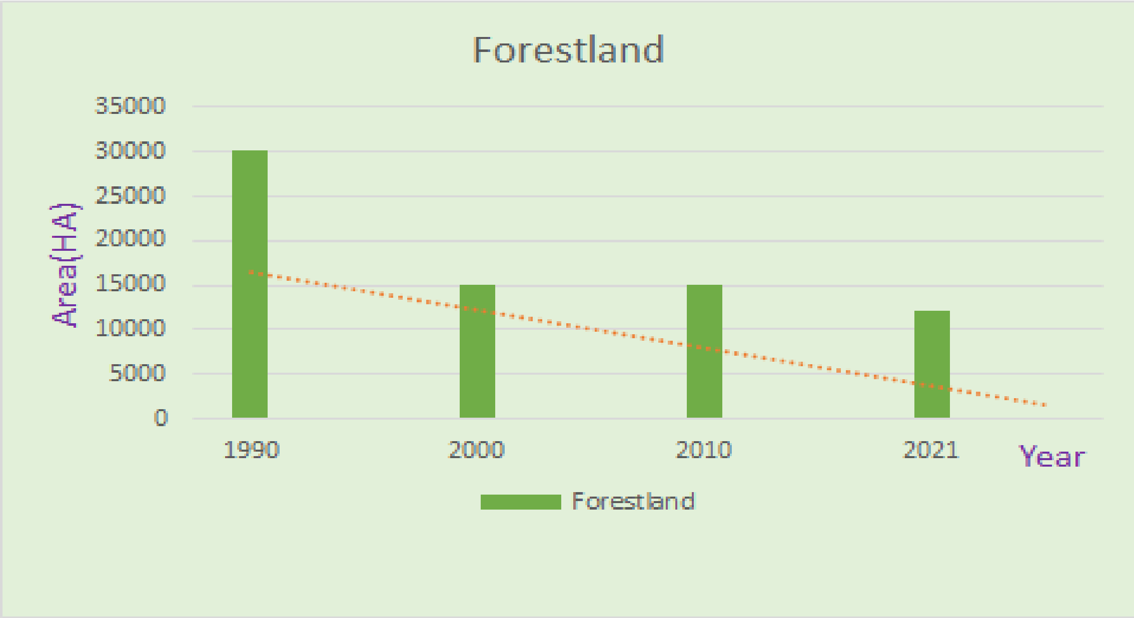


Fig. 27: Graph showing trend in Forestland area between 1990 and 2021

7.1.3 Open Grassland

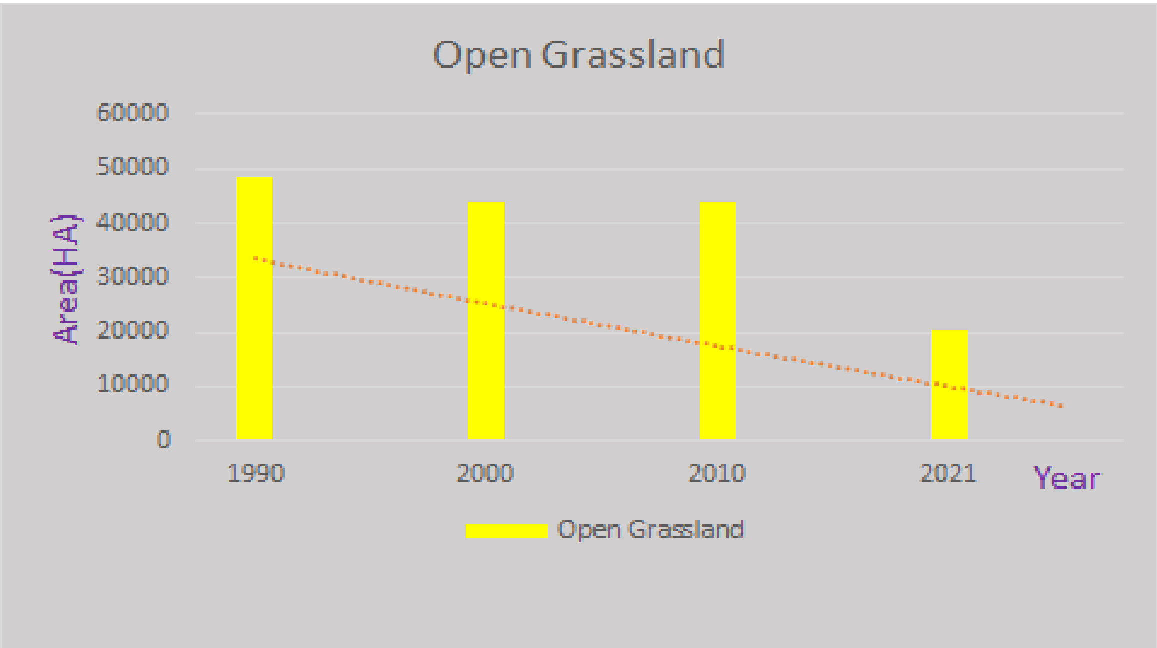


Fig.28: Graph showing trend in Open Grassland area between 1990 and 2021

7.1.4 Open Water

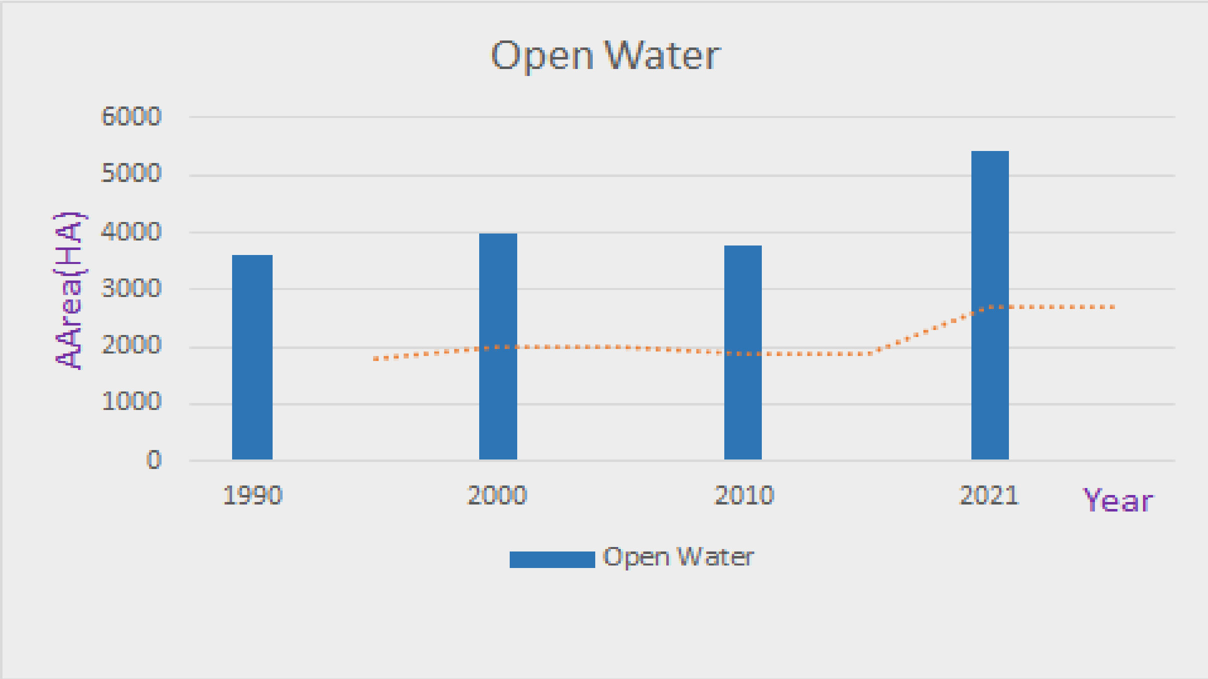


Fig.29: Graph showing trend in Open Water surface area between 1990 and 2021

7.1.5 Settlements

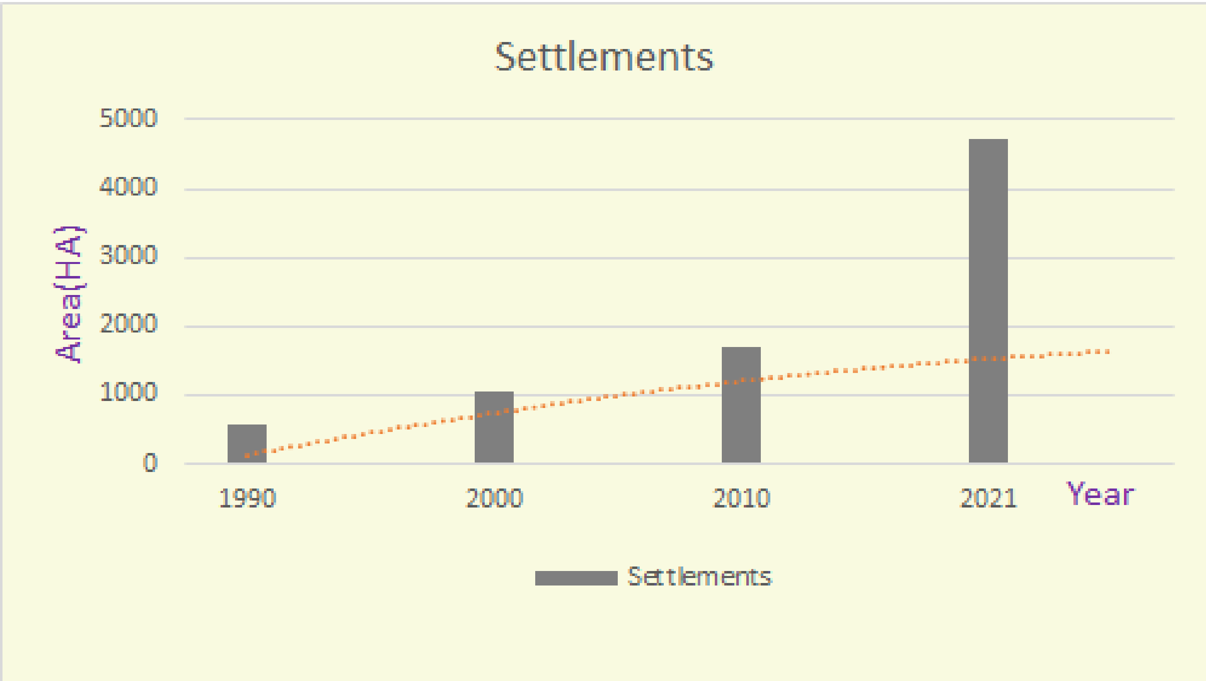


Fig.30: Graph showing trend in area under settlement between 1990 and 2021

7.1.6 Vegetated Wetland

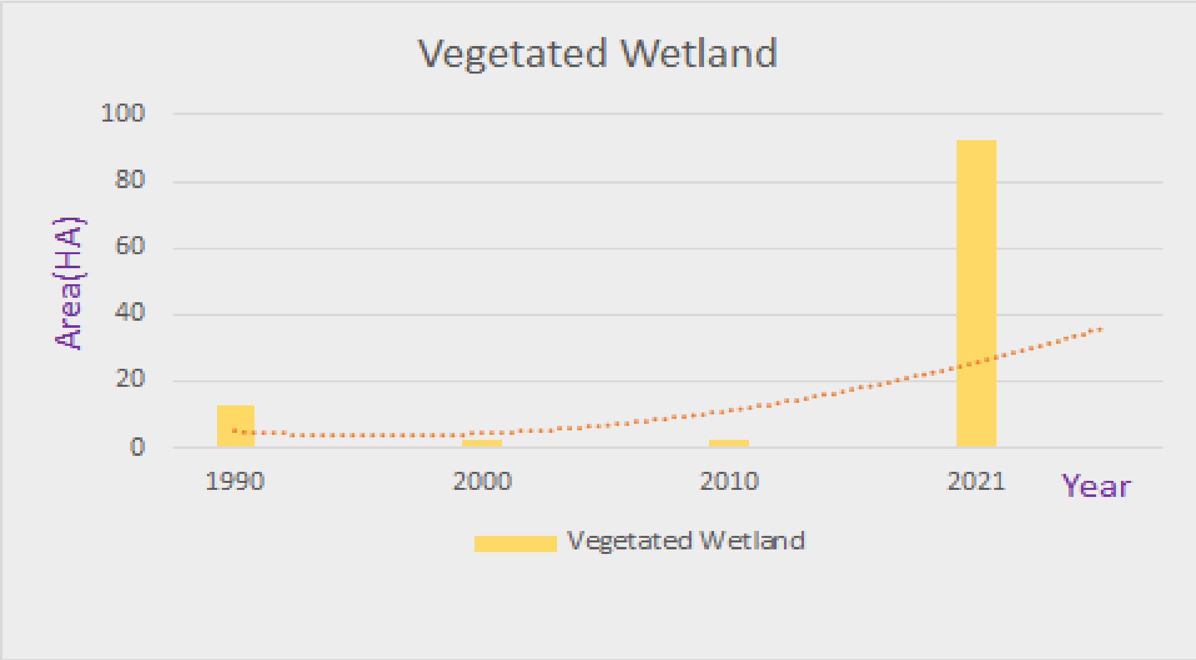


Fig.31: Graph showing trend in Vegetated Wetland area between 1990 and 2021

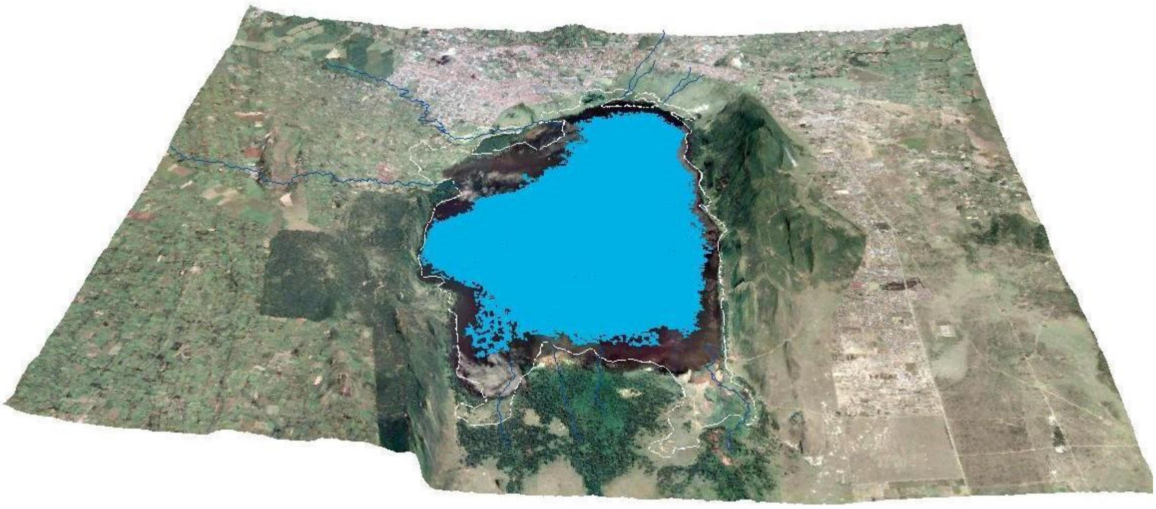
7.1.7 Wooded Grassland

Fig.32: Graph showing trend in area under Wooded Grassland between 1990 and 2021

7.2 Changes in lake areas and lake water levels over time

The changes in lake area were calculated based on various water level rise scenarios. Lake Nakuru measured approximately 43km^2 in December 2010 and 68km^2 as of June 2021 respectively. This represents an increase of 25km^2 (36.8%) between the two years. The Southern and North West side of the lake witnessed excessive overflow possible due to lower elevations.

Fig. 33: 3D Map showing Lake Nakuru Flood Level



8.0 SIMULATIONS

Since 2011, water levels in Lake Nakuru have been on the rise from an average of 3m to the highest level of about 8.5m recorded in April 2021 as observed from digital elevation models and satellite images. This trend exhibits an approximate water rise of about 0.7m per year.

Based on the 0.7m water level rise per year, an interval of two (2) years was used and therefore projection was done at 1.4m, 2.8m, 4.2m,5.6m and 7m respectively with the base year being 2021(June) and water level estimated at 9.2m during this year (2021,June).Consequently, the simulation was therefore projected for the years 2023,2025,2027,2029 and 2031 in order to assess the level of impact around the lake.

Table 4: Projected water depths from 2021 to 2031

YEAR	MONTH	DESCRIPTION	ESTIMATED DEPTH (M)
2021	JUNE	BASE YEAR	9.2
2023			10.6
2025			12
2027			13.4
2029			14.8
2031			16.2

8.1.0 Lake Water Levels and rise projections (scenarios)

8.1.1 Water Level Rise by 1.4m

From the simulation, if the water level rises by about 1.4m expected in 2023 based on the current scenario, the surface area of the lake will increase by about 5.9% from 68Km^2 to 72Km^2.The Northern, North-East and Southern part of Lake Nakuru may witness huge impact of the water overflow and flooding.

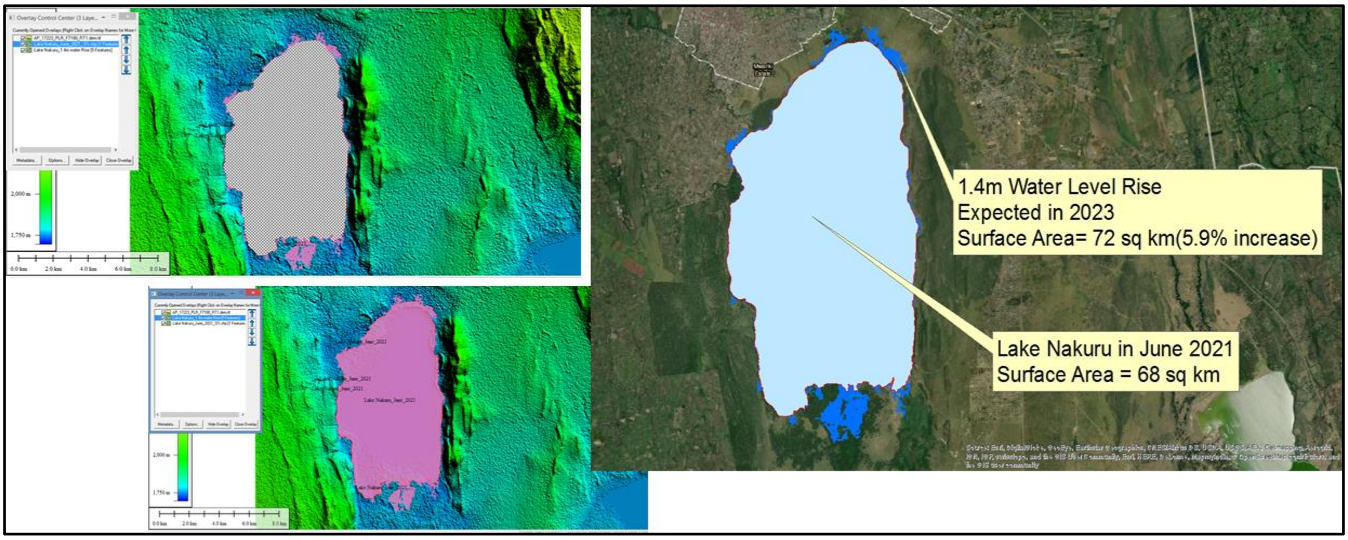


Fig 32: *Simulation for 1.4m water level Rise using ALOS PALSAR 12.5m Digital Elevation Model (DEM)*

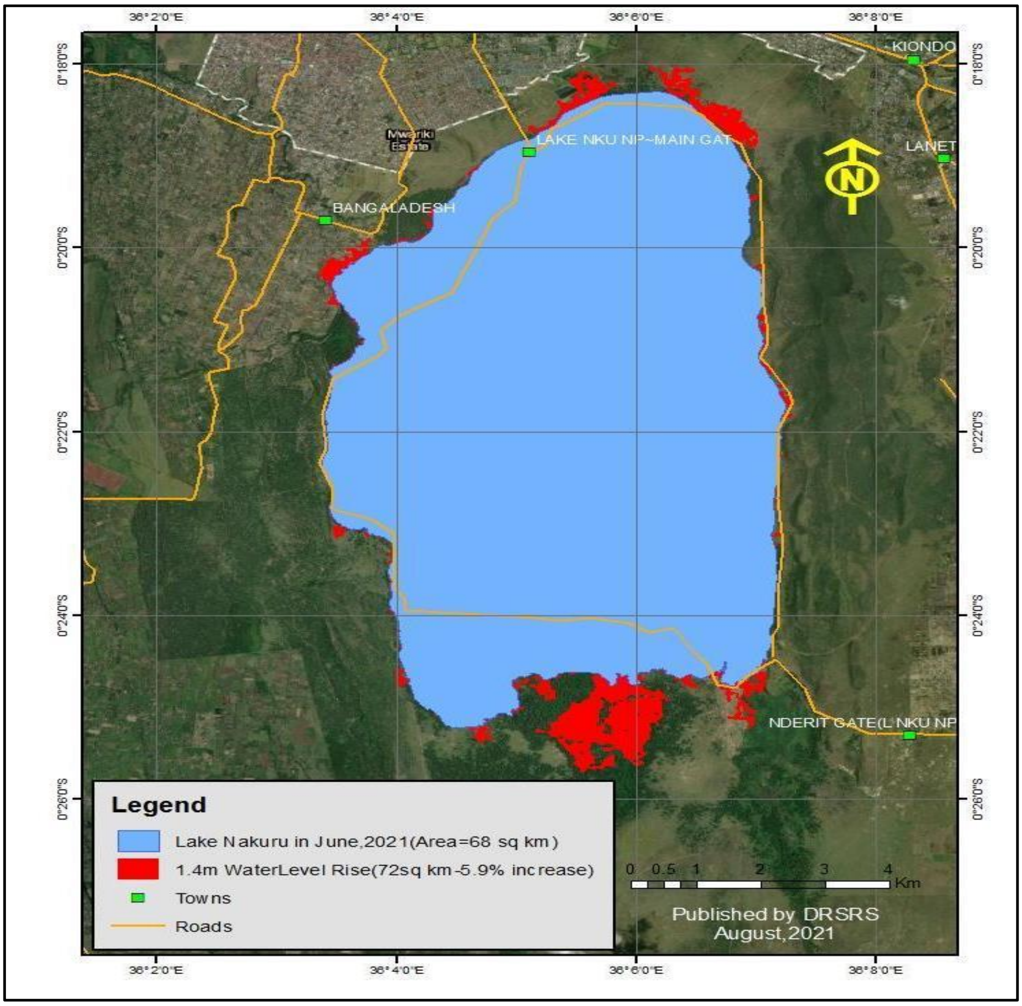


Fig. 34: Map showing expected increase in lake surface area for 1.4m water level rise

8.1.2 Water Level Rise by 2.8m

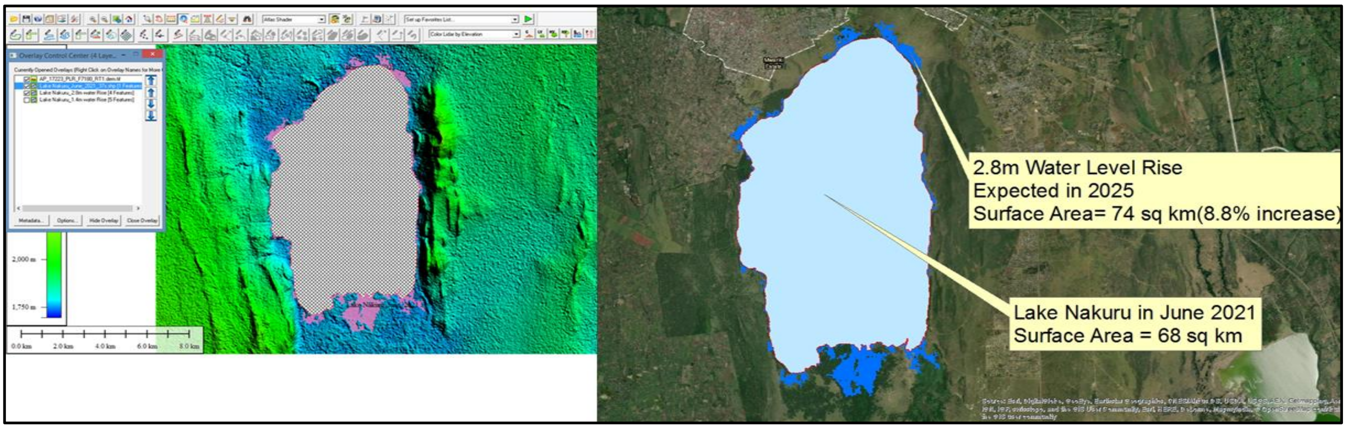


Fig.35: Simulation for 2.8m water level Rise using ALOS PALSAR 12.5m DEM

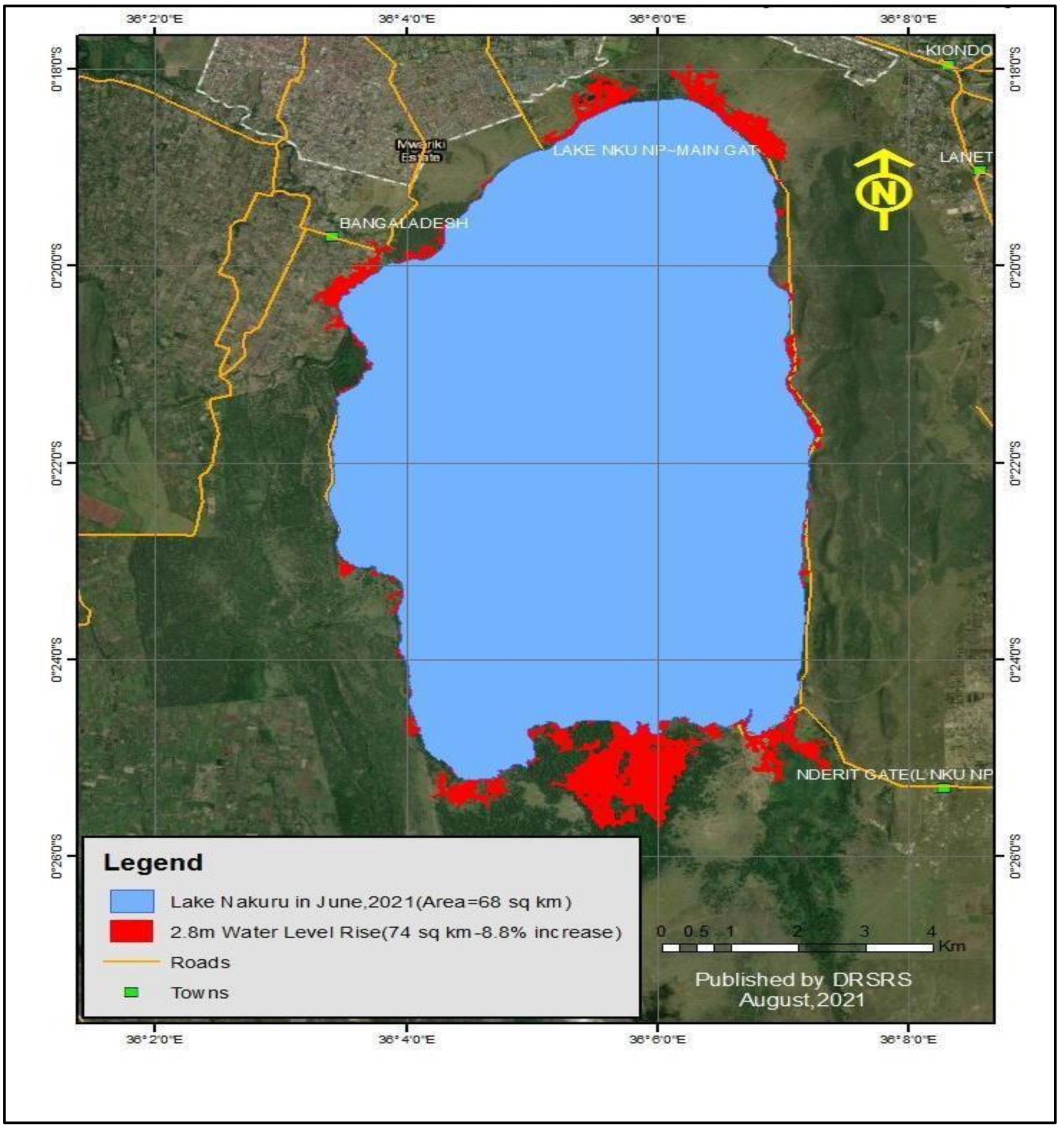


Fig.36: Map showing expected increase in Lake Nakuru surface area for 2.8m water level rise

8.1.3 Water Level Rise by 4.2m

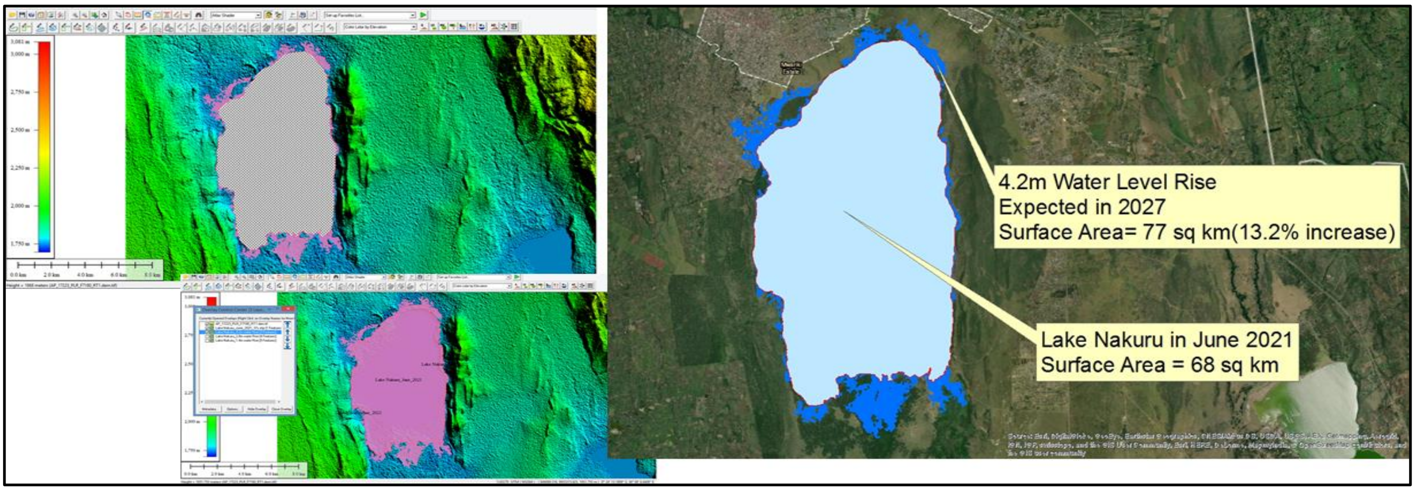


Fig.37: Simulation for 4.2m water level Rise using ALOS PALSAR 12.5m DEM

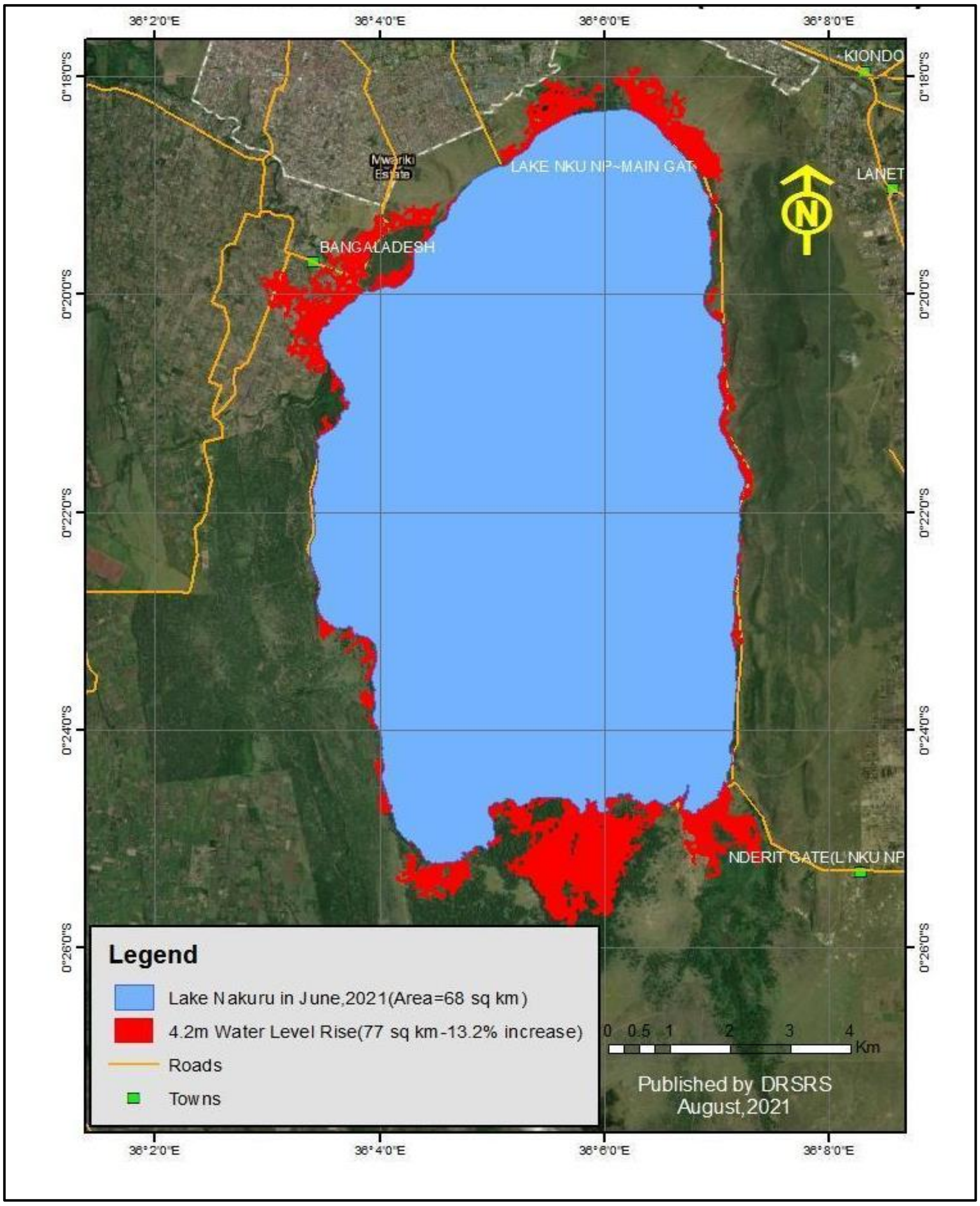


Fig.38: Map showing expected increase in lake surface area for 4.2m water level rise

8.1.4 Water Level Rise by 5.6m

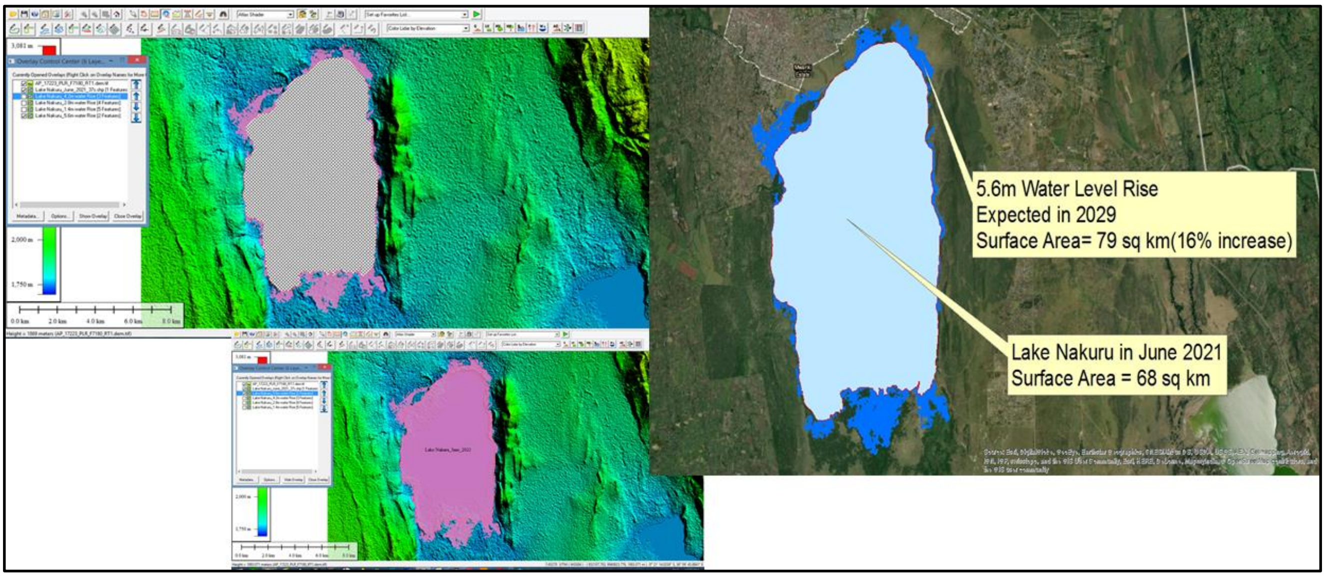


Fig.39: Simulation for 5.6m water level Rise using ALOS PALSAR 12.5m DEM

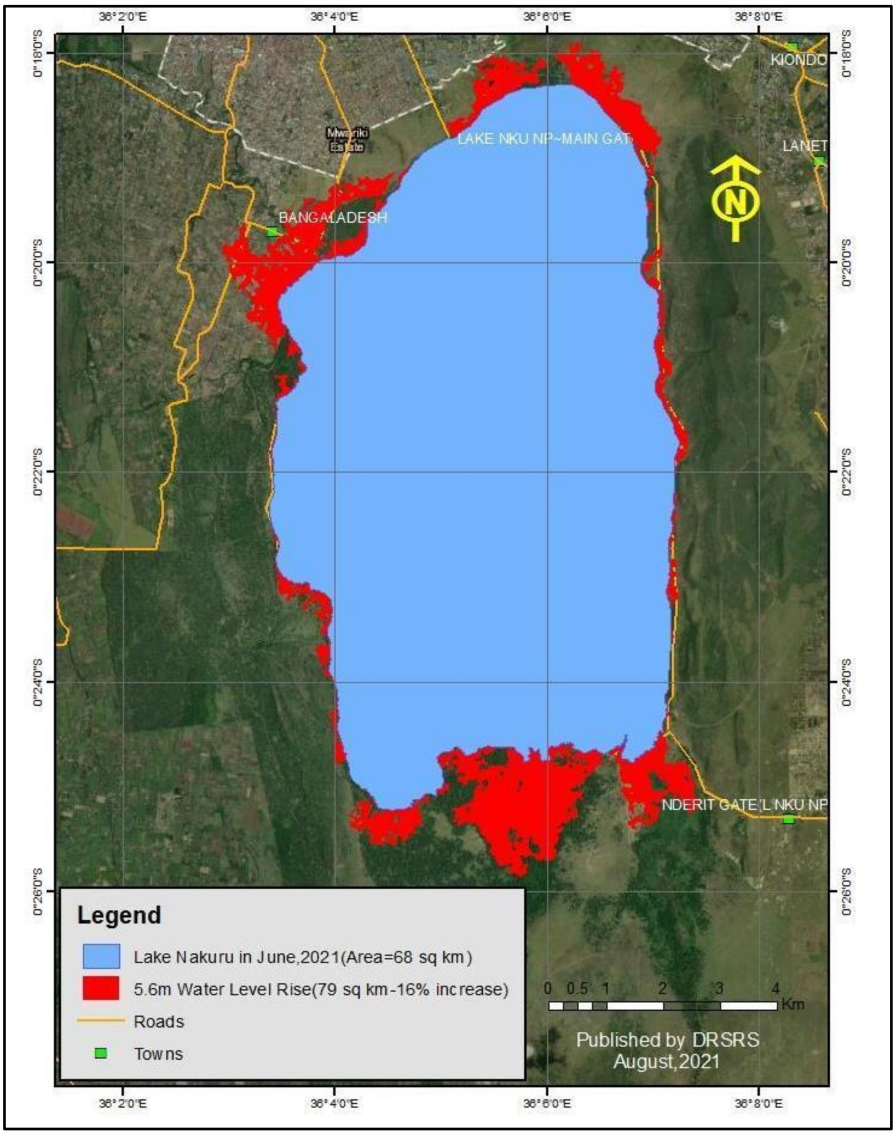


Fig.40: Map showing expected increase in lake surface area for 5.6m water level rise

8.1.5 Water Level Rise by 7m

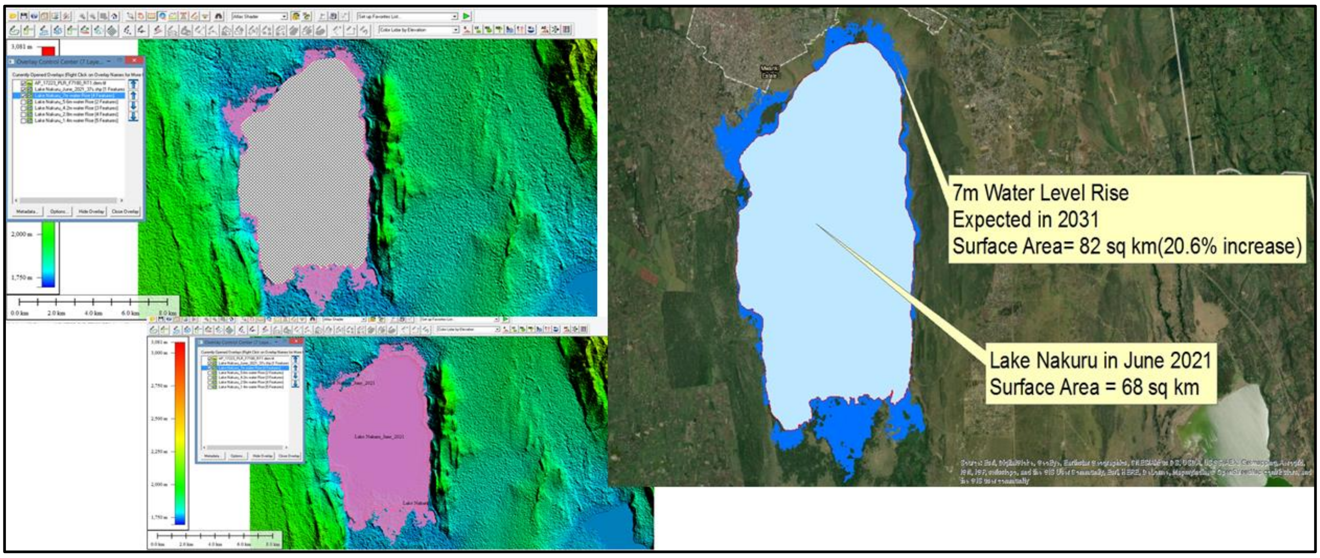


Fig.41: Simulation for 7m water level Rise using ALOS PALSAR 12.5m DEM

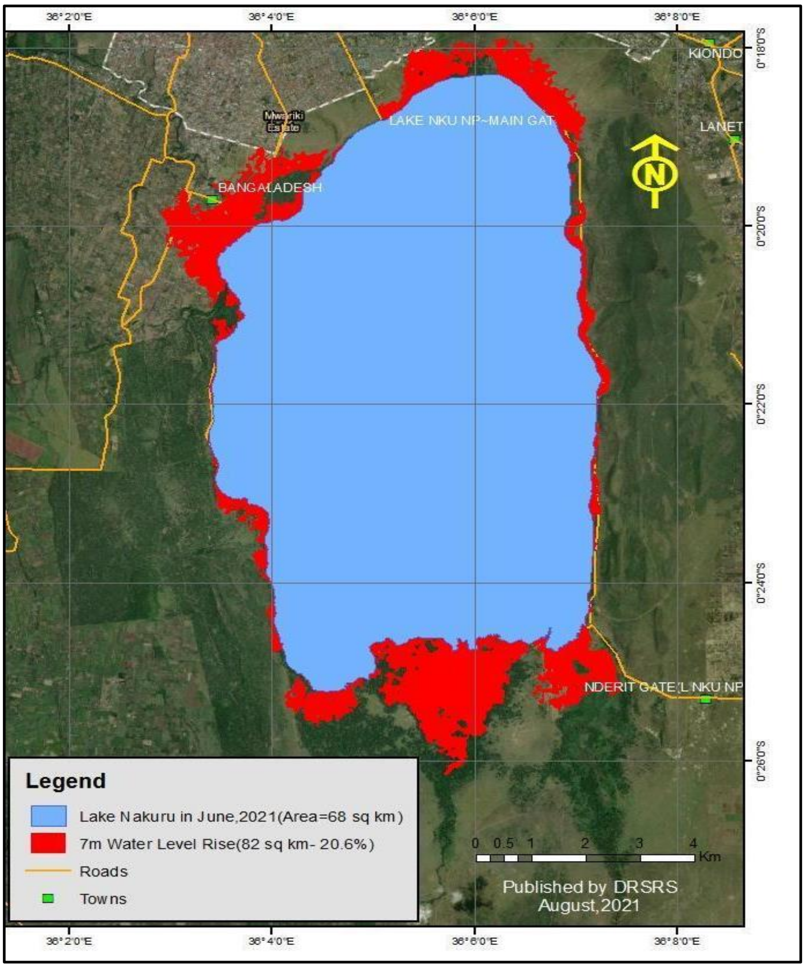


Fig.42: Map showing expected increase in Lake surface area for 7m water level rise

8.1.0 Proposed Beaconing

Based on the simulations above, beaconing of the lake boundary will be done using Global Navigation Satellite System (GNSS).This will precisely mark the boundaries by erecting visible beacons whose coordinates shall be availed for future reference. The interval between two beacons shall be guided by the reserved budget and the surrounding infrastructure and amenities.

Considering a 7m rise overflow as the worst scenario case, Lake Nakuru is projected to overflow by about 20.6% from 68 Km^2 in 2010 to 82 Km^2 in 2031.Considering establishment of lake beacons at an interval of 500m (as illustrated below),a total of 143 beacons will be required. It is important to note that the interval between two beacons shall be agreed upon after consultation with the County Government of Nakuru.

The beaconing approach will be similar to the one taken by KeNHA/ KURA in marking road reserve/ boundary beacons. The DRSRS will guide the County Government of Nakuru on the best approach with regards to design of the lake beacons and establishment of their precise coordinates using GNSS technology.

Upon completion of beaconing an appropriate compensation scheme will be established for the community surrounding the lake.

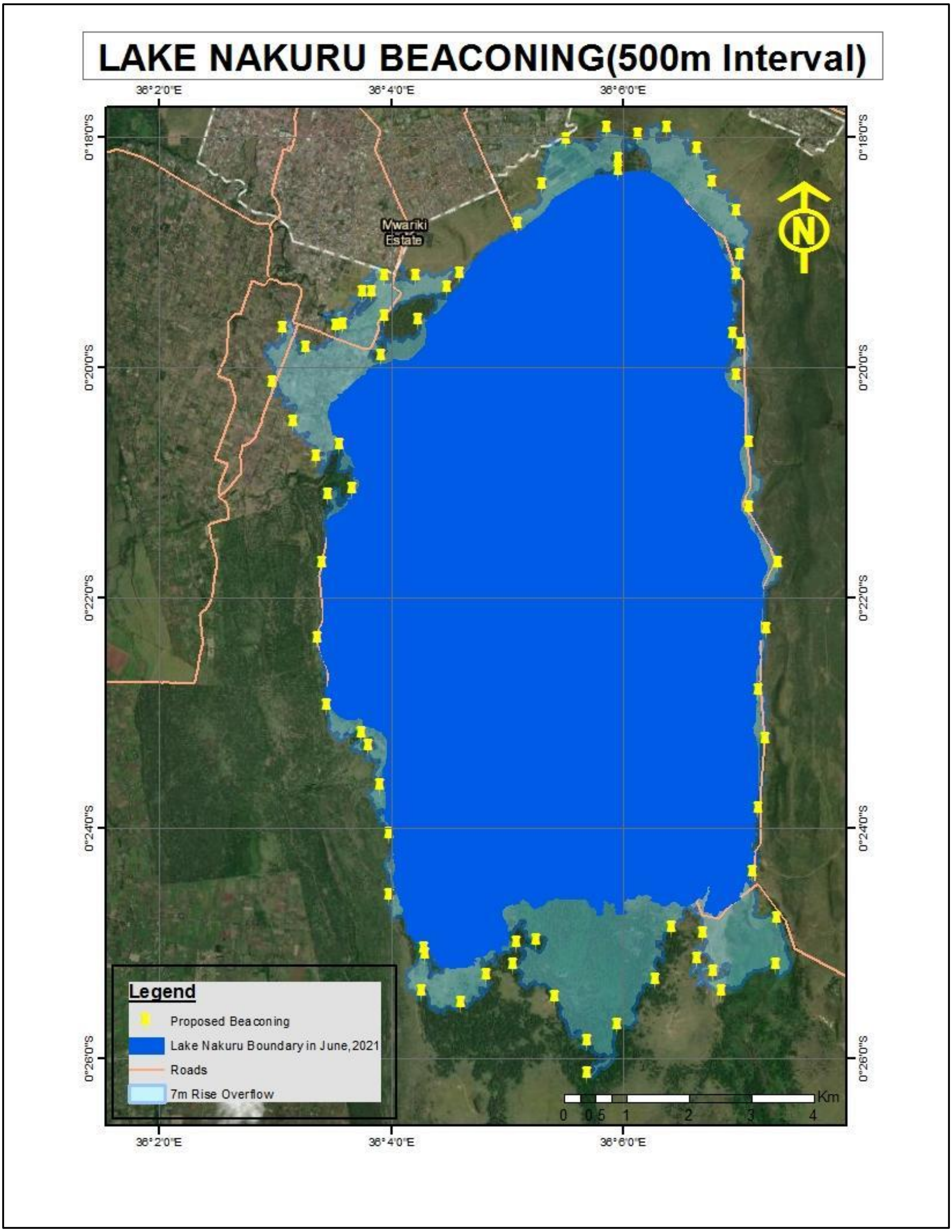
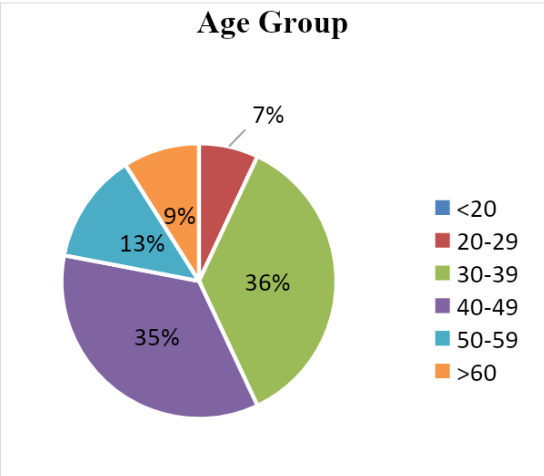


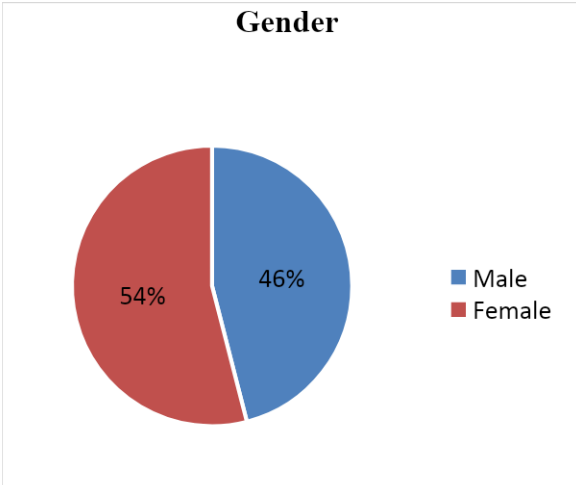
Fig.43: Graphical illustration of the proposed beaconing for 7m rise overflow(worst case scenario)

8.0 SOCIO-ECONOMIC IMPACTS

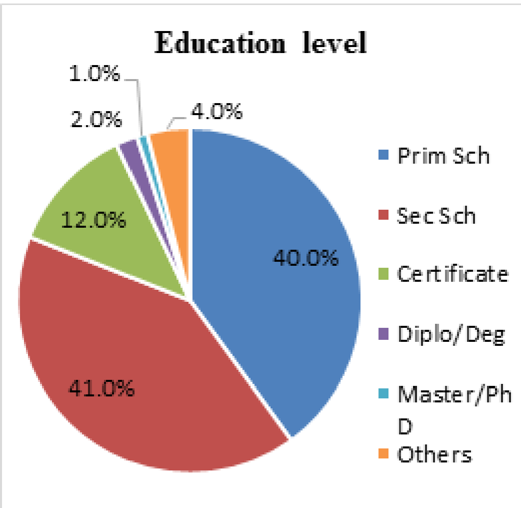
Mwariki is a settlement located at the north eastern border of Lake Nakuru National Park. Created in 1979, the settlement occupies an area of four (4) Km^2. Prior to human settlement; Mwariki was part of Rhonda sisal estate. Today the settlement has about 1000 households.

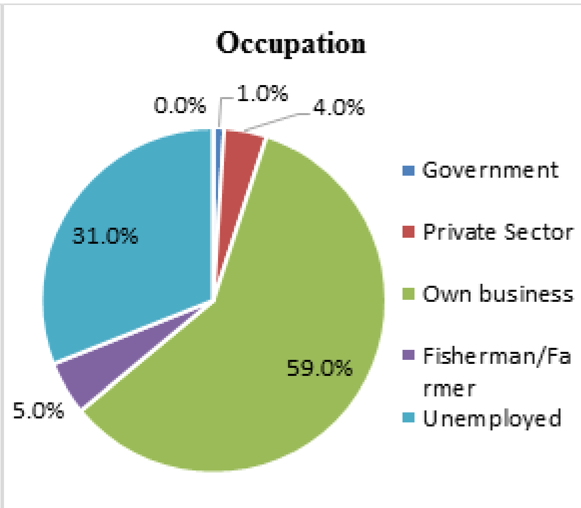
A total of 100 households were sampled with the help of five research assistants in the three settlements bordering Lake Nakuru National Park. The data was both quantitative and qualitative in nature. The data was analysed using the ILBM-Ecosystem-Service Shared Value Assessment Research Results Working Tool Ver. 1.0. Excel Template.





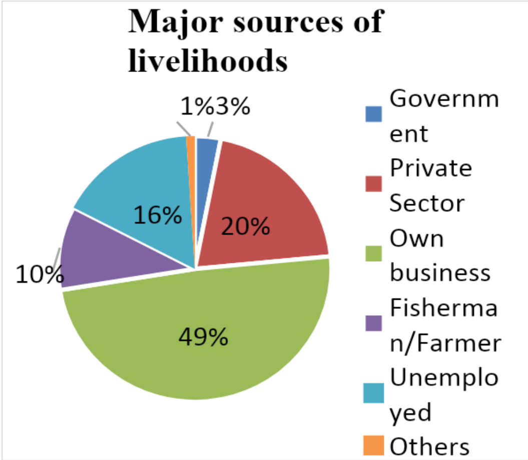
Most of the respondents interviewed were women (54%) and men (46%). There were more respondents in the 30-39 age brackets. The age group of the residents living around the Mwariki, Parkview and Barut Villages is comprised of 36% representing people aged between 30-39 years, 35% representing people aged between 40-49 years, 13% representing those aged between 50-59 years, 9% representing those aged above 60 years and 7% representing those aged between 20-29 years



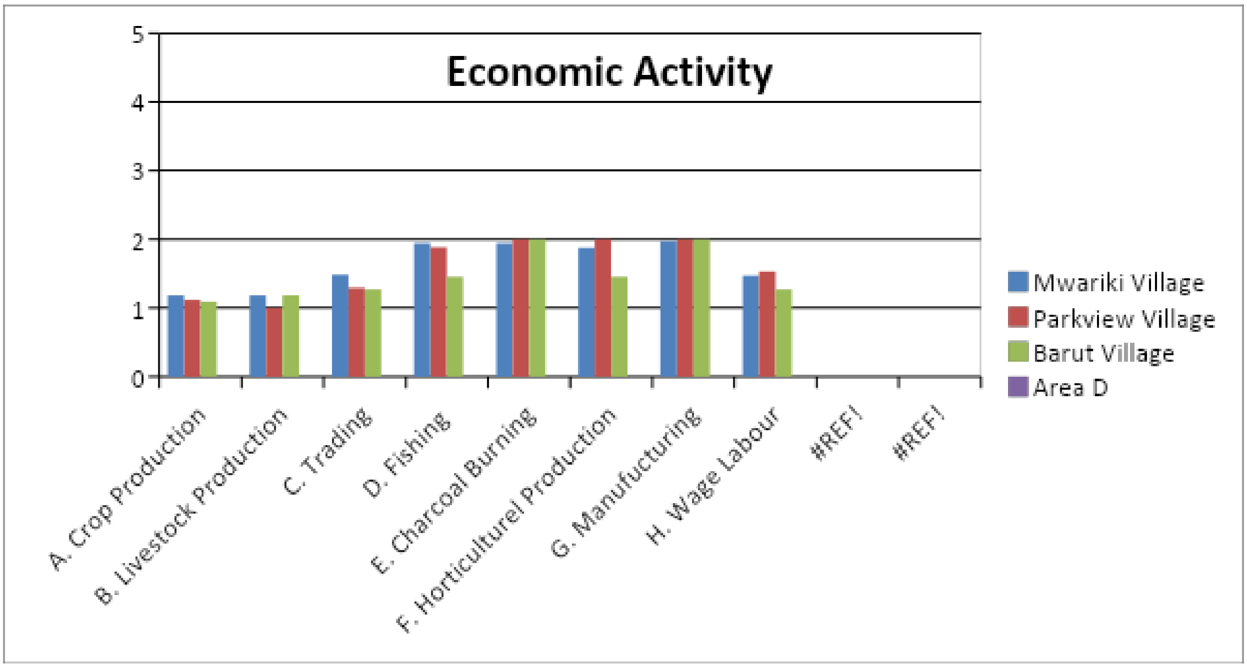


The results show that although most park neighbour residents have attained secondary education and above, many are unemployed.

The data indicates that about 81% of the residents within the settlements have attained primary education of 1-8 years; with 41% and 40% having gone through secondary and primary education respectively. Majority of the residents, 59% own their own business and 31% of the residents are unemployed.



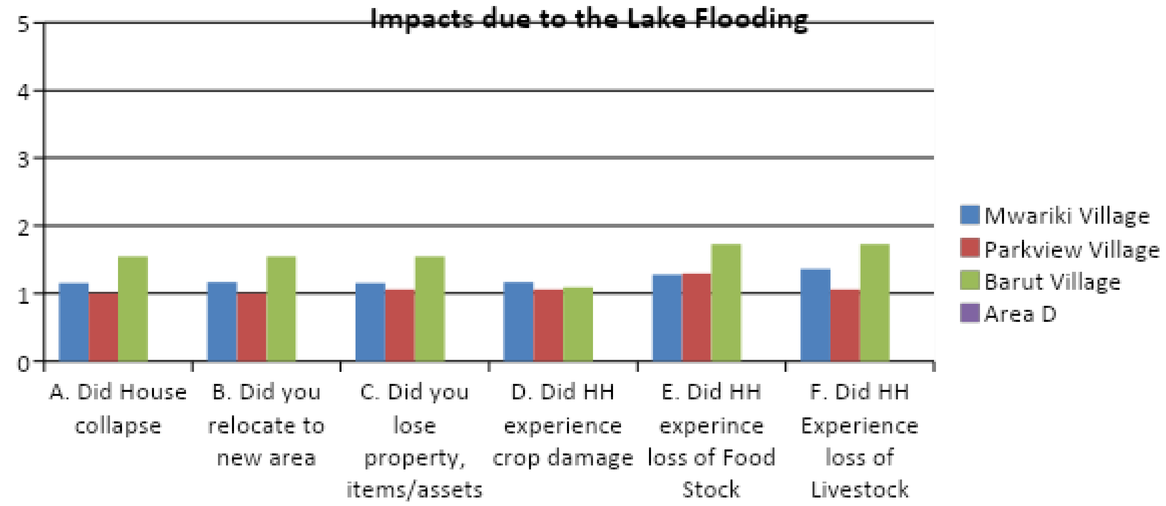
The percentage of people dependent on fishing which has now become a new livelihood activity is at 10% and projected to increase with time since the percentage of the unemployed is high at 31%.



Fishing as a source of livelihood was found to be more prevalent in Mwariki Village followed by Parkview and Barut Villages. Fishermen from Lake Naivasha and Victoria have been attracted to catch fish in Lake Nakuru, which is easily accessible through Mwariki settlement. The fishing has thrived and related business around the area is booming. Water levels of the lake that has been rising for the last six months continue affect livelihoods in the area.

The bigger part of the fishing dock is hosted on the farms of the displaced households since the water levels are spreading across the farms.

Charcoal burning was found to be the other major economic activity in the 3 villages and this has been attributed to the hard economic times the residents are facing as a result of the rising water level, and lake flooding that has submerged most of their agricultural land.



The impact of the lake flooding has resulted in the collapse of houses, loss of properties and loss of food stock among the 3 villages.

The leaders from the affected community reported that about 325 members have been displaced. The list is attached in the appendix. The Department of Lands and Physical Planning is currently undertaking the validation exercise.

In addition, there are a number of pertinent social economic issues that emerged from the study. These are:

1. Harassment of the local community which caused two deaths involving local fishermen in the Mwariki settlement.

2. Public health issues such as poor sanitation, lack of clean drinking water, congestion, currently the some hotels, open air food and fish vendors are operating without clearance from the public health. The water table is very high; toilets are filled with water, potentially contaminating the shallow wells, with threats of water borne diseases such as typhoid.

3. Security concerns are cropping up because of lack of proper beach management leadership that can resolve conflicts.

4. There's increasing consumption of illicit brews and drugs such as bhang amongst the local youths and general public within the settlement. There is increased prostitution and possibility of increasing diseases such as HIV/AIDS, Covid19 and other communicable diseases.

5. There are over 30 boats equipped with powerful engines currently in Mwariki settlement owned by outsiders especially experienced fishermen from Naivasha but hired and managed by the locals. These boats have not been licensed by the Nakuru west subcounty trade department to operate.

6. There are complaints from the locals whose land is being utilized by the fishermen to dock. Some of them have an agreement with the land owners on how they pay for landing and docking.

7. There is conflict of interest from some of the national government officials regarding the fishing at Mwariki area.

8. Lack proper lifesaving skills and equipment in the event of a boat capsizing or drowning cases.

9. The lake levels continue to rise, and at the time of the study, the lake had flooded about 500meters from the park fence into the settlement. The ground water spread is even more pronounced in a wider area.

10. There is a serious lack of awareness among residents of Nakuru about the dangers of living next to a national park without a secure fence.

11. On the social and cultural factors, the team noted that many of the affected community members have experienced trauma and psychosocial problems. A few people were reported to have died. Many of them are affected by depression which has been caused by the effects of displacement, insecurity, and economic losses incurred from disruption of livelihoods, business losses and unemployment.

Photos: Flooded crops in and Greenhouse in Mwariki, Fishing as well flooded homes in Mwariki and Parkview Settlements

Photos: Aerial view of the flooded Mwariki and Parkview Settlements and young children dangerously exposed to flood water in their homes.

8.2 Local and International Tourists visiting Lake Nakuru National Park

Nakuru County is estimated to have about 220 tourism related hotels with a capacity of 12,000 beds. There have been job losses in major hotels around Lake Nakuru National Park from 2008-2021. This is attributed to reduction in international visitors to the park. Major markets for food crops to the hotels have also decreased with the decrease in international visitors; this has affected the food suppliers to the hotels and consequently affected household incomes. The number of bed-nights occupied in hotels has also decreased.

8.3 Human/Wildlife Conflicts from 2010-2021

Human-wildlife conflicts were reported to be on the rise since about 4km of electric fence that acts as a deterrent between humans and wildlife is submerged hence switched off. The main problem animals are baboons and monkeys. There are reports of snakes taking refuge in people's homes as well as increased mosquitos and insect bites.

8.4 Damage to the infrastructure in Lake Nakuru National Park as a result of rising Water levels

Lake Nakuru National Park has had various impacts on park infrastructure as a result of the rising lake Nakuru Water level. This includes damage to park infrastructure namely the tourist infrastructure (Roads, Main Gate and the Campsites). In Lake Nakuru National Park the upsurge of water levels has damaged various infrastructures as follows:

1. Various tourist infrastructure have been submerged. These include;
    - The Main Gate hence there was a need to construct a temporary gate.
    - The Gift Shop adjacent to the main gate.
    - Backpackers campsite that was adjacent to the main gate.
    - The proposed Guest house that was adjacent to the mouth of Njoro river.
2. Residential and non-residential buildings were also lost to the rising lake. These include;
    - The Office block that was adjacent to the Main gate. This included the park management offices, Stores and fuelling station.

- The Smartcard point of sale offices.
- The former residential staff quarters behind the gate were also submerged and the new residential buildings were constructed at Lanet Gate, Behind the Area Assistant Directors Offices, and at Nderit Gate.
- Many public campsites are submerged in water.

3. Roads submerged and therefore it is impossible to cover the entire circuit of the park)-use of longer alternative routes. The main circuit road has been submerged. These include;

   - The road from the temporary main gate to the Wildlife Clubs of Kenya Educational Center.
   - The road from the temporary main gate to the Baboon Cliff. The section from the Njoro river to the Larmudiac river has been submerged.
   - The road from Naishi Rhino base to the Baboon Cliff along the lake Shore.

4. Part of the Electric fence (4kms) was submerged. This was along the western side of the park. The submerged part of the fence was powered off and the energizer house had to be moved. Two people have lost their lives as a result of illegal entry into the park through the submerged fence.
5. Economic loss damages include;

It is estimated that KWS will require KES 25 million to replace the submerged gate, KES 4 million per kilometre to rehabilitate the 3 kilometres electric fence submerged (Ksh 12M in total).

KWS incurred expenses in demolishing structures that were being submerged with the rising lake level as well relocating offices and staff to temporary facilities these costs amounted to Ksh 600,000

Building lost estimated at KSh.120,000,000. So far KWS has spent approximately KES 50 million to rehabilitate the infrastructure damaged by the rising water levels of Lake Nakuru and erect temporary facilities. The institution has spent approximately KES 105 million to rehabilitate the 20-kilometre road damaged by floods in the last 3 years.

6. The lake flood waters have inundated the parts of the Old Town Sewage Treatment Plant (STP). There is the risk that even the Njoro WWTP might get affected by rising waters. Based on this study it is therefore suggested that NAWASCO should decommission the Old Town WWTP and to identify a new location on higher grounds. Using the Njoro STP as a single source for waste water treatment would not be a reasonable proposal since under the worst case scenario this plant could also be affected by flooding.

Photo. Lake Nakuru Maingate May 2019

Photo. Lake Nakuru Maingate September 2020

The pictures above show the submerged main gate.

The photos above show the submerged fence along the park boundary

The pictures above show the submerged lake Nakuru National Park fence and the road repairs that were undertaken within the southern part of Lake Nakuru National Park at the mouth of Nderit river.

8.6. Impacts on Biodiversity in Lake Nakuru National Park

Other impacts of the rising lake are on the lake biodiversity. Lake Nakuru has since recorded high presence and biomass of 'new' tilapia fish species i.e. *Oreochromis niloticus*, *Oreochromis variabilis* and *Oreochromis leucosticus,* thought to have been introduced by surface runoff from the Njoro river sub-catchment. The abundance of Nile Tilapia *Tilapia nilotica* has resulted in illegal fishing within the lake.

Photos: Tilapia *Oreochromis leucosticus* and Nile Tilapia *Tilapia nilotica* from nets within Lake Nakuru August 2020.

8.7. Flamingo numbers to assess the Impact of Rising Water levels on flamingo populations.

Although the most numerous of the World's flamingos, the lesser flamingo (*Phoeniconaias minor* Geoffroy, 1798) is classified as "Near threatened" in the 2006 IUCN Red List of Threatened Species, indicating that it is considered likely to qualify for a threatened category in the near future. The species is also listed in Columns A and B of the Agreement on the Conservation of African- Eurasian Migratory Waterbirds (AEWA) Action plan, Appendix ll of the Bonn Convention (CMS) and

Appendix ll of the CITES convention. Implicit in those agreements is the need for the formulation and implementation of appropriate strategies to address the threats that affect the species.

The bi-annual estimates of Lesser flamingo population in Lake Nakuru show a declined from 10,168 in 2011 to 6,410 in 2021. During the same period, the greater flamingo population estimates fluctuated from a high of 5,150 in 2018 to a low of 44 in 2020. The table below shows the fluctuation of the Lesser flamingo population from 2011 to 2021.

Table 5: Flamingo population estimates from Lake Nakuru National Park 2011-2021

YEAR	LESSER FLAMINGO	GREATER FLAMINGO
2011	10,168	4,325
2012	110	478
2013	2,212	1,572
2014	3,263	440
2015	430	1,072
2017	35	170
2018	846	5,150
2020	486	44
2021	6,410	445

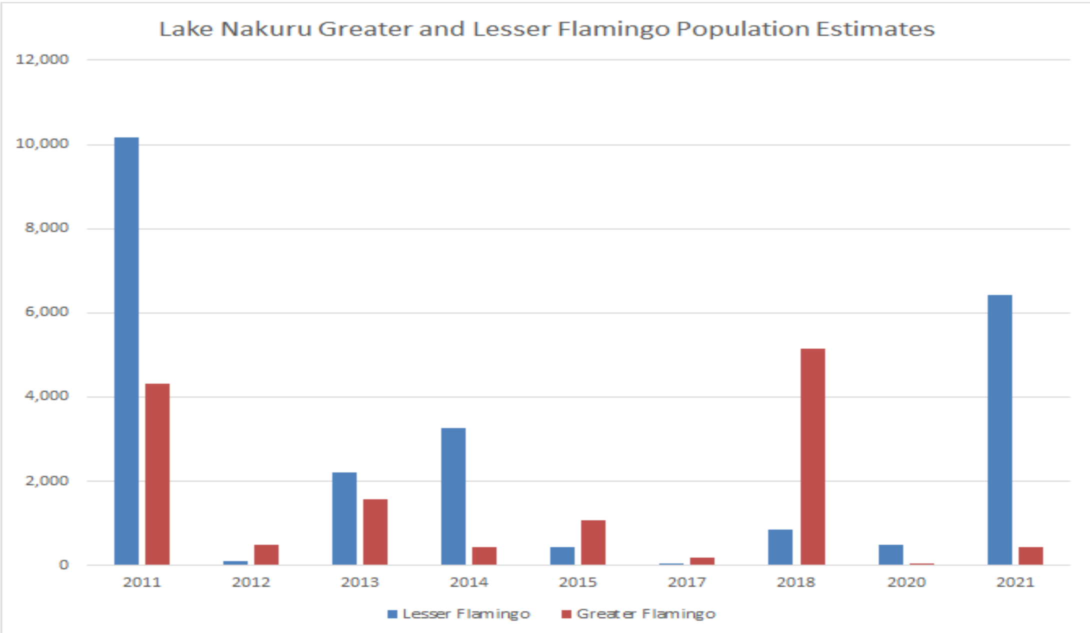


Fig 40: Annual estimates of Lesser and Greater Flamingos in Lake Nakuru (2011-2021)

The Lesser Flamingos feed on microscopic cyanobacterial and phytoplanktonic species (benthic diatoms) tolerant of saline conditions in open, eutrophic shallow habitats, such as saline lakes, saltpans, coastal mudflats, estuaries, salt works, and water from sewage treatment works (Vareschi, 1978; Vareschi, E. and Jacobs, J. 1985). Their food base primarily consists of the *Arthrospira fusiformis*, formerly known as *Spirulina platensis*. The feeding habitat requirement must have a stable water chemistry that enables growth of cyanobacteria.

The rising lake levels have resulted in a significant change in the water chemistry as indicated in the major ions and anions. The lake's salinity has declined to below 5g/l, exhibiting signs of a freshwater lake. This is demonstrated by the table indicating the results of the January 2021 waterfowl population estimates and species diversity is highest in Lake Nakuru compared with lakes Baringo (freshwater), Bogoria and Elementeita (Saline).

Recent Waterfowl population estimates within Lake Nakuru indicate increased numbers of water birds associated with fresh water systems. These include Greater cormorants, African fish Eagles. Further, Waterfowl species diversity according to the waterfowl population estimates carried out in January 2021 indicate that Lake Nakuru has the highest number of various waterbird species compared with the other rift Lakes of Baringo, Bogoria, Elementaita and the sewage ponds. This can be seen in the table below.

Table 6: Waterfowl Species Numbers and Abundance in Selected Rift Valley Lakes January 2021

Lake/ Site Name	**Number of Species**	**Abundance (Number of Individuals)**
Baringo	53	2,277
Bogoria	31	85,634
Elementaita	64	17,625
Nakuru	78	14,649
Nakuru Old Town Sewage Plant	52	4,276
Njoro Sewage Ponds	21	1,689

9.0 CONCLUSIONS

Lake Nakuru has shown increasing water levels since the rains of May and September 2010. L. Nakuru was the first of the Rift Valley Lakes to burst its bank. The lake increased its flood area from a low area of 3268.71 ha in January 2010 to a high of 5400.27 ha in Oct 2020, an increase of 2131.56 ha (over 39.47% increase by area).

The major cause for the rising water levels in Lake Nakuru is climate change with mounting evidence from the above normal level of rainfall in the catchment area as documented at the various rainfall gauging stations. The unusual rainfall is more associated with impacts of climate change and global warming. This is made much more prominent due to a positive Indian Ocean Dipole. Intensified land use in recent decades and the resulting land degradation, which is quite severe in some areas, has resulted in higher rainfall runoff from land, and less percolation of it into the groundwater systems, leading to larger volumes of water flowing directly and rapidly from the land surface into the lake.

The rainfall runoff over degraded lands and enhanced soil erosion as well as degradation of the lakes' riparian zones has decreased the depths of the lakes through enhanced sediment loading. Thus, while volumes of water flow into the lakes and volume retention within them may remain essentially the same, there is an increase in the lake levels due to reduced reservoirs as a consequence of rapid sedimentation (similar to the siltation effect in man-made dams).

Evidence from recent bathymetric studies demonstrates that the lake depth increases from the shoreline to the middle part of the lake with a maximum depth of 6.2 meters and the water storage of 264,699,344.54 m^3.

The sediment deposition with the layer thickness varies from 0 m to 0.7 m (maximum) and the total sediment storage capacity of 24,191,688.67 m^3. This implies that the sediment occupy 8.37% of the lake storage capacity due to the different activities in the watershed typically inadequate waste disposal systems in the urban watersheds, and increased land use and land cover changes along the River Njoro and Makalia which exhaust the rural watershed with a large amount of eroded soil resulted majorly from deforestation and land sub-division for small-scale.

The damages caused at Lake Nakuru National Park are estimated at KES 37 million, including the costs for replacement of submerged main gate and rehabilitation of 3 km-long electric fence. KWS already spent KES 600,000 as expenses in demolishing structures that were submerged with the rising lake level and building new staff quarters at an estimated KSh.120, 000,000. So far KWS has spent approximately KES 50 million to rehabilitate the park infrastructure damaged by the rising water levels of Lake Nakuru as well as KES 105 million to rehabilitate the 20Km road damaged by floods in the last 3 years.

The imminent danger of floods leading to Lake Nakuru breaking its banks, calls for stringent action measures to be taken so as to safeguard both the lives of the people living near the watershed area and the animals.

11. RECOMMENDATIONS

i). Immediate intervention Measures

a) Provision of immediate humanitarian assistance to the affected communities with food and non-food items as well as incentives, subsidies, and cash transfers to enable them to cope with the crisis. This includes food, shelter and shelter kits, emergency health services, health and nutrition, provision of portable water, hygiene, and sanitation facilities as well as psycho-social support which is urgently required in the immediate phase.

b) Government-led public engagements with affected persons to restore their confidence and give them hope as well as provide an assurance of government commitment to support and walk with the affected households is crucial as a first step of getting the affected persons back on their feet.

c) There is a need to create awareness on climate changes using simple illustrations that would lead to co-creation of solutions and therefore easy buy-in of proposed solutions using participatory scenario development approach. This should include addressing the issue of increasing human-wildlife conflicts.

d) Closer monitoring of lake levels is necessary to monitor the extent of the rising waters that may potentially shear-off from historical-boundaries hence avert future possible hazards.

e) Closer monitoring of meteorological patterns and simulation of future scenarios should be advanced as part of an immediate intervention approach.

f) Rapid assessment of impacts of rising lake levels on biodiversity and implications on Lake Nakuru National Park.

Medium-Long term Intervention Measures

a) Beaconing the highest watermark and Government to consider compensating and buying off the affected households in the flood prone areas to expand the park boundary and create a buffer zone along between the park and the human settlements.

b) Conduct studies on land use/land cover, as well as Water Balance studies on all lakes and their respective basins to inform establishment of the highest water mark under the worst-case scenarios in the history of the lakes to help in clearly defining and demarcating the lake boundaries.

c) Drilling and installation of groundwater monitoring boreholes to determine the likelihood of episodic recharge within the aquifers due to heavy rainfall against groundwater saturation potential. This is geared at monitoring potential isotactic adjustments that may often be catastrophic. There is also need to carry out research on tectonic movements and magmatic stresses including seismic monitoring to detect active zones potentially in distress due to swelling lakes.

c) Conduct bathymetric studies to determine the depth to lake bed and sediment topography as well anthropogenic inflows into Lake Nakuru.

d) Expansion and rehabilitation of the hydro-meteorological monitoring network

e) Consider redoing a more refined land use / land cover analysis within the lake catchment using medium/high resolution satellite imageries for enhanced results and continue monitoring using remote sensing techniques the LU changes within the catchment.

f) Acquisition of high precision DEM for accurate simulation of the water level rise overflows over time. Consequently, a 2-5m resolution DEM shall be required for accurate simulation.

g) Acquisition of high-resolution satellite imagery of about 50cm shall be required to undertake a more precise mapping of the affected households, infrastructure and other amenities around the Mwariki area and the Northern part of Lake Nakuru based on the worst water rise scenario. These data shall play a key role in the general planning of the compensation scheme.

h) Satellite image analysis and GIS simulation indicates extensive destruction of infrastructure and other relevant amenities around the lake. There is need to use various GIS tools to identify appropriate relocation for the affected infrastructure and amenities such as sewage plants, roads and public utilities.

i) There is need to promote Integrated Lake Basin Management (ILBM) as a framework for the sustainable management and use of Lake Basin resources through informing policies, strategies, plans, projects and programmes, as well as to guide coordinated agency actions. ILBM incorporates lakes and river basins and their associated wetlands as well as the entire scope of the biophysical, socioeconomic and governance aspects, while fully incorporating Integrated Water Resources Management (IWRM) and Integrated River Basin Management (IRBM) principles and approaches, to ensure that there is a balance between conservation and development.

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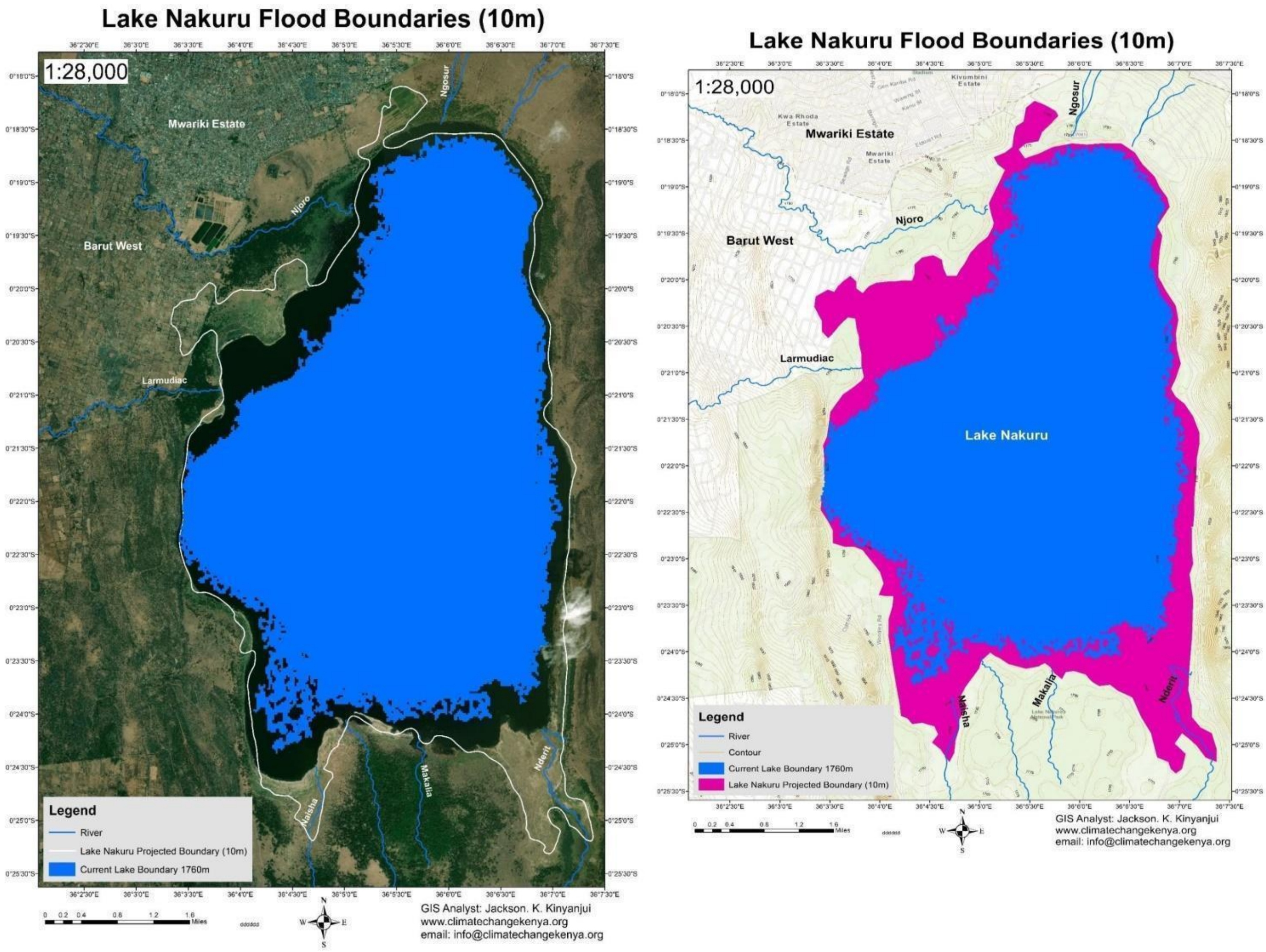
12. APPENDICES

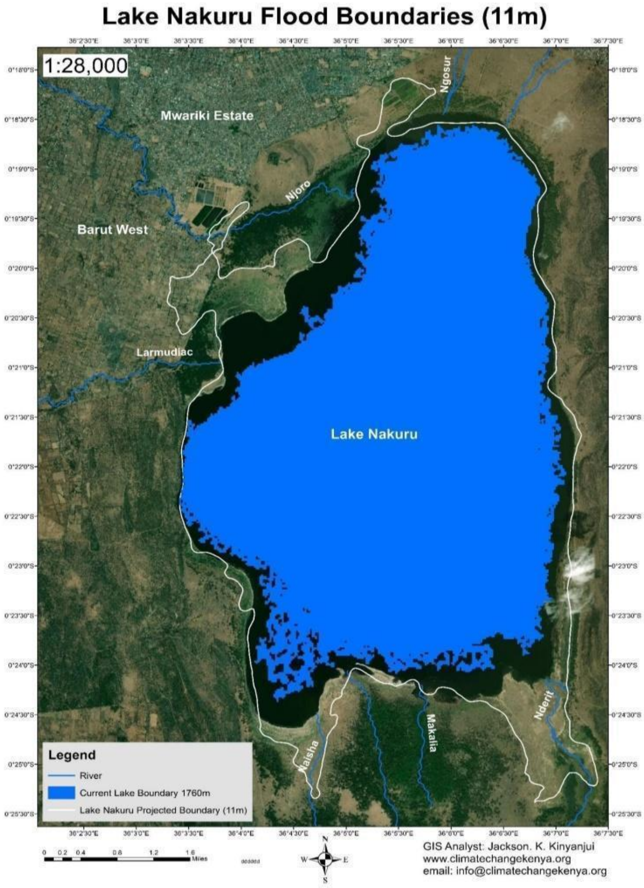
Table . Status of River Gauging Stations within Nakuru Catchment (Field Reconnaissance in June 2021)

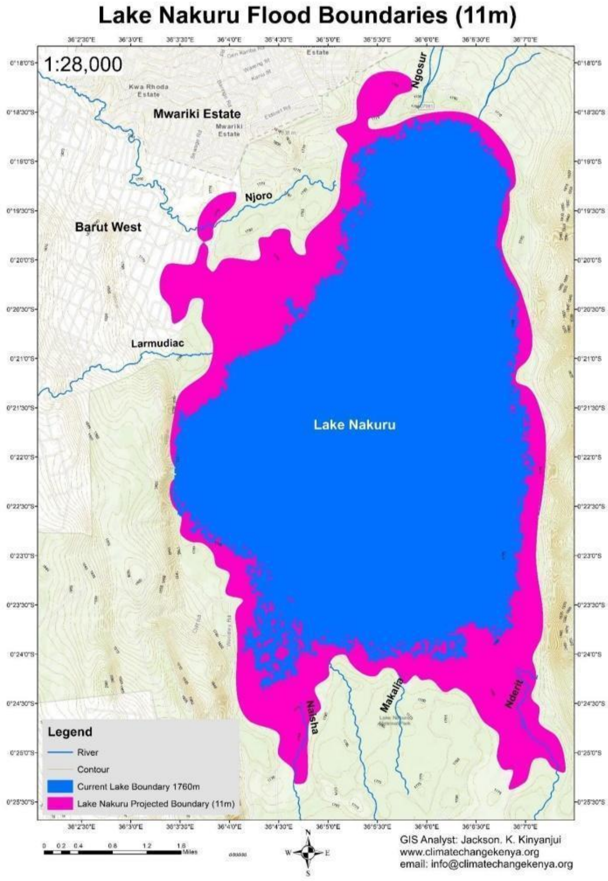
ID	Coordinates (x)	Coordinates (Y)	Catchment	River	Instruments	Update of Rating Curves	Comments	Status
2FC09	35,9880490000	-0,3060840000	Njoro	Njoro	Not available	Not applicable	abandoned	Not operational
2FC19	35,9419210000	-0,3718540000	Njoro (Egerton)	Njoro	Gauge Plate, Pressure Sensor, Telemetry Logger	Not applicable	abandoned	Not operational
2FC05	35,9203480000	-0,3751770000	Njoro	Njoro	Not available	unknown	Damaged gauge plate	Not in operation
2FC11	35,9182520000	-0,3747700000	Njoro	Little Shuru	Gauge Plate	Unknown	Maintenance required	Operational (poor)
2FC18	35,9132130000	-0,4026670000	Njoro (Sigotik)	Njoro	Not available	Unknown	Missing gauge plate, replacement required	Not in operation
2FC21	35,9892690000	-0,5740170000	Makalia	Makalia	Not available	unknown	Missing gauge plate, replacement required	Not in operation
2FC22	36,1040860000	-0,5189090000	Nderit	Nderit	Not available	unknown	Missing gauge plate, replacement required	Not in operation
2FC14	36,0811160000	-0,4918760000	Makalia	Makalia	Gauge plate	unknown	Maintenance required	Not in operation
2FC0	36,1889700	-	Ngosur	Bahati	Gauge plate	unknow	Maintena	Not in

ANNEX 2. Simulations



Figs: Lake Nakuru Elevation and Topographical Flood Boundary (10m)


Lake Nakuru Flood Boundaries (11m)
1:28,000
Mwariki Estate
Barut West
Njoro
Ngosur
Larmudiac
Lake Nakuru
Naisha
Makalia
Nderit
Legend
River
Current Lake Boundary 1760m
Lake Nakuru Projected Boundary (11m)
GIS Analyst: Jackson. K. Kinyanjui
www.climatechangekenya.org
email: info@climatechangekenya.org


Lake Nakuru Flood Boundaries (11m)
1:28,000
Mwariki Estate
Barut West
Njoro
Ngosur
Larmudiac
Lake Nakuru
Naisha
Makalia
Nderit
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River
Contour
Current Lake Boundary 1760m
Lake Nakuru Projected Boundary (11m)
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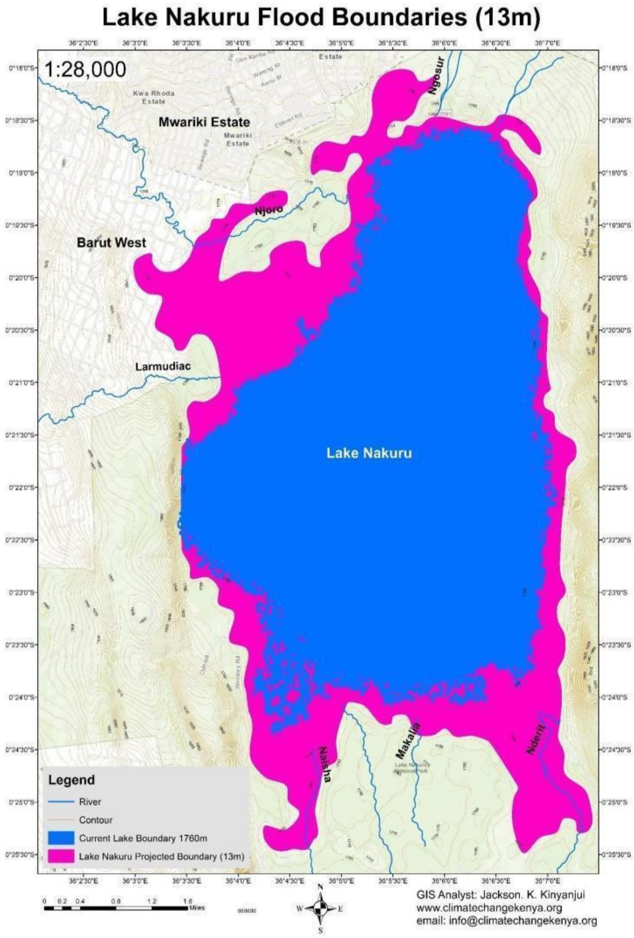
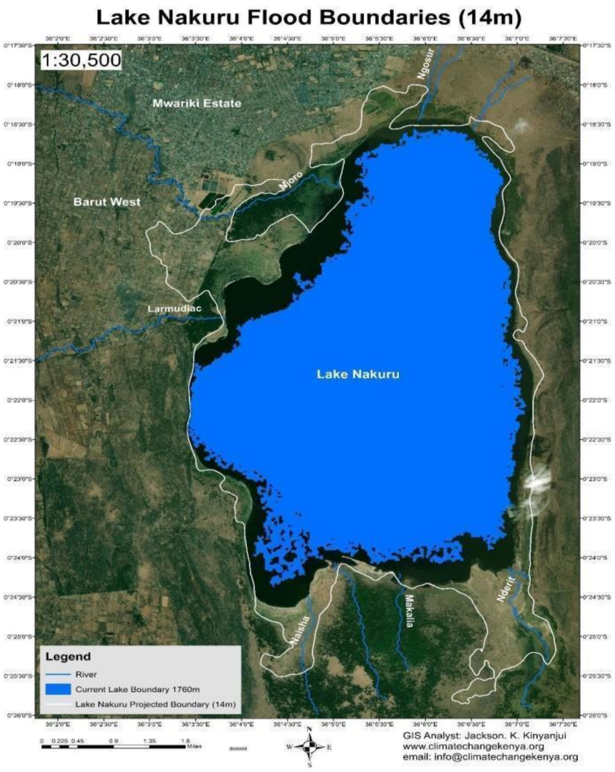
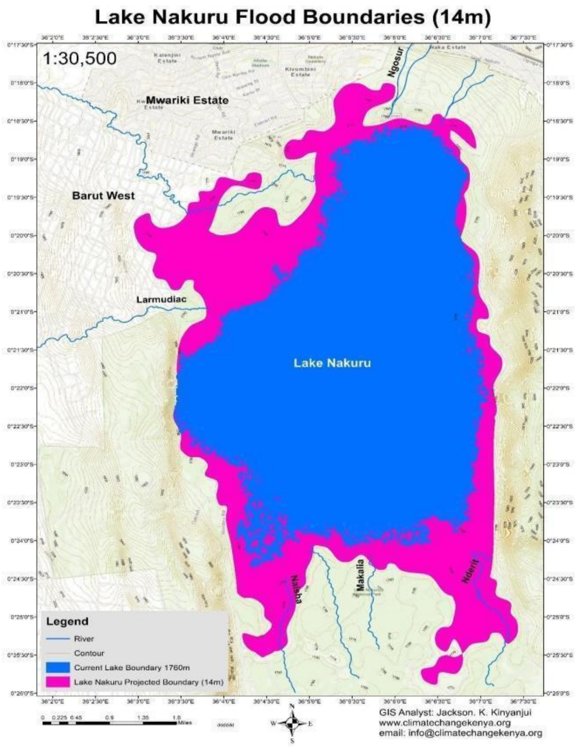
Figs: Lake Nakuru Elevation and Topographical



boundary (11m)

Figure 19: Lake Nakuru Topographical Flood and Elevation Flood Boundary (13m)





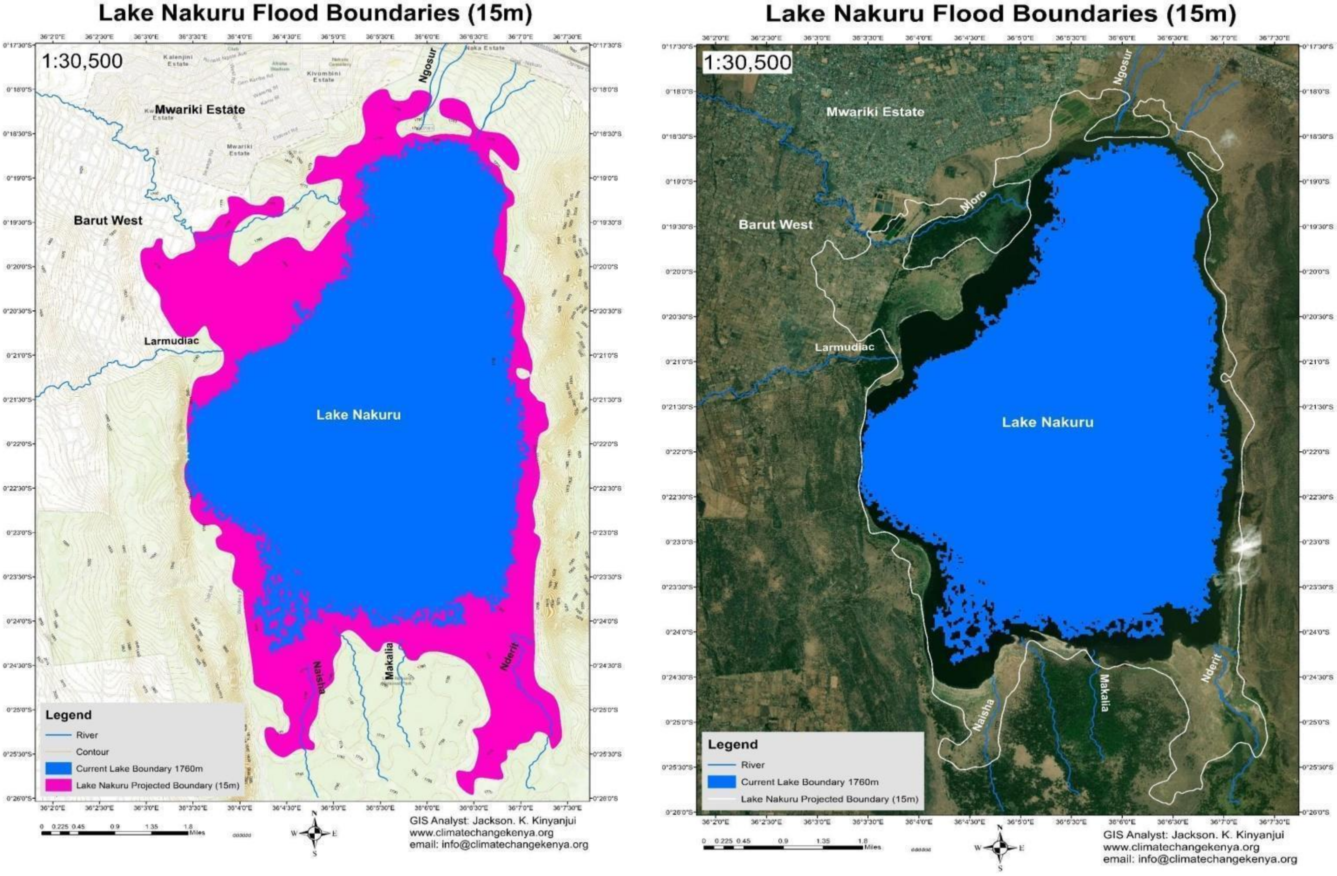


Figure 22: Lake Nakuru Topographic and Elevation Flood Boundary (14m)

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ASSESSMENT OF IMPACTS OF RISING WATER LEVELS IN LAKE NAKURU AND OPTIONS FOR FUTURE MANAGEMENT

TASK FORCE COMMITTEE

TERMS OF REFERENCE

11th MAY 2021

1. Background

The County Government of Nakuru led by H.E. Governor Lee Kinyanjui offered to support a scientific study around the continued rise of water levels at Lake Nakuru. Since 2010 the lake level has been rising from an average level of 3 meters to the highest level of approximately 9 meters recorded in April 2020. This has resulted in a great increase in lake area, as well as tremendous infrastructural destruction. The rising water levels is also impacting on the communities that have settled in areas bordering the lake such as Parkview Estate where about 500 Households have been displaced by the rising lake levels and portends even greater danger to Mwariki settlement on the north eastern border of Lake Nakuru National Park. Mwariki settlement was created in 1979 and covers an area of four-square kilometres with a human occupancy of about 1000 Households who are vulnerable. This challenge urgently requires a deeper scientific analysis as to the key drivers to this unprecedented rise in the waters of the lake.

Various factors are thought to contribute to this challenge. One of the main factors is attributed to climate change. The Eastern Africa region experiences extreme climate variability and in the last two years, above average rainfall was received in the Rift Valley Lake catchments. Lake water balance is normally affected by several factors; key among them is rainfall, evaporation, water abstraction and land cover/ land use as well as siltation and sedimentation. Recent geological changes across the active East Africa Rift Valley System could also be one of the factors. The East African Rift System (EARS) is one the geologic wonders of the world, a place where the earth's tectonic forces are presently trying to create new plates by splitting apart old ones. Recent changes have suggested a lot more dynamic shifts within the tectonic plates, which could well be driving up the lake waters.

Previously, unpublished records of the Eastern African Rift Valley lakes levels in Kenya show significant rise and flooding of the mudflats and the ring of acacia forest around the lakes in 1901 and 1963. The current flooding being witnessed suggests a return of a 50-year cyclic climatic event.

2. Justification for the Technical Working Group

The County Government of Nakuru seeks to undertake a scientific assessment of rising water levels in Lake Nakuru to determine the riparian zone dynamics and its related social-economic implications to inform management and any development in future.

To ensure ownership and technical guidance from relevant Government Ministries, Departments and Agencies, a Special Taskforce has been formed and officially appointed by H.E. Governor Lee Kinyanjui to support this process. This Taskforce will provide technical guidance on undertaking the study, including facilitating acquisition of critical data and information to guide the delivery of the study. It will also validate the results from the study, while contributing towards establishing and beaconing the highest watermark in Lake Nakuru to inform management and any future development.

Project scope and objectives

The overall objective of the study was to carry out an Assessment of the Rising Water Levels, Flood Related Implications and Riparian Zone Beaconing in Lake Nakuru.

The scope of the analysis involved the following; hydrological variations and trends, climatic variations and trends (Rainfall and, Evaporation), hydro-geological dynamics, groundwater, lake level trend analysis, bathymetry & sedimentation rates, seismic dynamics, landuse/ landcover changes and socio-economic impacts.

The specific objectives are as follows: -

6. To develop GIS Maps on Land use / Land cover changes from 1990, 2000, 2010 and 2021 to assess levels of catchment degradation in East Mau Forest in Lake Nakuru Basin.
7. To develop GIS maps marking the Highest Watermarks for L. Nakuru using recent High-Resolution images & Global Navigation Satellite System (GNSS) Reflectometry Technology.
8. To undertake Water Balance Modelling using SWAT tools to determine Lake Nakuru Depth-Volume-Surface area relationship establish the highest watermark as well as suggest likely reasons for the current high-water levels in the lake.
9. To establish the lake boundary, beaconing the riparian zone based on the highest watermark in the worst case scenario and prepare an inventory of the affected and vulnerable households from rising lake waters.

10. To conduct a socio-economic study of the affected local communities.

3. Terms of Reference for Task Force

The Taskforce team will meet regularly to review the roadmap for undertaking this study in a timely manner. It will provide technical advice to the County Government on project issues, identify risk and mitigation measures, and review project progress.

Specifically, the Taskforce Committee will:

Review and approve the Draft Terms of Reference, the proposed Roadmap/ Work plan towards the Study and all other key documents that will guide successful execution of this activity. This includes;

Share and Review Data Requirements for the Water Balance Model: -

- Geological data
- Geo-hydrology
- Ground water (borehole data),
- Land use/ Landcover GIS Data and maps
- Rainfall data for at least 5 stations,

- Radiation, Evaporation, and temperature data,
- Streamflow data
- Lake water levels data to calculate the return period of 50, 100-500 years.
- Sedimentation information and data
- Bathymetric survey data/information
- Socio-Economic data- Prepare an inventory of the affected households and individuals and land titles.

4. Proposed Composition of the Taskforce

The Taskforce will comprise of technical-level officers from the following institutions:

- County Government Representatives- Departments of Water, Environment, Natural Resources & Energy and Lands, Housing & Physical Planning
- Kenya Wildlife Service (KWS)
- Ministry of Water and Sanitation
- Water Resources Authority
- Kenya Meteorological Department
- Academia (JKUAT and Egerton University to be co-opted)
- Directorate of Resource Surveys and Remote Sensing (DRSRS)-To be co-opted
- Dept. of Mines and Geology (to be co-opted)
- Civil Society – Flamingo Net/ ILEC Kenya and Climate Change Kenya Organization

TASK FORCE MEMBERS

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