EFFECTS OF WATER LEVELRISE ON RIPARIAN AREAS OF LAKE NAIVASHA, KENYA

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A Project Submitted in Partial Fulfillment for the Requirements of the Award of the Degree of Master of Environmental Planning and Management in the School of Environmental Studies of Kenyatta University

NOVEMBER 2022

DECLARATION

Student's Declaration

I confirm that this research project is my original work and has not been presented in any other university.

Signature____________________ Date_________________

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Supervisors' Declaration

I confirm that the work reported in this project was carried out by the candidate under my supervision as University supervisor

Supervisor

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DEDICATION

This research is dedicated to my lovely wife Carol and my children Palmly, Asher and Fanaka for their prayers, encouragement and immense support during the course.

ACKNOWLEDGEMENT

I am full of thanks to Almighty for enabling me complete this study. I am highly indebted to my supervisor Prof. Simon M. Onywere for his professional advice and guidance which were crucial for the excellence of this research. Special thanks also to Dr. Christine Majale for her unwavering guidance.

To my lovely wife Carol, I am very grateful for encouragements and support in my journey of this study. A lot of appreciation to my children PalmlyJoy, Asher and Fanaka for their understanding; sacrificing the time we would have spent together.

Special thanks; to General Manager LNRA Mr. Silas Wanjala, WRA Naivasha office Mr. Macharia, Lakeview Chief Madam Josephine and Kihoto land owners' Chairman Mr. Zachary Kamau among many others who accorded me their time, information and assistance during the interviews.

I am grateful to the Department of Environmental Planning and Management (EPM) under chairmanship of Dr. Sammy Letema for the guidance and support all through the course. Finally, my gratitude goes to all those who assisted in any way and they have not been mentioned in this acknowledgement, please feel appreciated.

ABSTRACT

Globally, lakes levels fluctuate naturally but when the rise is unprecedented the impact is far reaching. Kenya's central rift valley lakes have swollen to the highest level in recorded recent history. The rise has severely affected livelihoods, destroyed infrastructure, inundated vegetation, caused human and wildlife displacement as well as destroyed ecosystem at large. One of the central Rift-Valley lakes that has experienced this rise is Lake Naivasha. Flooding of the lake has caused destruction of development infrastructures including homes, schools, churches, hotels, greenhouses, pump houses, roads, among many others. Also, a lot of vegetation has been lost which means loss of terrestrial habitat for wildlife and reduced protective riparian vegetation. The study used a combination of methods in analyzing quantitative and qualitative data collected using Google Earth historical imageries of December 2008 to October 2020, field observations and interviews among others. Geographic Information System (GIS) was used in the analysis, mapping and computing the amount of land and vegetation lost to water, and also to determine the number of structures and the length of road affected. Content analysis and Statistical Package for the Social Sciences (SPSS) was used to analyze qualitative data. Results from this research found that 34.42 km^2 of the terrestrial land has been lost to the lake especially on the northern side towards Gilgil River and Kihoto village. A lot of vegetation covering 29.01km^2 has vanished to the lake's water, which includes 4.33 km^2 of farmland, beside 362 trees toppled and 2112 trees drying. Yellow fever acacia *(Acacia xanthophloea)* was the most affected vegetation. Infrastructures were found to have been destroyed or rendered unusable by the flooding water, whereby 409 block buildings were identified and 35.936 kilometers of either tarmacked, loose surface roads or tracks were found to be no longer usable since they were water pooled or impassable. Seventy-five water intakes and canals were submerged and had to be relocated to higher grounds. The rise of the lake waters has affected the wellbeing of low income earners especially 500 Kihoto settlement homeowners, which has occasioned to some falling sick, being stressed, confused, uncertain of the future and culminated to 3 deaths. The flooding has caused wildlife-human conflict as a result of destruction of dry land wildlife habitat and also water borne diseases as a result of waste mixing with the flooding lake water. Information from this project is useful in planning and management to avoid further occurrences of such effects. It also informs physical planning and infrastructure development that will not be especially in vulnerable settlements and resources to avoid such disasters in view of future water rise of the lake.

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ACRONYMS

DEM:	Digital Elevation Model
EPM:	Environmental Planning and Management
ETM:	Enhanced Thematic Mapper
GIS:	Geographic Information Systems
GPS:	Global Positioning System
KMD:	Kenya Meteorological Department
KPC:	Kenya Pipeline Company Limited
KWS:	Kenya Wildlife Service
LANABLA:	Lake Naivasha Basin Landscape Association
LANAWRUA:	Lake Naivasha Water Resources Users Association
LNRA:	Lake Naivasha Riparian Association
MODIS:	Moderate Resolution Imaging Spectroradiometer
MSL:	Mean Sea Level
NDVI:	Normalized Difference Vegetation Index
QGIS:	Quantum Geographic Information System
RGS:	Regular Gauging Station
SPOT:	Satellite Pour l'Observation de la Terre
SPSS:	Statistical Package for the Social Sciences
TM:	Thematic Mapper
WRA:	Water Resource Authority
WWF:	World Wildlife Fund

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Lakes level rise across the globe, especially unprecedented floods have caused destruction to properties, community disruption and displacement, wildlife dislocation, degradation of ecosystems and have even resulted to irreparable losses such as loss of lives (Jenny *et al.*, 2020; Spitalar *et al.*, 2020). It has devastating effects such as destruction of roads, homes, schools, health facilities, tourist destinations, beside resourceful dry land being lost to the submergence water, thus interference with the natural landscape and their surroundings. Flooding also negatively affects vegetation by halting seed germination, delaying growth, plants being oxygen stressed since waterlogged soil is anoxic and eventually death of the root system and the plants (Nilsson & Berggren, 2000).When the flooded vegetation dies it decomposes, releasing greenhouse gases; nitrogen and phosphorous and an increase of floating aquatic vegetation (Nilsson & Berggren, 2000).The loss of vegetation affects dryland wildlife habitat, causing wildlife-human conflict as a result of the animals straying (Mekonen, 2020).

The frequency and impacts of floods have increased as a result of intensive rainfalls, lacustrine systems being more affected (Jones *et al.*, 2013). This is as a consequence of global warming which is altering the capacity of the atmosphere to retain water, rise in evaporation, uneven distribution of precipitation, snowmelt and glacial melt (Whitfield, 2012). Scientists' projections shows that floods will continue to rise not only being a consequence of climate change but also of land-use changes (Burn & Whitfield, 2017; Talbot *et al.*, 2018; Union of Concerned Scientists, 2013), and is bound to continue, since emission of greenhouse gases due to industrial revolution will also continuously increase (Aucan, 2018).

Global warming and land use change is different based on locality (Whitfield, 2012). The effect of lake flooding varies as per the geographical location, extent of flooding and the other environmental factors. For instance, Lake Chaplain in North America along the borders of New York and Vermont, bordering the United States, in 2011, experienced flooding of high magnitude due to high precipitation levels; and it resulted in swamped houses, displaced people, flooded roads, mudslides, raw sewage and rubble being washed into the lake, higher nutrient and sediment loading, increased soil erosion, eroded shorelines and brought into the lake phosphorus which promoted growth of algae blooms (Lake Champlain Committee Team, 2011). Flooding of Lake Erie, one of the Great Lakes of America in June-July 2015 caused significant phosphorous loading from nonpoint-source pollution which resulted in growth of alga blooms and pollution of drinking water (King *et al*., 2017). Talbot *et al.* (2018) study, reported that flooding of Lake Winnipeg in Canada due to changes from catchment area, increased phytoplankton, causing significant phosphorous loading that resulted into largest harmful alga blooms. The flooding also polluted the drinking water and affected recreation including fishing, boating, swimming, hunting and hiking.

In Africa, a study of the Inner Niger Delta, Mali, by Haque *et al.* (2020) observed that flooding of the delta strongly affected the ecosystem services. The findings of the research was in line with Mahe *et al.* (2011), which reported that flooding of the delta, overflowed to agricultural land destroying crops and killed livestock. Study by Farhat & Salem, (2015) on flooding of Lake Nasser, in Egypt, showed that as a result of flooding, large scale sediments were deposited at the lake which raised the turbidity levels of the lake. Habib *et al*. (2009), studied satellite observation to manage Lake Victoria flooding disaster and reported that the lake's flooding caused death of humans and animals beside infrastructure destruction and also triggered water borne diseases.

Kenya's Rift-Valley lakes have been experiencing extraordinary water level rise, most notably Lake Naivasha, Nakuru, Baringo, Bogoria and Turkana. Since 2010, the lakes' catchment areas have been receiving above normal rainfall (Wainwright *et al*. 2020) . The March-May 2018 season was the wettest on record, followed by above average rains in October-December 2019 and March-May 2020 (KMD, 2020). Onywere *et al*. (2013) reported that Kenya's Eastern African Rift Valley lakes during the period 2010-2013 experienced flooding which caused death of tilapia fishes and flamingo migration as result of alkaline water of Lake Oloidien mixing with the main lake water, dislodging of papyrus hyacinth and acacia trees, submergence of hotels and camping facilities thereby affecting tourism among others. Obando *et al*. (2016) study reported detrimental impacts instigated by Lake Naivasha water level rise on the livelihoods of the people living around the lake and the ecosystems such as loss of livelihoods and massive destruction of properties and infrastructures. Although these studies detail the impacts of the water rise, the timing, method and the satellite imageries used in this study differs. Additionally, the current area affected and vegetation lost, infrastructures damaged and well-being of the affected communities as a result of the water rise has not been documented. It is against this backdrop that the effect of Lake Naivasha's water level rise was studied.

1.2 Problem Statement

Lake Naivasha, has experienced unprecedented water level rise since 2010 (Onywere *et al*., 2013), and the water has increased all through to reach even a higher level in 2020 (Wainwright *et al*., 2020). This has led to a big area of the land being flooded, leading to displacement of people, loss of vegetation, loss of habitat, loss of livelihood and flooded infrastructures, besides other severe effects. This has negatively impacted on the wellbeing of the people, tourism and farming which are the main economic activities of the area, besides causing human-wildlife conflicts. According to Onywere *et al*. (2013), continuous flooding of the lake during the period January 2010 to December 2014, had detrimental effect on the ecosystem, infrastructures and the biodiversity. Considering that the level of the lake has raised even higher, the effect is more hazardous and far-reaching.

1.3 Research Questions

The research was guided by the following questions:

(i) What is the area affected by Lake Naivasha's water level rise?
(ii) How much of vegetation has been lost due to Lake Naivasha water level rise?
(iii) How much of the infrastructures have been destroyed or damaged due to the lake water level rise?
(iv) What is the effect of the lake's level rise to the well-being of the affected communities?

1.4 Objectives

The study aimed at achieving one general objective and four specific objectives.

1.4.1 General Objectives

The main objective of the study was to assess the effect of Lake Naivasha's water level rise and its consequences on the community, infrastructures and biodiversity around the riparian area of the lake.

1.4.2 Specific Objectives

The specific objectives were:

i). To map the spatial extent of land affected by the lake level rise between 2008 and 2020

ii). To quantify vegetation lost due to the rising level of the lake between 2008 and 2020

iii). To determine the infrastructures damaged or destroyed as result of the lake level rise

iv). To evaluate the effect of lake level rise on the well-being of the affected communities.

1.5 Justification

Lake Naivasha is experiencing water level rise which has severely affected livelihoods, vegetation, wildlife, development infrastructures and the ecosystem at large. The flooding has displaced residents and wildlife, destroyed buildings, greenhouses, roads and agricultural crops, beside resourceful dryland and vegetation being lost to water, thus resulting in loss of biodiversity. This has negatively impacted the owners of the flooded land and those who depends directly and indirectly on the affected properties.

The lake is a major economic booster of the area. It was identified by the "Ramsar Convention as Wetlands of International Importance" due to its ecological significance, uniqueness and rich biodiversity (Ramsar Convention Secretariat, 2016). This study's results are significant for sustainable development, wise use and conservation of the lake's riparian ecosystem. The study's outcome will also be useful in planning to avoid further occurrences of water level rise effects.

1.6 Significance of the study

To maintain a safe and sustainable ecosystem, reliable information on the effect of lake level rise is critical. The results obtained in this research especially the flood mapping will help in planning and conservation of the wetland, apart from identifying the affected biodiversity. It contributes in terms of the method used which can be replicated in assessing other flooded water bodies. The findings inform physical planning and infrastructure development that will not be vulnerable to future flooding.

1.7 Scope of the Study

The research was carried out on the area around Lake Naivasha. The focus was assessing the effect of the lake's level rise for the period 2008 - 2020. The discussion is limited to land surface extent and vegetation the lake has flooded, the impact of the level rise on development infrastructure, and the wellbeing of the affected persons.

1.8 Study Limitation

This study was limited in terms of accessing the flooded properties due to the restricted entry to the private land around the lake by the owners. The researcher relied on access by boat to observe the affected properties, besides using Google Earth historical imageries and interview responses to obtain adequate information.

1.9 Conceptual Framework

The conceptual framework (figure 1.1) shows the interaction between the study variables. Flooded land, vegetation lost, infrastructure destroyed, loss of diversity and habitat, human-wildlife conflicts and wellbeing change, causes a change to flood management, thus they are dependent variables. The vegetation lost and infrastructures destroyed are dependent on the flooded land. Loss of plant biodiversity, loss of habitat and human-wildlife conflict are dependent on loss of natural land cover vegetation. The wellbeing change is mainly dependent on farming, small-scale businesses, hotel industry and tourism for sustenance. Flood management is the only independent variable while legal and institutional frameworks are the intervening variables. Flooding is a natural occurrence that can be managed through constructing structures and using nonstructural mitigations. For Lake Naivasha due to its extent, nonstructural mitigation especially riparian reserve management will mitigate the flooding effects such as infrastructure damage. Riparian area is protected by legal and institutional framework.

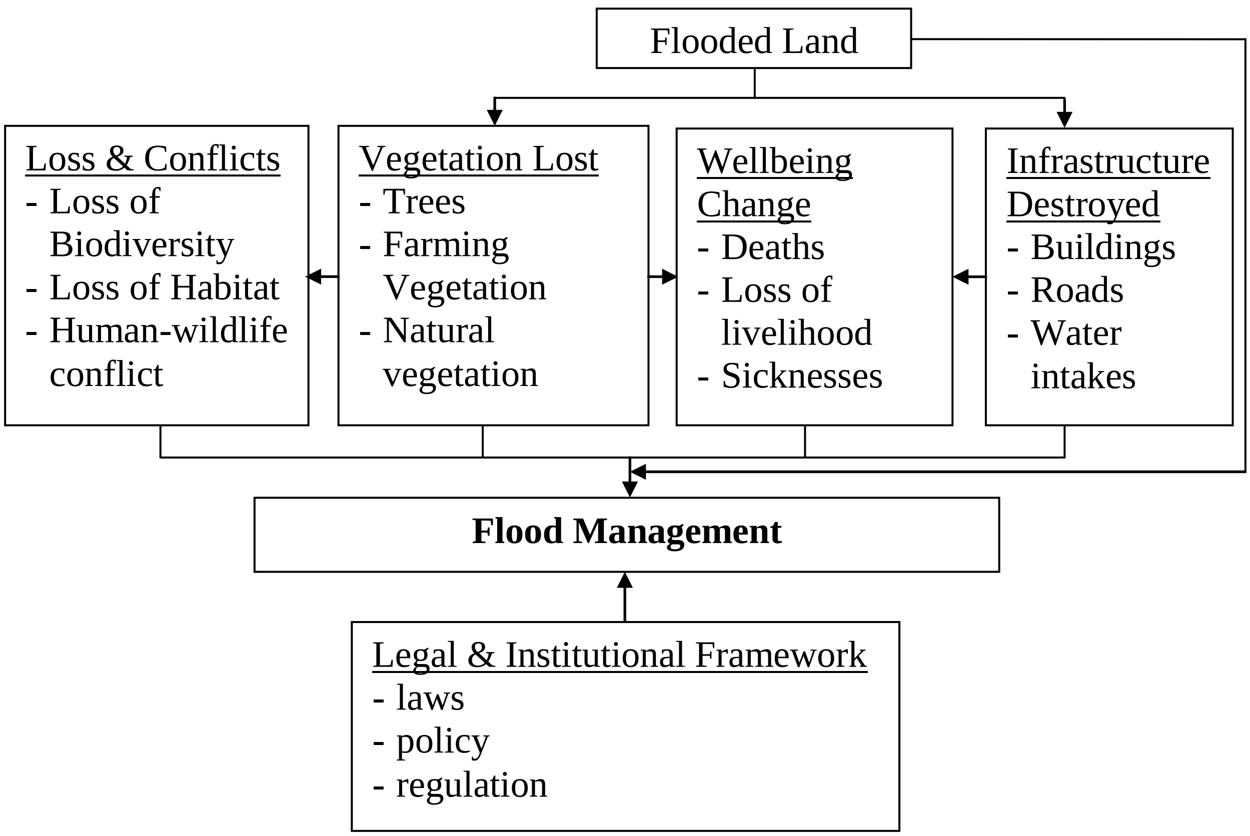

Figure 1.1: Conceptual framework to assess the effect of Lake Naivasha's water level rise

1.10 Definition of Terms

The following terminologies were used in this dissertation as per the context and understanding stated:

Biodiversity: It is the availability of flora or fauna or flora and fauna species in large quantities in particular area.

Ecosystem: These are self-sustaining, “natural systems of plants and animals interacting with each other plus their physical environment” (Palmer, Ambrose, & Poff, 1997).

Encroachment: Interference with an ecosystem or an area

Flood: When water inundates land that is normally dry (Geoff Garrett, 2011).

Flood Management: This refers to the actions that are taken to prevent, protect and reduce flood impact (Salazar *et al*., 2012).

Habitat loss: This is an occurrence when nature is not capable of supporting its species, the resultant being death or displacement of organisms thereby reducing the number of species and biodiversity (Oakley *et al*., 1985).

Infrastructure: This refers to buildings, transportation networks such as roads, electrical lines, and water and sewerage lines.

Lake level rise: Increase of water in lakes causing flooding in the surrounding areas.

Riparian: Land or area bordering wetland, stream, river, lake, sea, ocean or any other water body, creating a buffer zone to it (National Research Council, 2002).It is the transition land or interface between relatively drier upland areas and wetter areas (Nelle, 2014).

Riparian Management: This refers to the actions that are taken to protect and maintain the riparian areas.

Wellbeing: Something constituted through interplay of personal, social, and environmental processes that can somehow have a monetary equivalent (Hudson *et al*., 2018).

Wetlands: “areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres” (Ramsar, 2016).

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

This chapter reviews literature related to the study problem, presenting important information about methodology and implications of previous studies.

2.1 Flooding of Lakes and its Effect to the Land

Globally it is predicted that sea levels will keep on rising at a high rate as a consequence of climate change, loss of wetlands, riparian zone encroachment, urbanization and land-use changes (Talbot *et al.*, 2018). The land affected by flood can be determined in terms of surface area increase, surface area immersed, flooded water volume and water level (Burn & Whitfield, 2017). The water level of a water body is correlated to water volume and flood extent (Mahe *et al.*, 2013). Study by Verburg. (2018) demonstrated that large volume of water entering Lake Monona due to heavy rainfall in October 2018, raised the lake's level to 258.57m which was 19cm above its normal maximum level thereby causing flooding of homes and businesses. Water body storage which is the volume, is correlated to the depth of the water. Silting reduces the depth of a water body and water storage while it contribute to water level rising and hence flooding (Lachhab *et al*., 2015). A bathymetric survey of Lake Naivasha by Maina *et al*., (2018) in 2016 indicated that the lake's mean depth was 4.68m while its volume was 76,532m^3. Maina *et al*., (2019) study of the Lake Naivasha sedimentation for the past 50 years pointed an increase in sediment load, with the lake maximum sediment accumulation thickness being 1.9 m and average sediment thickness of 0.56 m. This was in tandem with Walker, (2016) study that found that the sedimentation of the lake was increasing at an average of 23mm per year, displacing 308.139 km^3 of water each year. The displaced water by the silt contribute to the flooding of the lake.

Several researches have emphasized on the usefulness of remote sensing in determining flooded lands. Chormanski *et al*. (2011), used 2002 Landsat Enhanced Thematic Mapper (ETM) images to determine the extent of flooded land during the flood of the River Biebrza, in Poland. The study compiled a map distinctive of flooded areas and dry areas.

Thomas *et al*. (2015), in the study mapping inundation in the heterogeneous floodplain wetlands of Australian Macquarie marshes, used 1999 and 2012 Landsat Thematic Mapper (TM). In the study, waters, mixed pixels and foliage were merged to map submerged land from non-inundated areas. Wang *et al.* (2002), used a pair of 1999Landsat TM image, in addition to Digital Elevation Model (DEM) data, to assess flooded extent of coastal floodplain areas of Pitt County, North Carolina. The study described the method as dependable and might be used for other floodplain areas, but one of the limitations noted was on availability of high-resolution DEMs especially for large floodplains.

Haque *et al*. (2020), used 2D hydrometric model in estimating the inundated areas and validated the results using July 2000 to December 2011 Moderate Resolution Imaging Spectroradiometer (MODIS) data of Inner Niger Delta of Mali, West Africa. The result showed that the method is simple, has reasonable accuracy, but noted that MODIS data have low resolution. Policelli *et al*. (2019), used remote sensing to model climatological and water analysis in evaluating Lake Chad total surface area. The main limitation of the model, the study showed that it is not an actual model and might not work elsewhere apart from the circumstances it was developed.

Onywere *et al*. (2013), in the study of Geospatial Extent of 2011-2013 flooding of Eastern Rift Valley lakes in Kenya and used Landsat satellite imageries. The study approximated that Lake Naivasha surface increased from 107.7 km^2 in January 2010 to 169.9 km^2 in 2013. Though Onywere *et al*. (2013) was thorough the time coverage was short and methodology used different.

This study conclusion on remote sensing data is that Landsat imageries are useful in flood evaluation but have low resolution thus less accurate as compared to high resolution imageries. High resolution imageries though accurate are expensive, thus this study used Google Earth historical imageries which are high resolution and are available free of charge to map the land and the land cover affected by the lake level rise.

2.2 Flooding of Lakes and its Effect to Vegetation

Flooding is a major phenomenon that affects vegetation. To determine the effect of a flood to vegetation, it is important to establish the condition of an ecosystem before flooding and the duration of flooding. Prolonged flooding will likely aggravate loss of the vegetation by possibly leaving inadequate recovery time (Talbot *et al*., 2018). The effects of short-term floods are usually less and the vegetation recovery may occur quickly. Extreme floods are associated with decline in vegetation where else small floods provide or enhance an ecosystem vegetation (Talbot *et al.*, 2018). In the case of the study area, flooding started in 2010 and has prolonged to 2020, thus the submerged vegetation had less time to recover.

Studies have demonstrated that flooding affect riparian vegetation negatively. In the study of effect of increased flooding on riparian vegetation of five areas in three European countries; Denmark, Germany, and the Netherlands; during late winter and early spring, it showed that there was decline in riparian biodiversity, increase in plant biomass and shift in plant species composition (Garssen *et al*., 2017). Boever *et al*. (2019), study on effects of a large flood on woody vegetation along the regulated Missouri River in the USA, using 168 samples in 2006-2009 and 80 samples in 2013-2014; the forest area declined among age classes with the greatest decline being the youngest classes. Basak *et al*. (2015), study on impacts of the flood on forest trees and their coping strategy, demonstrated that trees such as *Acacia auriculiformis, Acacia mangium* die due to floods and water logging over a time. These studies delved on effect of flood water to vegetation which is comparable to Lake Naivasha ecosystem under study.

Riparian vegetation which is more as compared to adjacent upland's vegetation, is important since it reduces the runoff velocity of water flow, effectively removing sediments and nutrients. The vegetation also sieves up aquatic pollutants such as chemical inputs; phosphorus, nitrogen, and other nutrients that can lead to eutrophication of aquatic ecosystems. The sieving improves water quality especially reducing the non-point source pollutants such as sewerage (Zaimes, 2007). The roots of the vegetation, control lakeshore erosion including in-stream scour and bank erosion, thereby also reducing the amount of sediment load received by a lake or a river (Vermont Agency of Natural Resources, 2015). Healthy maintenance of riparian areas is crucial for flood management and clean water.

Vegetation loss has been quantified by different authors using Landsat imageries. Guerra *et al*. (2020), used spatial explicit model to estimate riparian vegetation loss in the Pantanal, Upper Paraguay River Basin. The study results projected a vegetation loss of 1915 km^2 from 7960 km^2 in 2020 to 6045 km^2 in 2050. Mu *et al.* (2020), computed 1987 to 2017 vegetation change in comparison to water of Poyang Lake in China, using Landsat imageries and Normalized Difference Vegetation Index (NDVI) derived from MODIS imagery. The study results indicated vegetation increase rate of 18.4 km^2 per year. Venter *et al*. (2020), used 1984-2018 Landsat data to monitor vegetation change in South Africa and produced a map of enhanced vegetation index. Alemu *et al*. (2017), also assessed the effects of land use on plant communities in Gilgle Gibe riparian zone, Southwestern Ethiopia, using Landsat satellite images and Geographic Information Systems (GIS). The study classified the riparian zone into 5 classes, identified frequent species and assessed loss of the vegetation in the area. Onywere *et al.* (2012) used 1986 and 2000 Landsat imagery and 2007 Satellite Pour l'Observation de la Terre (SPOT) data to evaluate the extent of environmental degradation and its effect to Lake Naivasha. One of the conclusion of the study was that use of satellite data to assess the rate of change of vegetation has led to improved quantification of land cover units (Onywere *et al.*, 2012). From the review of these studies, satellite images, remote sensing and GIS technologies are effective in quantifying vegetation. Using higher resolution imagery such as the one used in this study gives more accurate results of the vegetation lost due to flooding.

2.2.1 Loss of Habitat

The importance of vegetation habitat cannot be gainsaid. It is home to many wildlife species such as amphibians, reptiles, birds, and insects. The riparian trees and vegetation provide shade, cools and moderates water temperatures for aquatic life, while organic materials such as leaves and other detritus provide food and cover for aquatic insects and fishes (Vermont Agency of Natural Resources, 2015). Habitat loss occurs when nature is not capable of supporting its species. The resultant is death or displacement of organisms thereby reducing species and biodiversity which results in disruption or degradation of an ecosystem (Oakley *et al.*, 1985).

Djihouessi *et al.* (2019) study of Lake Nakoue, in Benin, revealed a habitat profoundly affected by urbanization around the lake. The study reported that as a result of mangrove vegetation being destroyed the lake experienced sewage nutrient load which causes a periodic blossoming of hyacinth which perishes each year as a result of rise in salinity. A fishing practice in the area resulted in transportation of dry woods into the lake, which when it decays in combination with the dead hyacinth causes a great disturbance to the habitat. In addition, the lake flooding in 1980 to 2000 decreased riparian habitat species from 16 to 4 (Djihouessi *et al.*, 2019). The area around Lake Naivasha is experiencing urbanization; the main town being on the north-eastern side, Karagita estate on the eastern side, Kwa-muhia built-up area on the southern side and Kasarani estate on north-western side. As indicated by Onywere *et al*. (2012), the town waste disposal is a challenge such that the wash-off water and debris are carried down to the lake. The sewerage system covering a small part of the main town often breaks down flowing to the lake. The sewerage treatment plant is situated near the lake thus when it overflows it drains into the shores, while some lodges discharge raw sewage into the lake. Study by (Njiru, Waithaka, & Aloo, 2017) found out that discharges to the lake increased nutrient loading which led to death of fishes in 2015 and also posed serious threats to the habitat.

Habitats are directly affected by loss of vegetation. Loss of mangrove forest as a result of erosion in West Africa marine areas, led to loss of coastal forest habitat (Failler *et al*., 2020). Fernandes & Adams, (2016) quantified the loss of Nkomazi and Mvoti estuary habitats of South Africa in 2013 using historical data, aerial photographs and field surveys. The study results indicated that cultivation of sugarcane and colonization by alien plants had reduced the percentage of the native macrophytes. Study of ecohydrological evolution of Lake Naivasha for the past 1650 years recorded that papyrus swamp is associated with reduction of salinity of the lake and thus improving the habitat (Van der Meeren *et al*, 2019).

2.3 Flooding and its Effect to Infrastructures Around the Lake

Development infrastructures affected by lake flooding includes buildings, settlements, boathouses, water collection plants and pipes, roads network and any other structures put up on floodplains (Warner, 2011). One of the floodplains functions is to store floodwaters, helping to lessen flood damages. Given that many infrastructures have been established in riparian areas, the risk of being damaged is high when lakes experience surface level increase. Often the poor encroach riparian areas since it is a public land building informal settlements (Henrique & Tschakert, 2019). Because of the scenic nature of the riparian zone, the elite put-up hotels and houses, among other structures. In some of the floodplains it is also common to find farming and irrigation infrastructures such as greenhouses and water diversion structures.

Macfarlane, (2019) reported that 2019 lakes level rise of Great Lakes of North America, damaged many infrastructures such as docks, buildings, boathouses, among others. Policelli et al. (2019), studied on when and how extensive annual flooding of Lake Chad could be disastrous to crops, properties and the large number of people settled in the floodplains of the lake. People settled and farming in the lake's floodplain for example Lake Chilwa in Malawi, in the event of flooding the resultant damage to properties and crops was huge (Kafumbata et al., 2014). Olaka et al. (2019) study, projected that 2015–2100 Lake Victoria flooding will cause destruction of water supply infrastructures and cause concomitant damage to properties. Floods in Kenya in the past have damaged roads, buildings and social facilities (Njogu, 2021). With flooding of Lake Naivasha and encroachment of the lake's riparian zone by slums such as Kihoto, many infrastructures have been damaged.

2.4 Flooding of Lakes and its effect on wellbeing to affected persons

Lake level rise and its effect on the wellbeing of individuals is complex but there are diverse processes that identifies the changes for those who have experienced flooding (Walker-Springett *et al.*, 2017). Walker-Springett *et al.* (2017) study, used four key dimensions; temporal dynamics, social capital, perception of assisting agency and capacities of coping with changed future to the wellbeing of the individuals after flood event. The research findings showed that wellbeing follows a straight-forward linear fashion after an initial negative peak. The study also found that perceived lack of assisting agency has negative influence to the wellbeing of a community. It also linked the importance of wellbeing of individuals and ruptured futures to existing social capital. Hudson *et al*. (2018) uses disaster resilience three pillars that include resistance or ability of an individual to absorb the shock, recovery which relates to the time an individual takes to go back to the state before the flood and anticipatory learning which refers to the individual ability to learn from the flood event. To study the wellbeing of individuals of Thua Thien Hue province in Central Vietnam, that had severally experienced flooding, Hudson *et al*. (2018) used monetary equivalent (in % of annual income) of subjective well-being losses due to flooding to show the impact. This study adopted Hudson *et al*. (2018) and Walker-Springett *et al*. (2017) to study the wellbeing of the flooded Lake Naivasha community.

2.5 Flood Management

Lake flooding is a natural phenomenon that is impossible to prevent from occurring except that its magnitude and negative impact can be mitigated (Aslam, 2018). Flooding has been managed through construction of structures such as dykes, levees, flood walls, dams, among others (National Research Council, 2013a). Flooding has also managed through nonstructural mitigations which includes natural systems, land-use planning and zoning, risk mapping, hazard forecasting, flood preparedness, acquisition and relocation, insurance, to name the common (National Research Council, 2013a). Chen *et al*. (2019) studied, use of lake level regulation to mitigate flooding impact in the Yahara Watershed, a chain of four lakes in Wisconsin, USA. The limitation noted is that structural land surface and hydrologic-routing models used in the lake level regulation study may only be used to mitigate flood in Yahara Watershed and similar chain lakes watersheds. Nonstructural, land-use planning and zoning is one of the most effective flood management tool (National Research Council, 2013b), whereby the areas subject to flooding should not be developed. These areas are often the floodplains which constitute the riparian areas that are known to mitigate the effects of flood (Olokeogun *et al*., 2020).

Several studies demonstrate the significance of the riparian areas (Kate *et al*., 2017; Orewole *et al*., 2015; Papaioannou *et al*., 2018; Stutter *et al.*, 2019*)*. With world population growing day in day out, and with the ever rising demand for land, encroachments into riparian reserves have become very common. People are obstructing or degrading riparian areas, which is not only posing risk to water sustainability but also to flood management (Kingsford *et al*., 2011; Stutter *et al*., 2019). The most common encroachment of riparian land is usually in form of clearing of vegetation and conversion of a zone to other uses such as croplands and built up. Land use activities such as industrial, agricultural, transportation as well as residential uses on riparian land of late have been on the rise (National Research Council, 2002). The rich soils and presence of water makes riparian reserves biologically rich, creating productive lands for agriculture and desirable locations for urban development (Griggs, 2009). Nelle, (2014) guide on managing riparian areas, advocates for proper management of riparian areas due to their great value.

One of well managed riparian zone is Shoal Lakes watershed in Manitoba's Interlake region, USA, but recent years rise in water level has immensely affected farming and infrastructures which were noted for improvement (Lowdon *et al*., 2014). A study of 40 Vermont lakes, demonstrates the importance of protecting riparian area along the lakes through their Agency of Natural Resources (ANR) which advocates for protection, restoration and enhancement of riparian areas (Vermont Agency of Natural Resources, 2015).

Africa continent is endowed with many lakes whose riparian is under threat, increasing flood vulnerability of the community. Olokeogun *et al*. (2020), 2019 study of Eleyele Lake riparian reserve in Ibadan Nigeria, revealed decrease in riparian vegetation cover due to 18.9% increase in built-up areas of the flood zone. Another lake whose negative impacts on its eco-system is on the rise and have led to its riparian degradation is Lake Chad (Kafumbata *et al*., 2014). Malawi's, Lake Chilwa, one of the most densely populated wetlands in Africa is also facing threat of increased area of floodplains, making more land available for agriculture on its riparian. Lake Tanganyika which is the second largest lake in the world by volume, holding 17% of the liquid freshwater and is shared by four countries; agricultural and pastoral activities have led to its increased land cover loss, bank erosion, sedimentation, increased peak flows, decreased base flow, and contamination of groundwater sources (Kafumbata *et al*., 2014).

Riparian areas in Kenya are at risk as a result of man's encroachment. Lake Victoria shoreline on the Kenyan side estimated to be between 550 and 620 km long is experiencing over harvesting of papyrus, burning, grazing, drainage for irrigation, urbanization and human settlement (Okeyo-Owuor *et al*., 2012). Another lake in Great Rift Valley that conservation concerns have been raised due to increased hotels developments along its high use zone, that prompted for resurveying to substantiate its riparian area in order to accord it protection is Lake Elementaita (GoK, 2016a). Lake Naivasha is another lacustrine, who's riparian is dwindling and experiencing degradation as a result of encroachment. The original boundary of Lake Naivasha riparian land in accordance with Survey of Kenya cadastral maps and records is the 6210 feet contour (1892.808 metres). The survey plans and records sets out the extents of the lake as being a boundary designed as a give and take straight line to supplant the 1906 lake edge. According to Lake Naivasha Catchment Area Protection Order, 2012 (GoK, 2012), Lake Naivasha riparian is all that land and water enclosed within Moi North Road and South Lake Road of Naivasha District which falls below the 1892.8 metres above sea level contour, which was the highest lake level. Awange *et al*. (2013) study reported that the lake water level for the period 2000-2006 and 2006-2010 dropped by 1.92m and 1.38m per year respectively. For the period 1932-2010, the highest water mark of the lake kept on fluctuating to about 5.4m below the contour as a result of evaporation, water abstraction and seepage (Reta, 2011), creating a dry land for anthropogenic activities such as construction and cultivation. Nakuru 2018-2022 CIDP, records that Lake Naivasha riparian is faced by various challenges including; pollution, over abstraction, invasion of alien species, encroachment of riparian land, poaching, overexploitation, resource conflict, destruction of bio-diversity habitants among others. According to Onywere, (2012) and Onywere, (2005) the challenge in the conservation of the riparian zone is the implementation of intervention strategies mainly laws, policies and regulations in the management of the riparian area.

2.6 Legal and Institutional Framework

To determine whether the effects of flooding continue unabated or are minimized, legal and institutional framework comes in handy. Worldwide, there exists plethora of laws, policies and regulations in the management of riparian zones.

New Zealand which has a vast riparian area which is managed by several legal setting, The Resource Management Act 1993 and Conservation Amendment Act (No.2) 1993 being the main acts. The Resource Management Act 1993 (New Zealand Government, 1993b) provides for protection and preservation of wetlands, lakes and rivers and their margins from inappropriate subdivision, use and development. It lays down requirements for sustainable development, where the resources are to be managed well economically and socially for the present and future members of the society. Conservation Amendment Act (No.2) 1993 (New Zealand Government, 1993a) deals specially with management and conservation of protected areas, which includes riparian areas cited in The Act as marginal strips. The marginal strips are the land that is within 20 m of foreshores, lakes exceeding 80,000m^2 or bay or inlet of the lakes, and bank of rivers or streams of average width 3 m and above.

In South Africa, The National Water Act (Republic of South Africa, 1998), recognizes the whole watercourse ecosystem as a water resource, which should be “protected, used, developed and conserved, managed and controlled” sustainably. According to The Act (Republic of South Africa, 1998), the riparian zone is the physical area with its related vegetation all which are related to a watercourse. The other law in South Africa that is crucial in protection and management of riparian zones is The Environment Management Act (Republic of South Africa, 2014). The Republic of South Africa, (2014), Act provides that riparian areas should be well managed to meet the citizens needs equitably and responsibly. In Tanzania, The Environment Management Act, 2004 (Republic of Tanzania, 2004), provides for protection of riparian areas by empowering the minister in charge of environment to declare it as protected area and mandates the local government and councils to issue guidelines on sustainable use of the resources in riparian zones. The minister can also issue restrictions for protection of riparian areas from environmental degradation.

Riparian area in Kenya is a public land which is under the management and allocation of National Land Commission (GoK, 2012b). The Land Act (2012) (GoK, 2012a) established the National Land Commission and prevent it from allocating land that falls in wetlands, buffer zones and environmental sensitive areas. Approval of local physical development plans (PDP) are dealt with by The Physical Planning Act (GoK, 2009), which provide for the riparian zones conservation, reservation of not less than 10m width of the bank of rivers, streams or watercourses while reserves for oceans and lakes is not less than 2 km and 1km respectively. The Survey Act Chapter 299 (GoK, 2012), provides for riparian reservation of 30 metres from the highest water mark for the active mainstream rivers, between 6 – 12 metres for seasonal streams, 60 metres from highest water tide mark for the ocean and 30 metres from highest water mark or specified contour line for the lakes. The Environmental Management and Co-ordination Act (EMCA), 1999 (GoK, 2015), is involved in proper management and conservation of environment, demands conduction of environmental impact analysis before development project, prohibits construction of structures in the river, lake or wetland and minister in charge of environment issuing declaration of shore of ocean and lakes, wetlands and riverbanks as protected areas. Water Act Cap. 372 (GoK, 2016), is another law that provides for "protection, conservation, control and management of water resources and approved land use for the riparian area". The Act (GoK, 2016) establishes the Water Resource Authority (WRA) and defines riparian zone as the ecosystem adjacent and associated with a water course. There are enough provisions to protect riparian areas for successful flood management in Kenya, but fully implementation lags behind.

CHAPTER THREE: METHODOLOGY

3.0 Introduction

This chapter presents the regional background of the study area, research design, data collection and analysis.

3.1 Regional Background to Study Area

The study was conducted on the land enclosed within Nakuru Highway, Moi North Road and Moi South Lake Road, which is above 1882 meters contour above sea level (Figure 2). The area is approximately 64 square kilometers. The lake is located 100 Km north of Nairobi, between longitude 36º15´, 36º25´E and latitude 40º00´, 50º00´S. The lake comprises of 3 lakes: the main lake, Crescent Lake and Oloidien Lake, though near its southwestern side independently is Crater Lake (Sonachi). The depth of Crescent Lake on average is 18 m, Lake Oloidien is more alkaline with a mean of 10.49 ±0.01 PH levels in 2017 (Mutie *et al.*, 2020) and they both can be connected or distinct to the main lake depending on water levels (Becht *et al.*, 2006).

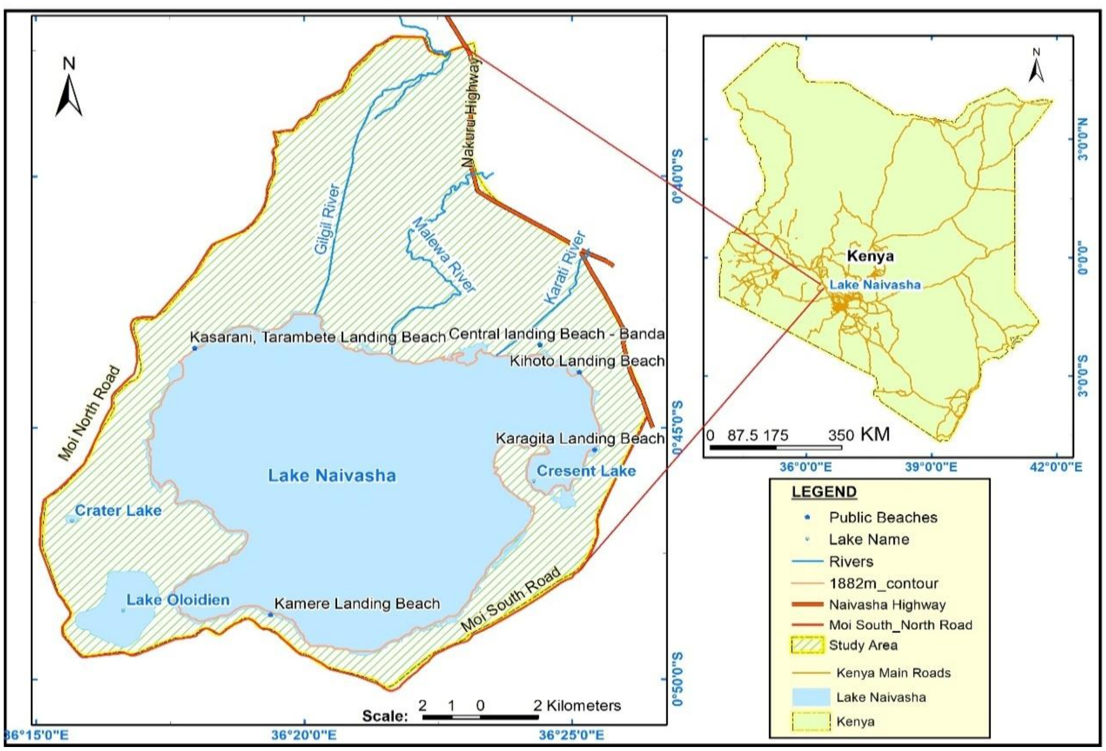

Figure 3.1: Kenya map showing the study area (Source: Survey of Kenya).

3.1.1 Geology and Soil

The geology of the area is a complex combination of lacustrine deposits, volcanic lavas and sedimentary deposits of pyroclastic acid rocks. The rocks range from being under saturated to acidic, having high contents of sodium while the pyroclastic rocks which cover the greater part of the surface area are consolidated and others incoherent (Thompson & Dodson, 1963). The soils around the lake have developed from volcanic ashes, composed of pumice thus very porous and has little capacity of holding water (Becht *et al*., 2006). This has led to the floodplain being covered with the volcanic ash sediments. The lake is a remnant of ancient, much larger Pleistocene epoch (about 2.58 million to 11,700 years ago) lake that is predicted to have been approximately 120 m above its present level (Thompson & Dodson, 1963). The current rise of the lake water level appears to be a minimal reclaim to its former level.

3.1.2 Hydrology

The rivers draining into Lake Naivasha includes Malewa with 90% of the water flowing permanently into the lake. Other rivers replenishing the lake are Gilgil, Karati which flow in during heavy rain season and Maraigushu among other ephemeral streams (Waithaka *et al*., 2018; Everard*et al*., 2002). Marmanet River from the lower western side is another river that replenish the lake though it disappears underground around Ndabibi before reaching the Lakeshore. Lake Naivasha is an endorheic lake, however, there is a consensus between several studies (Becht *et al*., 2006a, Becht *et al*., 2006b, Hogeboom *et al*., 2015,Walker, 2016), that there exists a subsurface outlet from the lake that removes salts and chemicals, thus making its waters fresh. The main lake depth ranges from 3m to 8m and the coverage surface area varies between 120km² in dry season to 189km² during wet season (Waithaka *et al*., 2018). Being a shallow lake, any rise in water level floods to a large area of the riparian land.

3.1.3 Climate

The climate of Naivasha is warm and temperate (Figure 3.2). The region is influenced by Intertropical Convergence Zone (ITCZ), which causes a bimodal cycle with long rains in

March-May and short rains in October-December (Stoof-Leichsenrin *et al., 2011;* Wainwright et al., 2020b). Average rainfall and temperature in Lake Naivasha basin is 677 mm and 17.1 ºC respectively (climate-data.org, n.d.). In recent years the areal rainfall in East Africa has increased in excess of 50-200 mm per month (USAID, 2020) and is associated with the swelling of the lake.

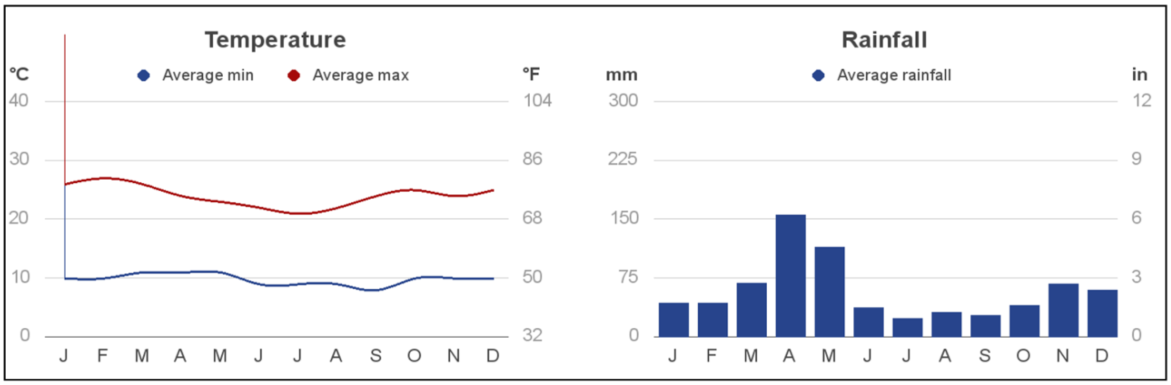

Figure 3.2: Naivasha's Climate. Average based on 30 years (1982-2012) of monthly climate data, taken from 1km² interpolated climate surfaces. Source: Climate grid data: WorldClim project.

3.1.4 Riparian Vegetation

Lake Naivasha ecosystem is endowed with a rich terrestrial and wetland vegetation (Harper *et al*., 2011). The vegetation consists of aquatic submerged plants mainly *Potamogeton spp* type and open waters floating vegetation comprising of floating water fern *Salvinia molesta* and water hyacinth *Eichhomia crassipes*. Waithaka *et al.* (2018) quantified the area covered by water hyacinth in March 2017 to be 14.8km² while that of papyrus was 5.7 km². Around the ecosystem are yellow fever acacia (*Acacia xanthophloea*), while papyrus (*Cyperus papylus*) and grassland forms a fringing zone around most parts of the lake (Onywere *et al*., 2013). Submerged plants are mostly found in the Cresent Island basin while open waters floating vegetation are mostly found in the west-northwestern parts of the lake. The southern and northern-west shores of the lake, apart from the natural vegetation consist of large-scale horticulture farming fields.

3.1.5 Socio-economic Activities

Lake Naivasha is a tranquil habitat alive with vibrant human economic activities. The town experience high number of influx migrant, in search of job opportunity in horticulture farms. The economy around the lake is largely influenced by the large-scale horticultural farming, where majority of the population works. Being a freshwater lake, it generates a lot of economic activities such as fishing, farming and tourism, all which were severely disrupted by the flooding.

3.1.6 Horticulture

Naivasha is the hub of large-scale horticulture farming. Around the lake are large floricultural farms growing flowers for export in greenhouses and also several vegetable farms cultivating on open fields and greenhouses. The flooding of Lake Naivasha affected some farms, damaging crops, greenhouse structures, irrigation systems, water intakes and electricity supply.

3.1.7 Settlement Pattern and Infrastructure

Around the shores of Lake Naivasha, population has increased tremendously, and resulted to informal settlements, which lack basic amenities such as water, sanitation and waste systems (Becht et al., 2006, Harper *et al.*, 2011). Naivasha Sub-county has an estimated population of 355,383 and 117633 households (KNBS, 2019), 57% increase from 1999 census. The town of Naivasha is situated on the northern-east side of the lake and it generate a lot of waste that flow into the lake when it floods (Onywere *et al.*, 2012). Beside the town, on the floodplain of the lake is Kihoto Estate, which is an informal settlement, thus when the lake level rises the area is affected. When it floods, solid waste and sewerage from the estate is swept into the lake from open dumping and overflowing pit latrines. Other informal settlements around the lake include Kamere and Karagita estates, found on southern side of the lake. Greenhouses, hotels and camping facilities are constructed on the southern and northern-west shores of the lake. The lake has five fish landing beaches; Karagita and Kamere on the southern side, Kasarani or Tarambete, Central Landing Beach also known as Banda and Kihoto on the northern side.

3.2 Research Design

Mixed method approach was used where descriptive research design was employed to assess the effect of the water rise (Figure 3.3). The choice of mixed methods design is because the study focused on an already existing phenomenon and an integration of methods provided better results for the research problem. Remote Sensing (RS), GIS and interviews were the techniques used to carry out the research. RS and GIS are well established techniques in studying floods because of their ability to assess, evaluate, analyze and map the phenomenon. Remote sensing is able to represent temporal information of the earth surface at relatively low observation cost (Chignell, *et al.*, 2015) depending on image type and spatial temporal resolution involved. Google Earth Pro, free version was used to capture flood data from Google Earth imageries.

To identify the inundated land, vegetation and infrastructures, Object Oriented Classification method also called Object Based Image Analysis (OBIA), was used to identify objects and extract them since they are visually visible. Object identified were evaluated with respect to their spectral characteristics, shape and texture, in addition to their relationship with surrounding. Field data was used in objects verification, wellbeing analysis and in result presentation. Lake extent, inundated vegetation and flooded infrastructures were visually identified from the images and vectorized.

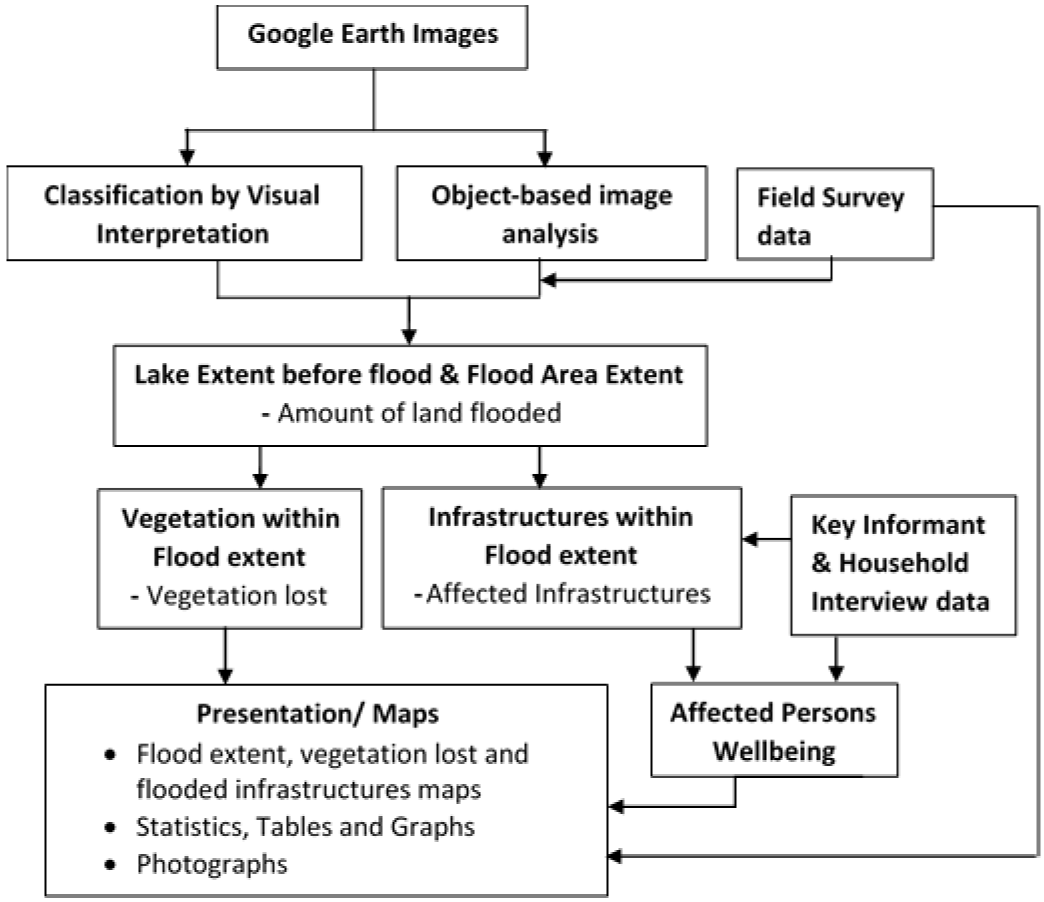

Figure 3.3: Flow chart showing the research approach and methodology

To extract the flooding extent data, Google Earth imagery for September 2008, November 2018 and September 2020 were the main imagery used which depended on their availability. The geometry of the land submerged by the water rise was delineated and computed using Field Calculator tool in QGIS. The amount of land taken up by flood was deducted from the extent of the lake before the level rise.

To quantify the vegetation loss, mapping of vegetation through Google Earth high resolution imagery for the period 2008 before flooding, was done. Using QGIS, the geometry area that was occupied by vegetation in 2008, 2018 and in 2020 is occupied by water was mapped and calculated using QGIS Field Calculator tool. This was performed using the same way the amount of land is calculated, whereby the vegetation in area displaced by flooding water is computed.

To quantify infrastructure destruction as result of the lake level rise, flooded infrastructures were identified. This was carried out using Google Earth imagery for the period September 2018 and September 2020. The number of structures that are in the flooded areas were mapped while the length of flooded roads computed using Field Calculator tool in QGIS.

To assess the effect of lake level rise to the well-being of the affected persons in the flooded land, key informant and household interviews were carried out. This was achieved through interviewing informants affected by the floods directly. The analysis of the interview response was performed and tabulated. Loss suffered for example due to structure, crop or livelihood loss such as displacement from their homes and loss of earnings was calculated in monetary form based on household interviews.

3.3 Target Population and Sample design

The study targeted community around the lake, local administrators, government ministries, NGOs and other relevant organizations whose operations are related to the lake level rise. The following institutions representatives were interviewed: Nakuru County Commissioner, Lake View Chief, Water Resource Authority (WRA) Naivasha Sub-Region, Lake Naivasha Water Resource Users Association (LANAWRUA), Lake Naivasha Riparian Association (LNRA), Lake Naivasha Basin Landscape Association (LANABLA), Kihoto United Homeowners Self Help Group, Karagita Beach Management Unit, Kamere Beach Management Unit, Kasarani also known as Tarabete Beach Management Unit, Banda also known as Central Landing Beach Management Unit, Lake Naivasha Boat Owners Association, Kenya Wildlife Service (KWS), Kenya Marine & Fisheries Institute, Kenya Power and Tourist Association Naivasha Chapter. To establish the sample size, Nassiuma, (2000) formula was used where a total of 100 households and the 17 institutions were sampled for the study. Purposive sampling technique was employed in sampling the target population to achieve the study objectives. The interviewees were selected based on the perceived informant’s knowledge about the effect of the Lake Naivasha water level rise. It was also based on literature review and what is shown in the high-resolution imagery of the area. Purposive sampling was also used to determine what to be photographed, points to pick GPS coordinates and riparian vegetation observation sites.

3.4 Study Variables

The study was guided by the general and the specific objectives whereby several measurements were made. To delineate the size of the land that has been submerged by lake water rise, the surface area occupied by water in square kilometers was determined. Likewise, the vegetation surface area inundated by water was quantified in square kilometers. For the impact of lake level increase on development infrastructures, the number of the affected infrastructures was identified and the total length of the roads computed. The wellbeing of the affected persons was determined from the interview response. The key issues identified included loss of earning due to crop or rental houses and business stalls damage.

3.5 Data Sources

Data sources refer to the origin of data used in the research. In this case, sources consist of primary and secondary data (Table 3.1). Primary data include field observations, interview responses, GPS coordinates and photographs captured. This data was collected from field survey in the study area. Secondary data included Google Earth historical imageries, Daily Regular Gauging Station data, Naivasha Registry Index Maps and Shuttle Radar Topography Mission (SRTM) data.

Table 3.1: Data Sources

NO.	SOURCE	DATA	RESOLUTION	DATE
1.	Google Earth	Google Earth historical imageries	1:0.15 m-1: 3 m	31.12.2008 11.07.2019 14.09.2020
2.	LANAWRUA	Monthly averages & Daily Regular Gauging Station data		1932 – 2020 Appendix III
3.	Survey of Kenya	Naivasha Registry Index Maps (133/2, & 133/4)	Scale 1:50,000	1964
4.	USGS EROS	Shuttle Radar Topography Mission (SRTM) data	1:30m	11.22.2000
5.	Field survey	Field observations, Photographs& GPS coordinates		23.09.2020
6.	Field survey	Interview responses		23.09.09.2020

3.6 Data Collection

The study employed five main methods of data collection. For primary data, employed techniques included key informants' interview, household interview, field observation and ground photography. The main methods applied for collecting secondary data are literature review and satellite imagery analysis. To map the land affected by the lake level rise, the lake spatial extent data was captured from the Google imageries and the area in km² calculated. The vegetation submerged by water was digitized and the coverage calculated in km² while affected trees counted. Damaged infrastructures as result of the lake level rise were identified, vectorized from the imagery and their number established. To evaluate the effect of lake level rise to the well-being of the affected communities, key informants and household response data was obtained and analyzed.

3.6.1 Interviews

Key informant interviews were conducted; whereby face-to-face meetings were held with key informants from the 17 institutions (Appendix II). Household survey was also done whereby 81 questionnaires (Appendix I) were distributed. The interviewees were selected based on their perceived knowledge about the effect of the Lake Naivasha water level rise and also based on literature review as well as what was shown in the imagery of the area. The analysis of the interview response was performed and tabulated. Loss suffered for example due to structure, crop or livelihood destruction such as displacement from homes and loss of earnings.

3.6.2 Field Observation and Documentation

Field observation is a purposeful and selective way of scrutinizing an interaction or a phenomenon. Purposive sampling was used to determine what to be photographed, points to pick GPS coordinates and riparian vegetation observation sites. Field observations performed included verification of vegetation species affected, infrastructures affected and the extent of the ground affected by the water rise. For verification purposes, coordinate points were picked using handheld GPS. To record and document observations, photographs were taken and used in the outcome presentation to provide sight information that was hard to achieve with text alone. Photographs of flooded vegetation and flooded infrastructures were captured.

3.6.3 Satellite Image Processing

The study utilized free Google Earth images, which are open source and of high resolution; 1:0.15 m - 1: 3 m depending with locality. Another advantage of Google Earth tool is that using the History icon, images taken at different times in the past are visualized thus very useful in change detection to analyze flood effect (Malarvizhi *et al.*, 2016). Limitation of Google Earth images is that it is not possible to carry out image classification using supervised and unsupervised methods, since not possible to get multispectral data.

Google Earth Pro was downloaded and installed. Using a slider at the History button navigated back in time analyzing past images in terms of availability and clarity. The lake earnest water level rise took place in 2010, but the study also sought to establish how the situation was in the previous 12 years. The March 2009 imagery was not covering some parts of the lake, thus the 31st December 2008 imagery that covered the whole lake was adopted as the start and 14th September 2020 as the end of the study period. September

2020 was chosen as the end of the study period to avoid result interference by October seasonal rainfall. To capture how the flood spread took place, January 2013, October 2014, March 2016 and 7th November 2018 Google imageries were also selected since they were the available one creating a span in between them. Using Google Earth, the lake extent polygons were created for the various years and saved as Keyhole Markup Language (.kml) file in "Places" folder. Using QGIS 3.10.14, the kml files were converted into GIS shapefiles. The surface area of the land submerged by the water rise was computed using Field Calculator tool in QGIS 3.10.14. The amount of land taken up by flood was deducted from 31stDecember 2008 extent of the lake.

To quantify the amount of vegetation lost to flooding, vegetation was mapped through visualization and change detection. The surface area occupied by vegetation in 2008, 2018 and in 2020 is occupied by water was vectorized through visualization, identification and change detection, using Google Earth saved as kml files in "Places" folder and converted into GIS shapefiles. Using QGIS Field Calculator the area previously occupied by natural vegetation and farming vegetation was computed in Km^2.The 2008 imagery was used since this was the beginning of the study period. The 2018 imagery was used since by then water had not risen to the extreme and it was possible to identify some vegetation. The end of the study period was 2020 and thus the imagery of the year was also used. In addition, the dislodged and drying trees in semi-submerged areas as well as in the flood extent area were evaluated from 2018 and 2020 imagery, captured as Place Marks and saved as kml files in "Places" folder and converted into GIS shapefiles. The number of affected trees was established through querying using QGIS.

Affected development infrastructures such as buildings, water intakes and roads in the flooded areas were vectorized from 2018 and 2020 imagery using Google Earth and converted to GIS shapefiles. Assessment of elements at risk was done by observation and through household questionnaires. Using QGIS, the total number of flooded buildings captured was queried while the length of flooded roads was computed using Field Calculator tool.

3.7 Data Analysis

The study relied on desktop qualitative and quantitative data analysis which was interpreted to meaningful insights. The vectorized lake extent GIS shapefiles for the various years; 6 in number were mapped separately, tables of the areas change, percentages and bar graph prepared. The shapefiles for submerged and semi-submerged natural vegetation, farming vegetation, dislodged trees and drying trees were mapped, tables of the affected vegetation area and affected trees created. The tables and photographs of dislodged trees and drying trees were inserted into the map. The vectorized flooded infrastructures were mapped together, tables showing number of affected buildings, water intakes and roads in lengths inserted. Content analysis was carried out to evaluate key informants' data and the effects of the water level rise established from their responses. Statistical Package for the Social Sciences (SPSS) was used to analyze household interview response data whereby the affected sectors, land acreages, value of damaged infrastructures and earnings per month were established and presented in form of tables, graphs and pie charts.

CHAPTER FOUR: RESULTS AND DISCUSION

4.0 Introduction

This chapter presents results arrived and discusses the effects of water level rise on riparian areas of Lake Naivasha as collected and analyzed in tandem with the research objectives.

4.1 Spatial extent of the land affected by the lake level rise

The size of the land that has been affected by the lake level rise was mapped from the imageries and ground truth survey. The land affected by flooding was calculated through GIS overlay procedures. To capture the change that has taken place from December 2008 to September 2020, January 2013, October 2014, March 2016 and November 2018 were also mapped and surface area computed (Table 4.1, Figure 4.1 and Figure 4.2).

Table 4.1: Lake Naivasha surface area change in km² and % Δ during December 2008, January 2013, October 2014, March 2016, November 2018 and September 2020. Source Google Earth

MONTH & YEAR	LAKE NAIVASHA (KM²)	Δ (KM²)	% Δ	LAKE OLOIDIEN (KM²)	Δ (KM²)	% Δ	CRATER LAKE (KM²)	Δ (KM²)	% Δ
Dec. 2008	123.016			4.549			0.106		
Jan. 2013	141.639	18.623	15	5.013	0.464	10	0.119	0.013	12
Oct. 2014	150.388	8.749	6	5.632	0.619	12	0.155	0.036	30
Mar. 2016	146.999	-3.389	-2	5.553	-0.079	-1	0.152	0.003	-2
Nov. 2018	153.176	6.177	4	5.708	0.155	3	0.162	0.01	6
Sep. 2020	156.066	2.89	2	5.819	0.111	2	0.201	0.039	24
Sep. 2020 Flood Extent	179.818	23.752	15	6.387	0.568	9.8	0.201		

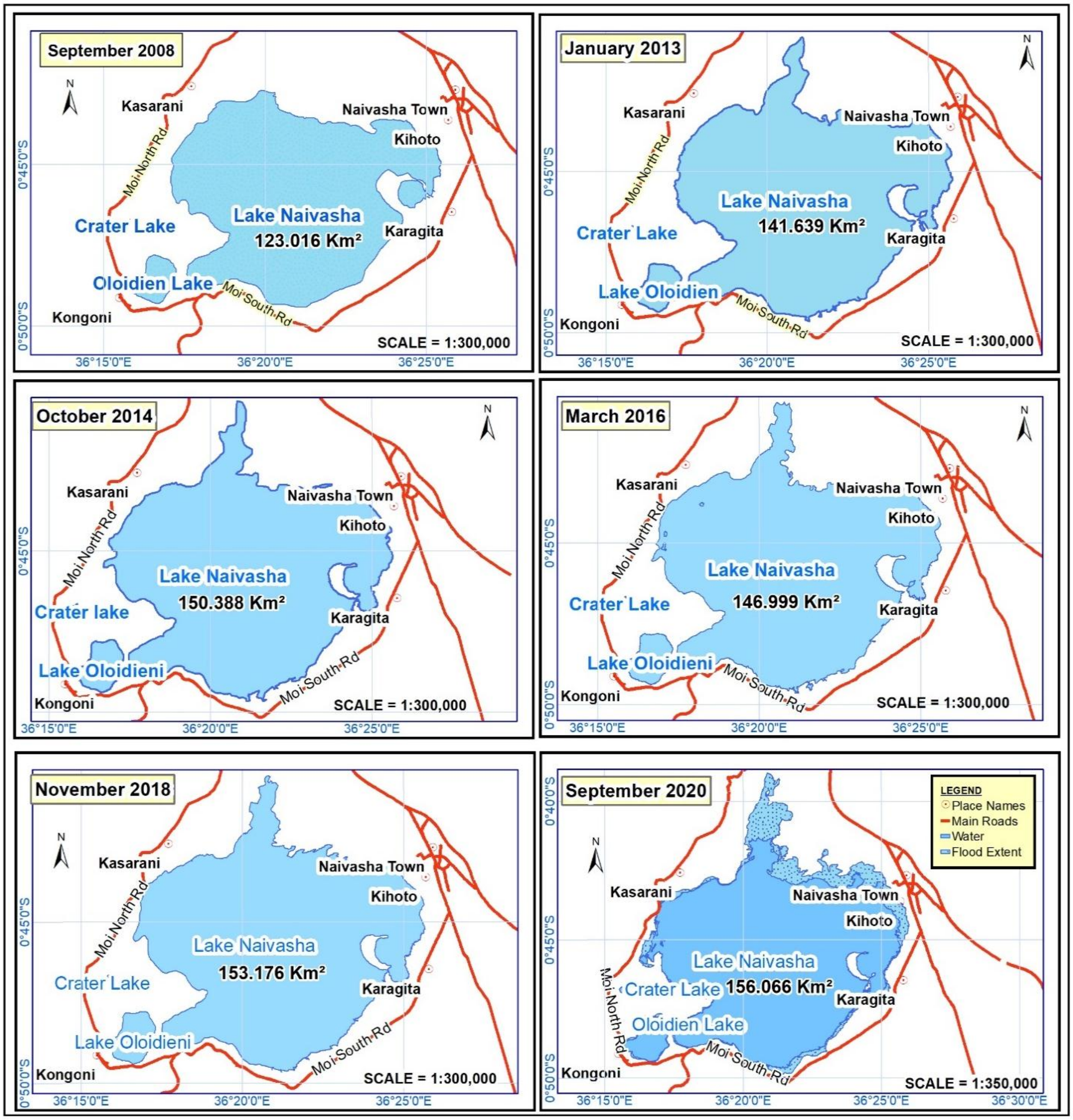

Figure 4.1: Lake Naivasha surface area change in km² maps for December 2008, January 2013, October 2014, March 2016, November 2018 and September 2020. Source Google Earth

The results (Table 4.1, Figure 4.1 and Figure 4.2) showed that the surface area of the main lake from 2008 to 2020, increased from 123.016 km² to 156.066 Km²; submerging 33.05 km² of land, which is a 27% increase. For Lake Oloiden and Crater Lake, the water surface area increased from 4.549 km² to 5.819 km² and from 0.106 km² to 0.201km², an increase of 28% and 10% respectively. In total 34.42 km² of the land has been submerged. Apart from the land fully submerged under water, the flood extent in 2020 was mapped. Flood extent was found to be 23.752 km² for the main lake and 0.568 km² for Oloidien. In total, the combined lakes extent in addition to flooded land is 186.406 km².

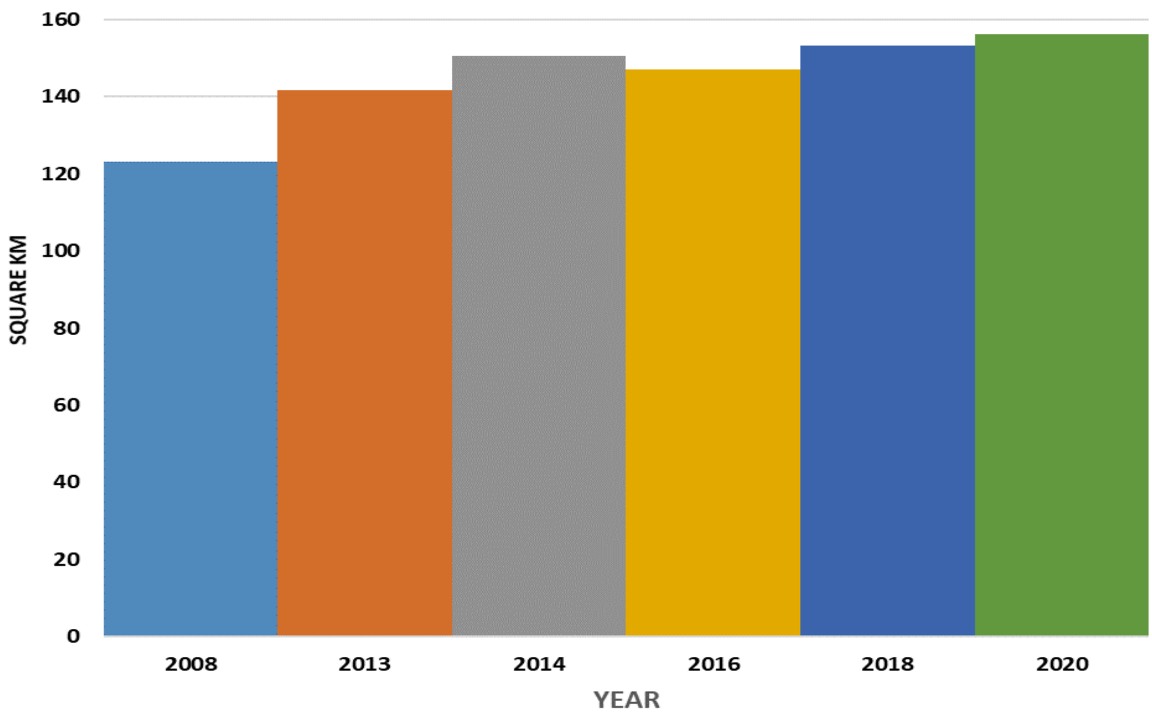

Figure 4.2: Lake Naivasha surface area in km² during December 2008, January 2013, October 2014, March 2016, November 2018 and September 2020. Source: Google Earth.

4.1.1 Riparian Area

The riparian reserve area of the main lake together with Oloidien Lake is 186.570 km², in accordance with the 1906 Survey of Kenya cadastral boundary records (Figure 4.3). The flooded lake extent which is 186.204 km² is within the boundary. Ten parcels of land in the riparian zone have been registered.

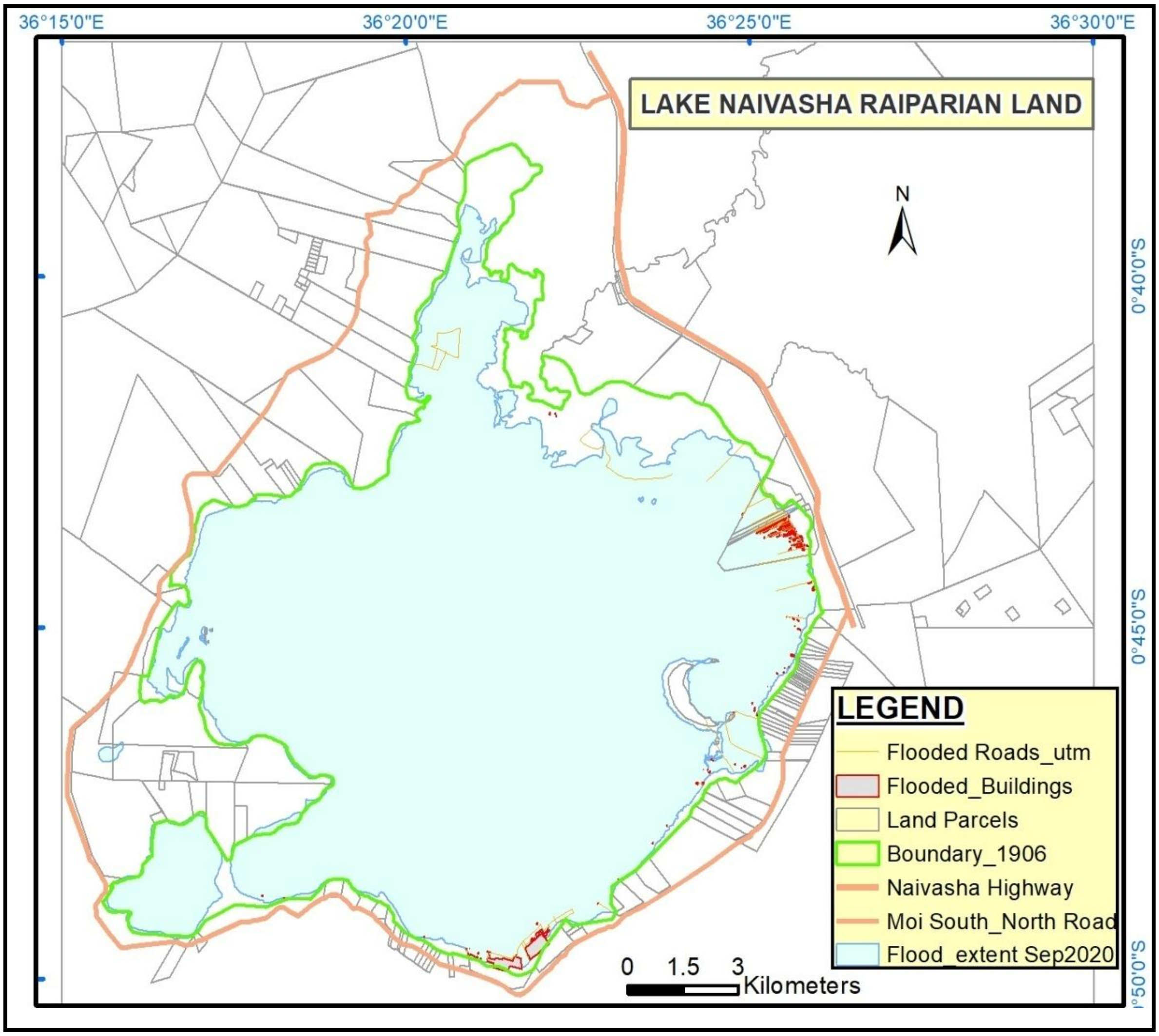

Figure 4.3: Lake Naivasha riparian land. Source: Survey of Kenya

4.1.2 Water Level Rise

The graph in Figure 4.1, shows Lake Naivasha's monthly average water levels trend from 1932 to January 2020. The last time the Lake level was very high was in 1965, when it rose to 1889.75 MSL. Regular Gauging Stations (RTGS) data was used to monitor the rise and fall of the lake water level. Figure 4.4 shows Lake Naivasha's monthly average water levels trend from 1932 to January 2020. From the data, the highest, the lake level has risen is 1890.80 MSL in 2020, followed by 1889.75 MSL in 1965, thus this could be attributed to a 50-year climatic cycle.

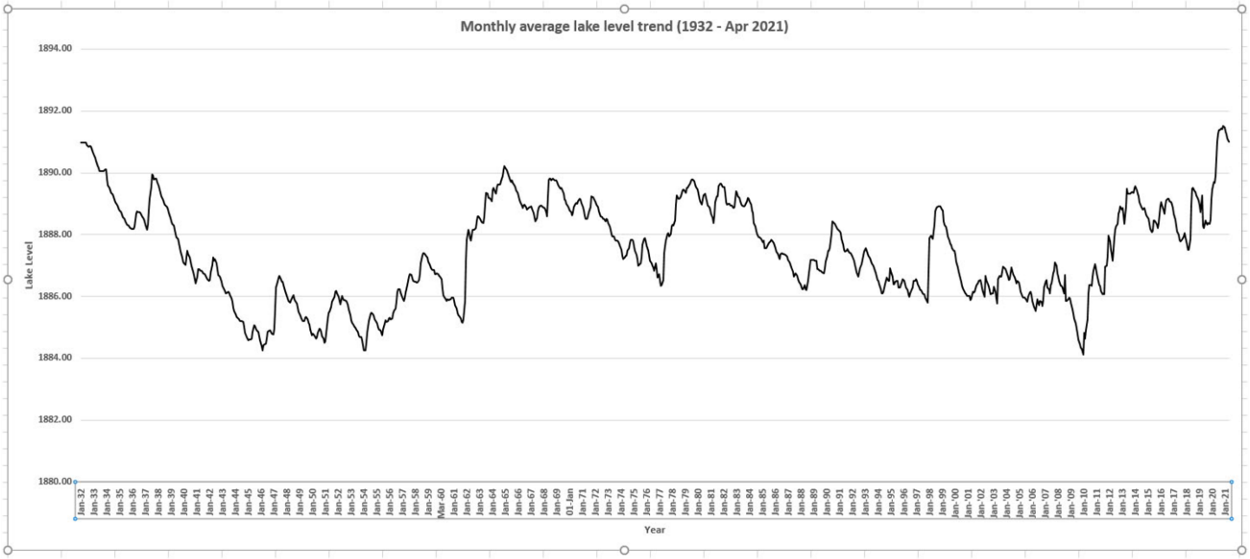

Figure 4.4: Lake Naivasha, monthly average water levels trend from 1932 to January 2020. Source: WRA.

The lake water level rise has been consistently increasing since the 2009 *La Nina* drought that recorded 1884.12 MSL in month of December. By 2014, the water level rose to almost 1890 MSL (Figure 4.4), and receded in 2015, 2016 before rising earnestly from 2018. The significant level rise took place in 2019 short rains which prolonged to February 2020, and April long rains which continued to October 2020 (Figure 4.5).

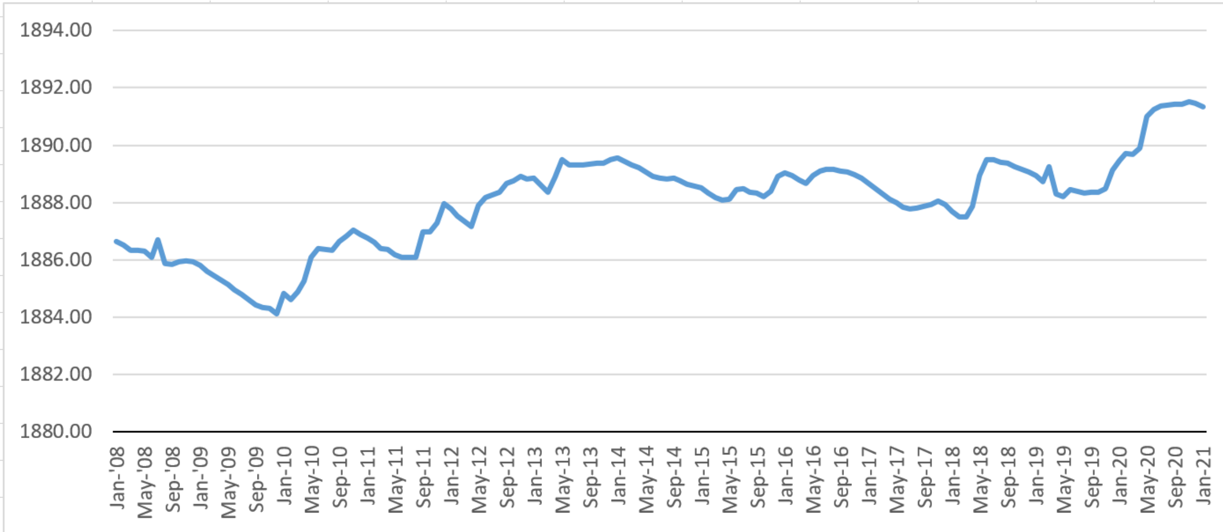

Figure 4.5: Lake Naivasha's', monthly average lake level trend (January 2008 - January 2021). Source: WRA, Lake Naivasha RGS levels.

4.2 Vegetation loss

The vegetation that has been lost to water was mapped in relation 2008 to, 2018 and 2020 lake surface area. The vegetation mapped has been gradually covered by water since 2008. The vegetation mapped has been gradually covered by water since 2008. The total amount of submerged vegetation was calculated to be 24.68 km² (figure 4.6). The vegetation included grass, yellow fever acacia trees *(Acacia xanthophloea)*, papyrus *(Cyperus papyrus)* among others resulting to diversity loss. The other affected vegetation was the farmland vegetation which was mapped separately. The farms identified included; 18 large scale farms, 7 medium size farms and 113 small scale farms (Figure 4.7). The farming vegetation submerged occupied 4.33km². In total the amount of vegetation lost was 29.01km², which signifies the vegetation lost due to the lake water rise. Onywere *et al.* (2012) study reported that from 1986 to 2007, the papyrus and grassland along the lake shore decreased from 134.9 km² to 117.5km², thus according to the results obtained the rate of vegetation loss has increased.

The other natural vegetation flooded but not fully submerged, which mostly includes yellow fever acacia trees and grass computed to be 0.71 Km^2, of which 174 trees were visibly dislodged and 1497 trees were drying up or already dry. In addition, by October 2020, 188 trees in flood extent areas were dislodged and 615 trees were visibly drying from being inundated. In total 362 trees are toppled and 2112 trees drying, yellow fever acacia being the variety mostly affected.

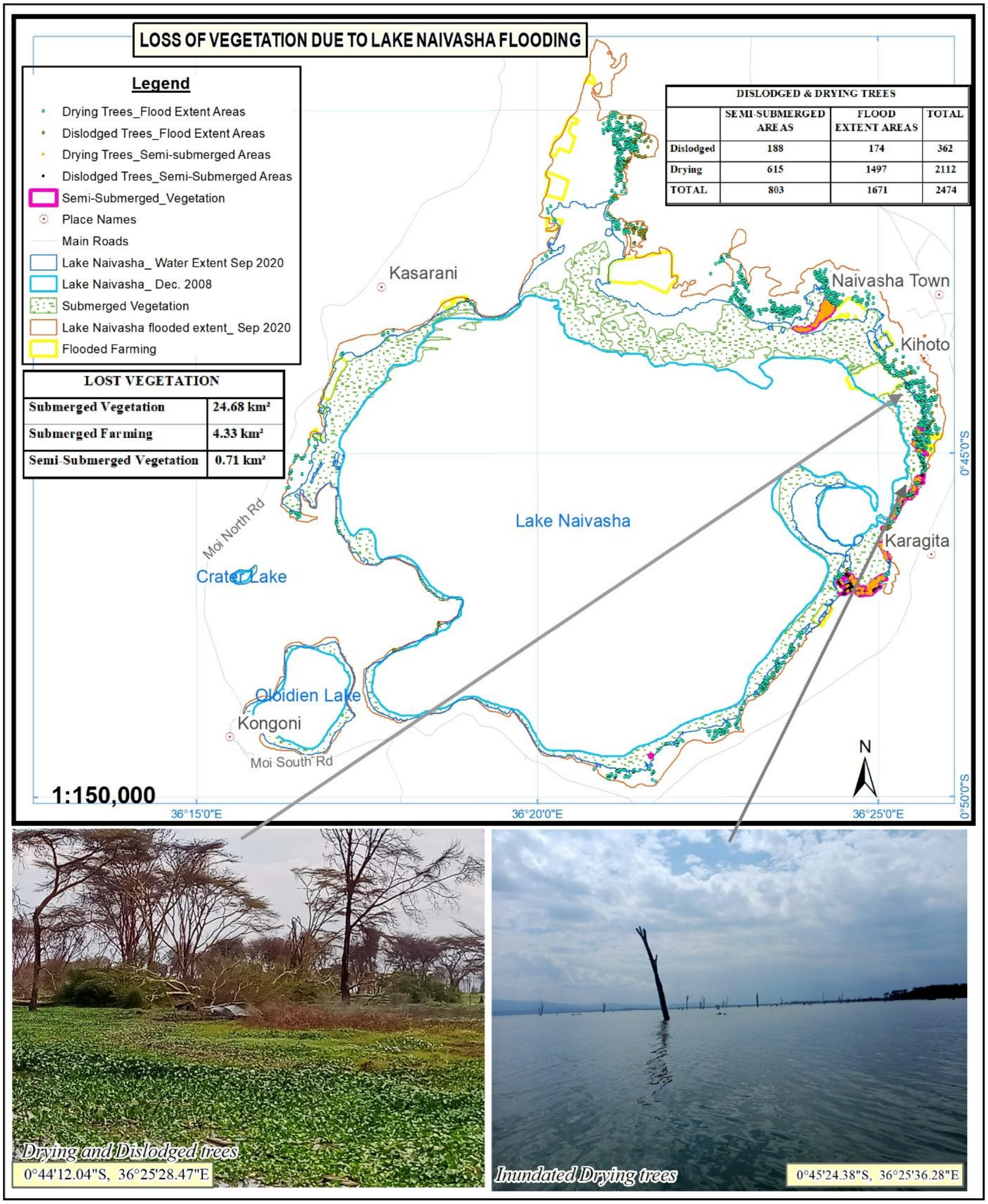

Figure 4.6: Vegetation lost dislodged trees and drying trees as a result of Lake Naivasha water level rise. Source: Google Earth and field photograph 23.09.2020.

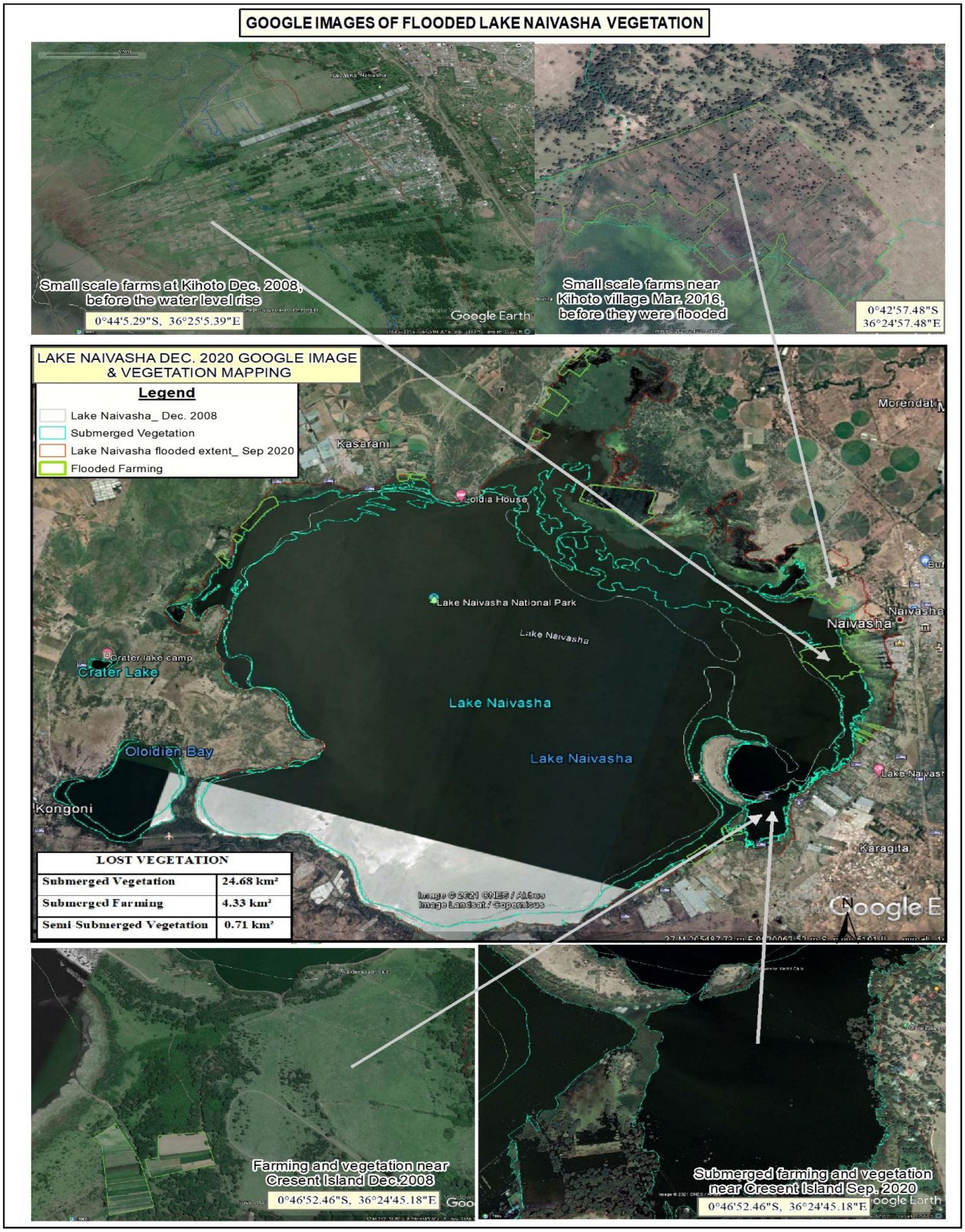

Figure 4.7: Submerged farms and vegetation. Source: Google Earth

4.3 Infrastructures destroyed as result of the lake level rise

Submerged infrastructures were identified and mapped from 2017, 2018 and 2020 imagery (Figure 4.8). At Kihoto, it was not possible to define individual structures thus some were mapped as blocks. In total 409 submerged structures were identified. The facilities identified from Google Maps and ground survey included hotels, camps, churches, schools, public beach, greenhouses, and pump houses among others. The total length of submerged roads was computed to be 35.936 kilometers. These roads were motorable, tarmacked or loose surface roads and tracks, which are no longer usable because they are either submerged in water or they are water-logged thus impassable, for example Crescent Island was accessible by road in 2008 but by 2020 it could only be accessed by boat or air.

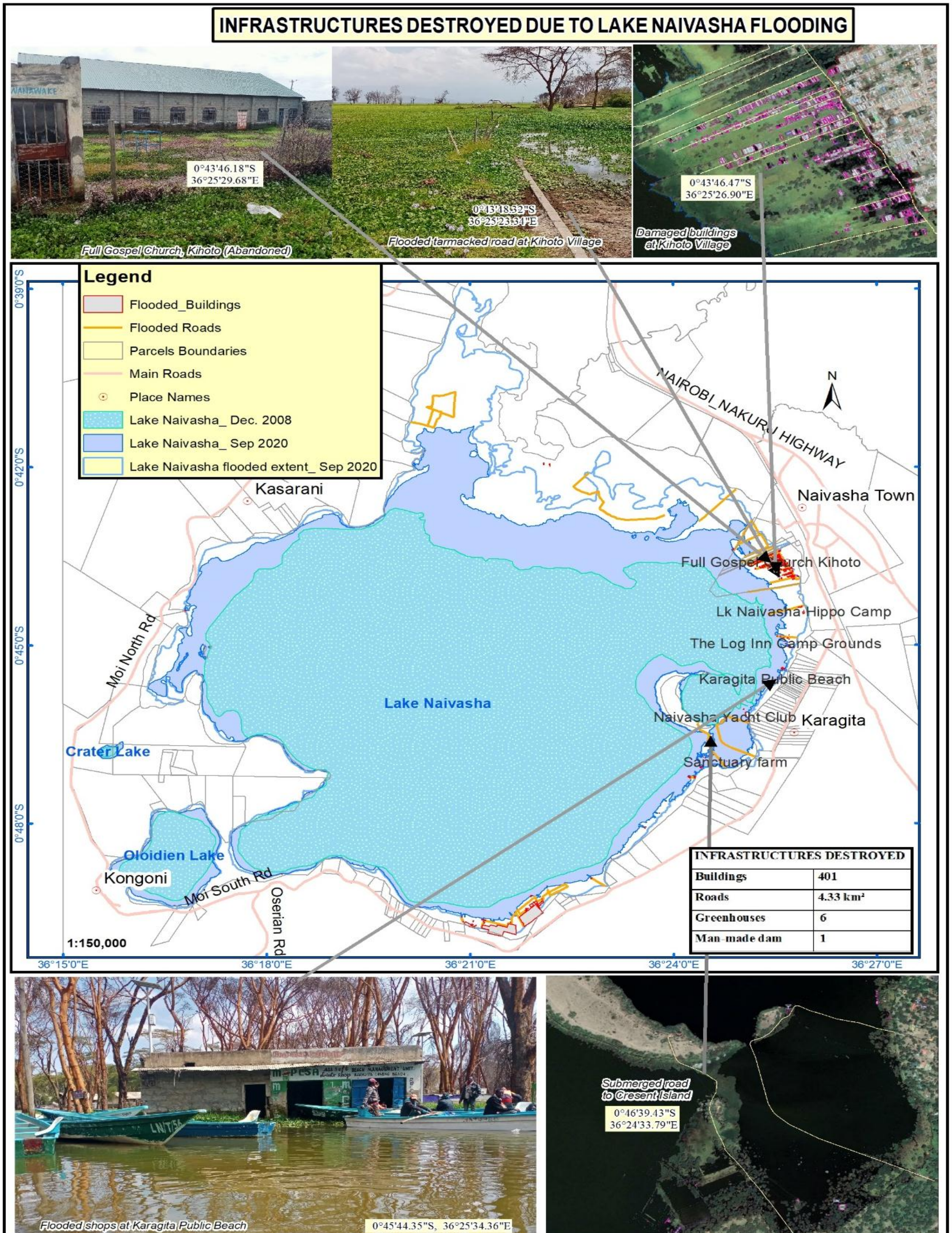

Figure 4.8: Buildings and roads destroyed as result of the lake level rise. Source: Google Earth and field photograph 23.09.2020

4.4 Effect of water level rise on the well-being of affected persons

To assess the effect of water level rise on the well-being of the affected persons, a total number of 17 institutions and 81 households were interviewed. The key issues identified include the loss suffered for example due to structure, crop or livelihood destruction such as dislocation from homes and loss of earning in monetary form (Figure 4.9). The monetary loss suffered for instance due to structures and crop destruction, income or livelihood was used as the variable for determining the wellbeing change of the affected, beside health and psychosocial impacts. The incidents of times the residents experienced human-wildlife conflicts was also assessed. The most affected are Kihoto residents West of Kenya Oil Pipeline; being low-income class and the area being overpopulated. Due their plight, they have petitioned (GoK, 2021) the government for consideration. Table 4.2 is a summary of the effects that were highlighted.

Table 4.2: Effects and recommendations that were highlighted by institutional respondents

INSTITUTION	EFFECT & RECCOMENDATIONS
- Kihoto United Homeowners Self Help Group	- 500 Kihoto residents displaced - Homes, rental houses, business premises, churches and schools damaged beyond re-occupation by the water level rise - Loss of jobs and livelihood for those who relied on affected rental houses and small businesses such shops, water vending and groceries, also because of displacement of people - Has caused a lot of psycho-social related ailments culminating in rising stress levels and the unfortunate deaths of 3 members and hospitalization of many others. - Wild animals such as hippos and buffalos straying to the unaffected fields and homes in the rest of the estate causing fear and anxiety to the residents. Some individuals have fallen prey to the wildlife's attacks - Pollution as pit latrines, septic pits waste mix with the flooding water has led to rise of waterborne diseases - Some livestock were swept away by the flood - Recommended resettlement of the affected or government to repossess the affected lands and compensate the owners with

	alternative land and erection of barrier to minimize cases of human-wildlife conflict as well as hastened compensation of individual falling prey to the wildlife
WRA & LANAWRUA	- 75 water intakes and canals relocated to higher grounds and some submerged - Pump houses flooded and also transformers had to be relocated to higher grounds - Recommended enforcement of the Lake Naivasha Catchment Area Protection Order, 2012 and sustainable management of the lake and the catchment through continuously increasing the tree cover, controlling sediment and protection of lake water from pollutants
LNRA	- Rise in insecurity, vandalism, burglary of flooded hotels, farms and homes, since fences on the lakeside are submerged. Fixtures such as windows and doors have been vandalized and stolen - Destruction of homes, churches, schools, homes, shops, greenhouses and other structures by the flood water - Harmful chemicals such as pesticides from the flooded farms and structures mixed with lake water - Reduced riparian land - Toppled and drying trees - Destruction of farm produce - Roads flooded and no longer usable
Karagita Public Beach	- Sand beach submerged - Playfield submerged - Fish landing site submerged, thus fishermen falsely occupying adjacent private lands - Flooded shops, premises, toilets and department of fisheries' office. - Recommendation that the government consider buying land on riparian area to tie it to the beach entrance road
Kamere Public Beach	- Buildings and structures flooded - Displaced to neighboring private land - In 2016/2017, lake partly blocked by water hyacinth
Kasarani / Tarabete Public Beach	- Submerged stalls

Banda / Central Landing Public	- Relocated to adjacent higher level grounds - Submerged buildings and stalls
Lake Naivasha Boat Owners	- Loss of livelihood as a result of decline in number of tourists visiting the beaches for boat riding
KWS	- Destruction of breeding sites for mammals and birds - Destruction of wildlife grazing areas and displacement of wildlife, causing wildlife-human conflict - Increasing poaching of impalas and dik-diks
Kenya Power	- Destruction of electricity lines, transformers and others vandalized - Flooded electric poles

4.4.1 Affected Households and Farmland

The study targeted 100 household respondents, of which a response rate of 81% was achieved. Respondents were 62% males and 38% females, meaning that there are more males than females in the area. The majority of the respondents were aged between 18 - 34 years (48%) and 35 - 50 years (44%), while those 51 years and above were 5%; which shows the majority in the area are youths. Only few have stayed in this area for more than 20 years (4%), 39% having stayed for 11-20 years, 34% for 6-10 years and 23% for 5 years and below.

Out of 81 respondents, 3 were not affected by the lake water level rise; the most affected area was the earning by 44%, buildings that included business stalls 18%, farmland 17%, flooded land 13% and 8% being the affected in regard to their health. Most of the earners are low income, with most earning less than Kshs.10, 000 (49%), Kshs. 10,000 to Kshs.100, 000 are 35%, and above Kshs. 100,000 are16%.

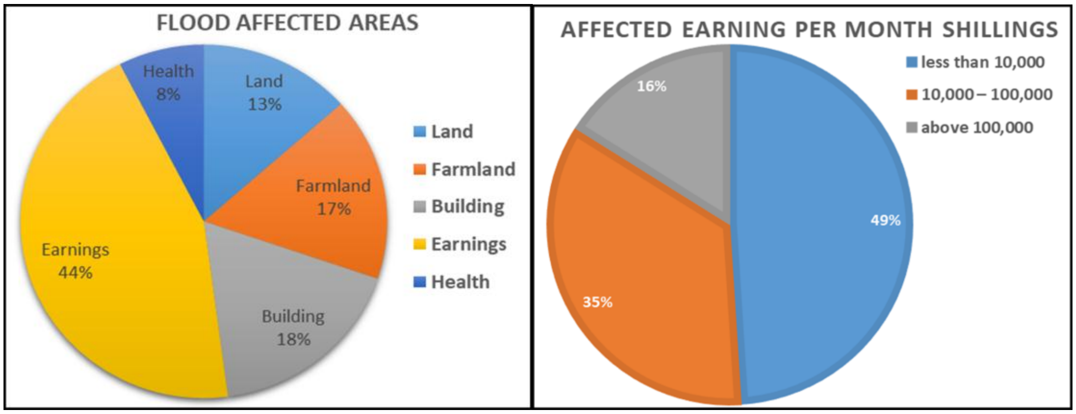

Figure 4.9: Affected percentages and the affected earnings per month for Lake Naivasha's households. Source: Field survey 23.09.2020.

Most of the flooded land (46%) was less than eighth of an acre, between 1/4 to1 acre being 37% and above one acre being 17%. Most of the affected were Kihoto residents, who own less than 1/8 acre. The percentage acreage of the flooded farmland included 7 % of less than 1/8, 11% of one acre and above, the bigger portions being 82% of 1/4 to1 acre.

Table 1.3: Proportions of the flooded land and farmland Source: Field survey 23.09.2020

Range	**Flooded land %**	**Farmland %**
less than 1/8 acre	46	7
1/4 to1 acre	37	82
Above 1 acre	17	11

Most of the damaged structures (68%) were worth 1 million to 5million Kenya Shillings, followed by 21% of Ksh. 100, 000 to 1million, 5 million and above being 7% and less than Ksh. 100,000 Kenya shillings being 4%. High Blood Pressure, typhoid, diarrhea, cholera, stress, depression, and headache were the sicknesses named by the respondents. Only 1% knew somebody who had experienced attack as a result of wildlife straying due to flood. Forty-two percent of the flood victims had gotten assistance from well-wishers, NGOs and County Government in term of food, clothing's, finances and free medical checkup. Recommendations respondents gave toward the flooding and how it can be averted in future includes government resettlement, relocation of flood victims, more research to be done on cause of the water level rise, enforcement of policy and regulations, proper control of wildlife and establishment of quality emergency response.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The rationale behind this study was to determine the spread, losses and impacts of the flooding of the lake. This was achieved using free high resolution Google Earth historical imageries in addition to interviews and observation to gather data from the field. Answers to the research questions were reached, justifying their relevance.

The study results show that, 34.42Km^{2}of the dry land has been submerged under the lake, while the surface area of main lake and Lake Oloiden have increased from 123.016 Km^2 to 156.066 Km^2 and from 4.549 Km^2 to 5.819 Km^2 respectively. These results show quite good congruence with Maina, *et al*. (2018) study in 2016 that found the lake to have increased to 154.17 Km^2 and that of Oloiden 5.47 Km^2. Onywere, *et al*. (2013) results showed the lake area to have increased from 107.7 Km^2 in January 2010 to 169.9 km^2 in September 2013 which is reflected well in this study. The water level rose from 1884.12 msl in 2009 to 1891.43 msl in September 2020, which is in tandem with Herrnegger, *et al*. (2021) findings. The northern side and the northeastern side of the lake towards Gilgil River, especially Kihoto area were the most severely affected, since they sit on flood plain. These areas are predominantly flat and thus get inundated with just a few centimeters water level rise. Much of the southern and southwestern shores are cliffy and thus resulting to minimal inundation with the rise of the Lake. Crater Lake's shores are also very steep thus has minimal water rise.

Vegetation on land lost to water, covering 29.01 km^{2}has also vanished much of it being wildlife habitat and agricultural crop, 362 trees were toppled and 2112 trees in the process of drying for being waterlogged, most of it being they yellow fever acacia variety. The findings are in line with Onywere, *et al*. (2013), whereby papyrus and yellow fever acacia constituted most of the submerged vegetation. From the study, 500 homeowners have been displaced, lost livelihood, 40 are sick, confused, stressed, and uncertain of future and as result 3 deaths were reported. These residents have suffered loss in terms of buildings being unusable and some vandalized, lost source of incomes from rental houses and places of work such as beaches and shops destroyed, some lost livestock and farm crops to the flood. The flooding has caused wildlife-human conflict as a result of destruction of dryland wildlife habitat and also, they fear outbreak of water borne diseases as a result of flooded pit latrines. In total, infrastructures that have been destroyed or rendered unusable were found to be409 single houses and block buildings as well as 35.936 kilometers of either tarmacked, loose surface roads or tracks found to be no longer usable since they were submerged, water pooled or impassable. Apart from Kihoto Village residential, hotels were the most affected which has significantly impacted tourism. Seventy-five water intakes had to be relocated to higher grounds thus power lines and transformers supplying power were also affected. These resources were severely disrupted by the flooding, some hotels and camping sites had to indefinitely close while some relocated since their facilities were totally submerged.

5.2 Recommendations

In consideration of these research findings and in order to avoid further occurrences of the effects experienced as result of the lake water rise, policies, such as The Lake Naivasha Catchment Area Protection Order 2012, should be enforced. This will prohibit cultivation, clearing of indigenous trees or other vegetation, building of permanent structures, developing of greenhouses and tunnels within the lake’s riparian land. New high water mark should also be delineated to define boundaries around the lake and also issue regulations on land use to avoid further degradation in the area. The government should consider repossessing the affected flooded land especially Kihoto Village, to be part of the lake riparian and compensate or resettle the affected home and landowners on alternative land. With rise of the lake level the public beaches that sit on riparian land have been reclaimed by the lake, thus the government should consider buying land on a higher level, adjacent to public beach entrances. The number of acacia trees toppled and others in the process of drying is big and replanting exercises should be expedited. Further study on impact of the flooding to the biodiversity as well as a research on health implications related to the pollution of the lake as a result of the water level rise is recommended.

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Appendix I: Household Questionnaires

1. Name of the locality/area

   …………………………………………….................................

2. Gender: (a) Male (b) Female

3. Age:*(a)* 18 - 34 years *(b)*35 - 50 years*(c)*51 –& above

4. For how long have you lived in this area?

   (a) 5 years & below *(b)*6 – 10 years*(c)*11 – 20 years *(d)*21 & above

5. Were you affected by the flooding / Lake water level rise?

   (a) Yes (*b)* No

   If yes, in which areas were you affected (losses incurred)?

   (i) Acreage of land flooded………………………Acres

   (a) less than 1/8 acre(b)1/8 - 1acre(c)above 1 acre

   (ii) Acreage of farmland flooded………………………Acres

   (a) less than 1/8 (b) 1/8 to1 acre (c) above 1 acre

   (iii) Building / structure damaged, worth ...………………. Ksh.

   (a) less than Ksh. 100,000
   (b) Ksh. 100,000 toKsh.1million
   (c) Ksh.1million toKsh. 5million(d) Ksh. 5million and above

   (iv) Employment earnings per month lost …………………. Ksh

   (a) less than Ksh. 10,000
   (b) Ksh. 10,000 toKsh. 100,000
   (c) above Ksh. 100,000

(v) Health wise; name the sickness:

....

6. How many people you know have experienced attack as a result of wildlife straying?

....

7. Have you received any assistance because of being affected by the flooding?

   (a) Yes *(b)* No

   If yes, what kind of assistance and from whom,

   explain?…………………………………………………………………………………

   ……………………………………………………………………………………………

   ……...............................

8. What is your recommendation on solution towards averting losses or lake level rise?...

   ...

Appendix II: Key Informants Interview Question Guide

1. Name of the locality/area
   …………………………………………….................................
2. Name of the representation e.g., Community leader, professional, administrative, resident etc.
   ……………………………………………….............................……….......................
   .
3. Title of the respondent
   ………………………..
4. In your view, how many people related to your institution were affected by the lake water level rise from December 2008 to September 2020?
   ....
5. What are the losses/ effect experienced as a result of the lake water level rise?
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………..
6. Which policies, strategies and legal framework that should be enforced to avert future effects of Lake Naivasha water level rise?
   Policies
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ……………...
   Strategies
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ……………...
   Legal framework
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ……………...
7. What are your recommendations as solution towards the water rise and how it can be averted in future?

....

....

Appendix III: Monthly Averages of Daily Lake Levels

			(1932 to 1973)										
Jan-32	1890.98	Jan-38	1889.57	Jan-44	1885.43	Jan-50	1884.79	Jan-56	1885.31	Jan-62	1887.82	Jan-68	1888.87
Feb-32	1890.98	Feb-38	1889.46	Feb-44	1885.35	Feb-50	1884.77	Feb-56	1885.27	Feb-62	1888.17	Feb-68	1888.81
Mar-32	1890.98	Mar-38	1889.34	Mar-44	1885.30	Mar-50	1884.68	Mar-56	1885.28	Mar-62	1888.05	Mar-68	1888.72
Apr-32	1890.98	Apr-38	1889.24	Apr-44	1885.25	Apr-50	1884.64	Apr-56	1885.45	Apr-62	1887.89	Apr-68	1888.59
May-32	1890.98	May-38	1889.14	May-44	1885.20	May-50	1884.69	May-56	1885.53	May-62	1887.81	May-68	1889.75
Jun-32	1890.89	Jun-38	1889.04	Jun-44	1885.20	Jun-50	1884.82	Jun-56	1885.61	Jun-62	1888.15	Jun-68	1889.80
Jul-32	1890.86	Jul-38	1888.96	Jul-44	1885.19	Jul-50	1884.95	Jul-56	1885.82	Jul-62	1888.17	Jul-68	1889.82
Aug-32	1890.83	Aug-38	1888.92	Aug-44	1885.18	Aug-50	1884.93	Aug-56	1886.13	Aug-62	1888.15	Aug-68	1889.75
Sep-32	1890.86	Sep-38	1888.88	Sep-44	1885.02	Sep-50	1884.85	Sep-56	1886.24	Sep-62	1888.21	Sep-68	1889.81
Oct-32	1890.83	Oct-38	1888.82	Oct-44	1884.81	Oct-50	1884.72	Oct-56	1886.23	Oct-62	1888.42	Oct-68	1889.79
Nov-32	1890.77	Nov-38	1888.69	Nov-44	1884.70	Nov-50	1884.62	Nov-56	1886.13	Nov-62	1888.59	Nov-68	1889.75
Dec-32	1890.67	Dec-38	1888.55	Dec-44	1884.62	Dec-50	1884.50	Dec-56	1886.03	Dec-62	1888.59	Dec-68	1889.75
Jan-33	1890.55	Jan-39	1888.43	Jan-45	1884.59	Jan-51	1884.56	Jan-57	1885.92	Jan-63	1888.52	Jan-69	1889.69
Feb-33	1890.49	Feb-39	1888.35	Feb-45	1884.61	Feb-51	1885.05	Feb-57	1885.86	Feb-63	1888.45	Feb-69	1889.61
Mar-33	1890.37	Mar-39	1888.28	Mar-45	1884.61	Mar-51	1885.28	Mar-57	1885.95	Mar-63	1888.40	Mar-69	1889.56
Apr-33	1890.22	Apr-39	1888.15	Apr-45	1884.63	Apr-51	1885.47	Apr-57	1886.13	Apr-63	1888.38	Apr-69	1889.48
May-33	1890.16	May-39	1888.01	May-45	1884.86	May-51	1885.51	May-57	1886.37	May-63	1888.59	May-69	1889.50
Jun-33	1890.06	Jun-39	1887.92	Jun-45	1885.07	Jun-51	1885.66	Jun-57	1886.50	Jun-63	1889.00	Jun-69	1889.45
Jul-33	1890.06	Jul-39	1887.85	Jul-45	1885.03	Jul-51	1885.82	Jul-57	1886.63	Jul-63	1889.36	Jul-69	1889.32
Aug-33	1890.06	Aug-39	1887.72	Aug-45	1884.97	Aug-51	1885.88	Aug-57	1886.73	Aug-63	1889.31	Aug-69	1889.12
Sep-33	1890.06	Sep-39	1887.60	Sep-45	1884.90	Sep-51	1885.99	Sep-57	1886.68	Sep-63	1889.19	Sep-69	1889.11
Oct-33	1890.06	Oct-39	1887.45	Oct-45	1884.84	Oct-51	1886.15	Oct-57	1886.59	Oct-63	1889.20	Oct-69	1889.01
Nov-33	1890.10	Nov-39	1887.25	Nov-45	1884.72	Nov-51	1886.19	Nov-57	1886.51	Nov-63	1889.12	Nov-69	1888.91
Dec-33	1890.10	Dec-39	1887.12	Dec-45	1884.57	Dec-51	1886.09	Dec-57	1886.49	Dec-63	1889.07	Dec-69	1888.86
Jan-34	1889.82	Jan-40	1887.06	Jan-46	1884.39	Jan-52	1885.98	Jan-58	1886.47	Jan-64	1889.43	01-Jan	1888.79
Feb-34	1889.59	Feb-40	1887.02	Feb-46	1884.26	Feb-52	1885.85	Feb-58	1886.46	Feb-64	1889.52	Feb-70	1888.74
Mar-34	1889.52	Mar-40	1887.26	Mar-46	1884.43	Mar-52	1885.74	Mar-58	1886.45	Mar-64	1889.39	Mar-70	1888.63
Apr-34	1889.44	Apr-40	1887.47	Apr-46	1884.44	Apr-52	1886.01	Apr-58	1886.53	Apr-64	1889.33	Apr-70	1888.72
May-34	1889.36	May-40	1887.38	May-46	1884.46	May-52	1885.93	May-58	1886.73	May-64	1889.52	May-70	1888.90
Jun-34	1889.29	Jun-40	1887.25	Jun-46	1884.62	Jun-52	1885.87	Jun-58	1887.07	Jun-64	1889.62	Jun-70	1888.99
Jul-34	1889.21	Jul-40	1887.14	Jul-46	1884.86	Jul-52	1885.87	Jul-58	1887.33	Jul-64	1889.61	Jul-70	1889.03
Aug-34	1889.13	Aug-40	1886.99	Aug-46	1884.89	Aug-52	1885.86	Aug-58	1887.40	Aug-64	1889.61	Aug-70	1888.99
Sep-34	1889.06	Sep-40	1886.79	Sep-46	1884.91	Sep-52	1885.81	Sep-58	1887.39	Sep-64	1889.72	Sep-70	1889.07
Oct-34	1888.98	Oct-40	1886.69	Oct-46	1884.85	Oct-52	1885.71	Oct-58	1887.36	Oct-64	1889.88	Oct-70	1889.15
Nov-34	1888.91	Nov-40	1886.56	Nov-46	1884.79	Nov-52	1885.58	Nov-58	1887.28	Nov-64	1890.07	Nov-70	1889.12
Dec-34	1888.84	Dec-40	1886.43	Dec-46	1884.78	Dec-52	1885.40	Dec-58	1887.25	Dec-64	1890.22	Dec-70	1889.03
Jan-35	1888.78	Jan-41	1886.64	Jan-47	1884.97	Jan-53	1885.23	Jan-59	1887.14	Jan-65	1890.16	Jan-71	1888.89
Feb-35	1888.72	Feb-41	1886.89	Feb-47	1885.58	Feb-53	1885.14	Feb-59	1887.02	Feb-65	1890.08	Feb-71	1888.78
Mar-35	1888.65	Mar-41	1886.88	Mar-47	1886.29	Mar-53	1885.08	Mar-59	1886.95	Mar-65	1890.01	Mar-71	1888.61
Apr-35	1888.57	Apr-41	1886.83	Apr-47	1886.48	Apr-53	1885.01	Apr-59	1886.88	Apr-65	1889.91	Apr-71	1888.50
May-35	1888.50	May-41	1886.82	May-47	1886.58	May-53	1884.99	May-59	1886.86	May-65	1889.77	May-71	1888.50
Jun-35	1888.44	Jun-41	1886.79	Jun-47	1886.66	Jun-53	1884.94	Jun-59	1886.85	Jun-65	1889.71	Jun-71	1888.61
Jul-35	1888.38	Jul-41	1886.75	Jul-47	1886.55	Jul-5.3	1884.84	Jul-59	1886.73	Jul-65	1889.76	Jul-71	1888.72
Aug-35	1888.32	Aug-41	1886.71	Aug-47	1886.48	Aug-53	1884.74	Aug-59	1886.73	Aug-65	1889.68	Aug-71	1888.89
Sep-35	1888.28	Sep-41	1886.66	Sep-47	1886.47	Sep-53	1884.70	Sep-59	1886.74	Sep-65	1889.60	Sep-71	1889.23
Oct-35	1888.25	Oct-41	1886.60	Oct-47	1886.37	Oct-53	1884.69	Oct-59	1886.72	Oct-65	1889.53	Oct-71	1889.21
Nov-35	1888.21	Nov-41	1886.55	Nov-47	1886.18	Nov-53	1884.58	Nov-59	1886.66	Nov-65	1889.44	Nov-71	1889.21
Dec-35	1888.19	Dec-41	1886.50	Dec-47	1886.11	Dec-53	1884.42	Dec-59	1886.63	Dec-65	1889.34	Dec-71	1889.11
Jan-36	1888.18	Jan-42	1886.54	Jan-48	1886.02	Jan-54	1884.25	Mar-60	1886.55	Jan-66	1889.24	Jan-72	1889.04
Feb-36	1888.18	Feb-42	1886.78	Feb-48	1885.85	Feb-54	1884.25	Feb-60	1886.25	Feb-66	1889.14	Feb-72	1888.98
Mar-36	1888.27	Mar-42	1887.03	Mar-48	1885.83	Mar-54	1884.50	Mar-60	1886.05	Mar-66	1889.04	Mar-72	1888.90
Apr-36	1888.67	Apr-42	1887.26	Apr-48	1885.81	Apr-54	1884.83	Apr-60	1885.99	Apr-66	1888.94	Apr-72	1888.75
May-36	1888.75	May-42	1887.16	May-48	1885.88	May-54	1885.19	May-60	1885.92	May-66	1888.86	May-72	1888.66
Jun-36	1888.74	Jun-42	1887.20	Jun-48	1885.99	Jun-54	1885.32	Jun-60	1885.84	Jun-66	1888.94	Jun-72	1888.59
Jul-36	1888.73	Jul-42	1887.07	Jul-48	1886.04	Jul-54	1885.42	Jul-60	1885.92	Jul-66	1888.96	Jul-72	1888.57
Aug-36	1888.69	Aug-42	1886.87	Aug-48	1885.92	Aug-54	1885.48	Aug-60	1885.87	Aug-66	1888.90	Aug-72	1888.52
Sep-36	1888.65	Sep-42	1886.70	Sep-48	1885.85	Sep-54	1885.43	Sep-60	1885.91	Sep-66	1888.82	Sep-72	1888.51
Oct-36	1888.60	Oct-42	1886.63	Oct-48	1885.76	Oct-54	1885.37	Oct-60	1885.92	Oct-66	1888.83	Oct-72	1888.44
Nov-36	1888.51	Nov-42	1886.56	Nov-48	1885.63	Nov-54	1885.27	Nov-60	1885.95	Nov-66	1888.90	Nov-72	1888.50
Dec-36	1888.42	Dec-42	1886.47	Dec-48	1885.50	Dec-54	1885.17	Dec-60	1885.96	Dec-66	1888.89	Dec-72	1888.47
Jan-37	1888.31	Jan-43	1886.34	Jan-49	1885.39	Jan-55	1885.12	Jan-61	1885.85	Jan-67	1888.92	Jan-73	1888.38
Feb-37	1888.15	Feb-43	1886.24	Feb-49	1885.31	Feb-55	1885.01	Feb-61	1885.73	Feb-67	1888.83	Feb-73	1888.27
Mar-37	1888.31	Mar-43	1886.17	Mar-49	1885.27	Mar-55	1884.94	Mar-61	1885.60	Mar-67	1888.70	Mar-73	1888.16
Apr-37	1888.79	Apr-43	1886.09	Apr-49	1885.19	Apr-55	1884.90	Apr-61	1885.47	Apr-67	1888.57	Apr-73	1888.03
May-37	1889.15	May-43	1886.12	May-49	1885.19	May-55	1884.82	May-61	1885.38	May-67	1888.43	May-73	1887.95
Jun-37	1889.55	Jun-43	1886.15	Jun-49	1885.31	Jun-55	1884.75	Jun-61	1885.37	Jun-67	1888.54	Jun-73	1887.93
Jul-37	1889.95	Jul-43	1886.12	Jul-49	1885.34	Jul-55	1884.92	Jul-61	1885.29	Jul-67	1888.75	Jul-73	1887.85
Aug-37	1889.91	Aug-43	1886.05	Aug-49	1885.25	Aug-55	1885.12	Aug-61	1885.18	Aug-67	1888.85	Aug-73	1887.80
Sep-37	1889.78	Sep-43	1885.94	Sep-49	1885.16	Sep-55	1885.23	Sep-61	1885.15	Sep-67	1888.92	Sep-73	1887.80
Oct-37	1889.80	Oct-43	1885.82	Oct-49	1885.10	Oct-55	1885.18	Oct-61	1885.27	Oct-67	1888.94	Oct-73	1887.77
Nov-37	1889.81	Nov-43	1885.64	Nov-49	1884.94	Nov-55	1885.21	Nov-61	1885.86	Nov-67	1888.92	Nov-73	1887.73
Dec-37	1889.70	Dec-43	1885.53	Dec-49	1884.74	Dec-55	1885.29	Dec-61	1887.16	Dec-67	1888.89	Dec-73	1887.63

			(1974 to 2015)										
Jan-74	**1887.50**	Jan-80	**1889.32**	Jan-86	**1887.55**	Jan-92	**1887.28**	Jan-98	**1887.88**	Jan-'04	**1886.72**	Jan-10	**1884.82**
Feb-74	**1887.33**	Feb-80	**1889.20**	Feb-86	**1887.46**	Feb-92	**1887.16**	Feb-98	**1887.96**	Feb-'04	**1886.65**	Feb-10	**1884.62**
Mar-74	**1887.21**	Mar-80	**1889.09**	Mar-86	**1887.38**	Mar-92	**1887.03**	Mar-98	**1887.91**	Mar-'04	**1886.52**	Mar-10	**1884.90**
Apr-74	**1887.25**	Apr-80	**1888.98**	Apr-86	**1887.29**	Apr-92	**1886.90**	Apr-98	**1887.85**	Apr-'04	**1886.56**	Apr-10	**1885.26**
May-74	**1887.33**	May-80	**1889.13**	May-86	**1887.20**	May-92	**1886.77**	May-98	**1888.31**	May-'04	**1886.93**	May-10	**1886.08**
Jun-74	**1887.32**	Jun-80	**1889.28**	Jun-86	**1887.38**	Jun-92	**1886.64**	Jun-98	**1888.75**	Jun-'04	**1886.82**	Jun-10	**1886.38**
Jul-74	**1887.47**	Jul-80	**1889.33**	Jul-86	**1887.40**	Jul-92	**1886.77**	Jul-98	**1888.84**	Jul-'04	**1886.71**	Jul-10	**1886.36**
Aug-74	**1887.55**	Aug-80	**1889.20**	Aug-86	**1887.38**	Aug-92	**1886.91**	Aug-98	**1888.89**	Aug-'04	**1886.61**	Aug-10	**1886.33**
Sep-74	**1887.72**	Sep-80	**1889.08**	Sep-86	**1887.36**	Sep-92	**1887.04**	Sep-98	**1888.91**	Sep-'04	**1886.54**	Sep-10	**1886.64**
Oct-74	**1887.82**	Oct-80	**1888.93**	Oct-86	**1887.34**	Oct-92	**1887.18**	Oct-98	**1888.92**	Oct-'04	**1886.41**	Oct-10	**1886.82**
Nov-74	**1887.83**	Nov-80	**1888.88**	Nov-86	**1887.32**	Nov-92	**1887.32**	Nov-98	**1888.92**	Nov-'04	**1886.50**	Nov-10	**1887.04**
Dec-74	**1887.78**	Dec-80	**1888.82**	Dec-86	**1887.28**	Dec-92	**1887.45**	Dec-98	**1888.82**	Dec-'04	**1886.45**	Dec-10	**1886.90**
Jan-75	**1887.62**	Jan-81	**1888.67**	Jan-87	**1887.19**	Jan-93	**1887.56**	Jan-99	**1888.79**	Jan-'05	**1886.31**	Jan-11	**1886.76**
Feb-75	**1887.47**	Feb-81	**1888.53**	Feb-87	**1887.11**	Feb-93	**1887.48**	Feb-99	**1888.44**	Feb-'05	**1886.15**	Feb-11	**1886.62**
Mar-75	**1887.34**	Mar-81	**1888.37**	Mar-87	**1887.03**	Mar-93	**1887.40**	Mar-99	**1888.31**	Mar-'05	**1886.01**	Mar-11	**1886.38**
Apr-75	**1887.20**	Apr-81	**1888.63**	Apr-87	**1886.94**	Apr-93	**1887.32**	Apr-99	**1888.24**	Apr-'05	**1885.95**	Apr-11	**1886.35**
May-75	**1886.99**	May-81	**1889.04**	May-87	**1886.81**	May-93	**1887.24**	May-99	**1888.10**	May-'05	**1885.95**	May-11	**1886.19**
Jun-75	**1887.03**	Jun-81	**1889.23**	Jun-87	**1886.63**	Jun-93	**1887.16**	Jun-99	**1887.94**	Jun-'05	**1885.97**	Jun-11	**1886.08**
Jul-75	**1887.08**	Jul-81	**1889.25**	Jul-87	**1886.70**	Jul-93	**1887.08**	Jul-99	**1887.80**	Jul-'05	**1885.88**	Jul-11	**1886.10**
Aug-75	**1887.27**	Aug-81	**1889.56**	Aug-87	**1886.75**	Aug-93	**1887.00**	Aug-99	**1887.70**	Aug-'05	**1885.82**	Aug-11	**1886.08**
Sep-75	**1887.66**	Sep-81	**1889.64**	Sep-87	**1886.66**	Sep-93	**1886.92**	Sep-99	**1887.68**	Sep-'05	**1885.98**	Sep-11	**1886.97**
Oct-75	**1887.86**	Oct-81	**1889.65**	Oct-87	**1886.57**	Oct-93	**1886.84**	Oct-99	**1887.57**	Oct-'05	**1886.12**	Oct-11	**1886.99**
Nov-75	**1887.89**	Nov-81	**1889.59**	Nov-87	**1886.49**	Nov-93	**1886.76**	Nov-99	**1887.49**	Nov-'05	**1886.16**	Nov-11	**1887.29**
Dec-75	**1887.79**	Dec-81	**1889.54**	Dec-87	**1886.40**	Dec-93	**1886.54**	Dec-99	**1887.49**	Dec-'05	**1886.03**	Dec-11	**1887.97**
Jan-76	**1887.64**	Jan-82	**1889.53**	Jan-88	**1886.31**	Jan-94	**1886.50**	Jan-'00	**1887.34**	Jan-'06	**1885.84**	Jan-12	**1887.78**
Feb-76	**1887.49**	Feb-82	**1889.31**	Feb-88	**1886.23**	Feb-94	**1886.40**	Feb-'00	**1887.13**	Feb-'06	**1885.67**	Feb-12	**1887.52**
Mar-76	**1887.32**	Mar-82	**1889.04**	Mar-88	**1886.22**	Mar-94	**1886.23**	Mar-'00	**1886.93**	Mar-'06	**1885.62**	Mar-12	**1887.35**
Apr-76	**1887.16**	Apr-82	**1888.98**	Apr-88	**1886.38**	Apr-94	**1886.10**	Apr-'00	**1886.79**	Apr-'06	**1885.53**	Apr-12	**1887.16**
May-76	**1887.06**	May-82	**1889.01**	May-88	**1886.23**	May-94	**1886.10**	May-'00	**1886.69**	May-'06	**1885.92**	May-12	**1887.89**
Jun-76	**1887.00**	Jun-82	**1889.01**	Jun-88	**1886.21**	Jun-94	**1886.16**	Jun-'00	**1886.47**	Jun-'06	**1885.80**	Jun-12	**1888.16**
Jul-76	**1886.93**	Jul-82	**1888.95**	Jul-88	**1886.50**	Jul-94	**1886.40**	Jul-'00	**1886.35**	Jul-'06	**1885.73**	Jul-12	**1888.26**
Aug-76	**1886.82**	Aug-82	**1888.95**	Aug-88	**1886.75**	Aug-94	**1886.50**	Aug-'00	**1886.27**	Aug-'06	**1885.86**	Aug-12	**1888.35**
Sep-76	**1887.06**	Sep-82	**1888.89**	Sep-88	**1886.97**	Sep-94	**1886.60**	Sep-'00	**1886.20**	Sep-'06	**1885.83**	Sep-12	**1888.68**
Oct-76	**1886.87**	Oct-82	**1888.85**	Oct-88	**1887.19**	Oct-94	**1886.50**	Oct-'00	**1886.09**	Oct-'06	**1885.68**	Oct-12	**1888.76**
Nov-76	**1886.60**	Nov-82	**1888.89**	Nov-88	**1887.18**	Nov-94	**1886.50**	Nov-'00	**1886.08**	Nov-'06	**1885.87**	Nov-12	**1888.91**
Dec-76	**1886.73**	Dec-82	**1889.41**	Dec-88	**1887.17**	Dec-94	**1886.92**	Dec-'00	**1886.02**	Dec-'06	**1886.30**	Dec-12	**1888.81**
Jan-77	**1886.50**	Jan-83	**1889.35**	Jan-89	**1887.17**	Jan-95	**1886.80**	Jan-'01	**1886.01**	Jan-'07	**1886.48**	Jan-13	**1888.85**
Feb-77	**1886.34**	Feb-83	**1889.25**	Feb-89	**1887.16**	Feb-95	**1886.64**	Feb-'01	**1886.02**	Feb-'07	**1886.52**	Feb-13	**1888.62**
Mar-77	**1886.37**	Mar-83	**1889.18**	Mar-89	**1887.15**	Mar-95	**1886.40**	Mar-'01	**1885.87**	Mar-'07	**1886.28**	Mar-13	**1888.36**
Apr-77	**1886.53**	Apr-83	**1889.09**	Apr-89	**1886.89**	Apr-95	**1886.40**	Apr-'01	**1885.94**	Apr-'07	**1886.22**	Apr-13	**1888.89**
May-77	**1887.41**	May-83	**1889.00**	May-89	**1886.87**	May-95	**1886.47**	May-'01	**1886.15**	May-'07	**1886.11**	May-13	**1889.49**
Jun-77	**1887.62**	Jun-83	**1888.93**	Jun-89	**1886.84**	Jun-95	**1886.50**	Jun-'01	**1886.13**	Jun-'07	**1886.36**	Jun-13	**1889.31**
Jul-77	**1887.81**	Jul-83	**1888.92**	Jul-89	**1886.82**	Jul-95	**1886.51**	Jul-'01	**1886.15**	Jul-'07	**1886.42**	Jul-13	**1889.31**
Aug-77	**1888.02**	Aug-83	**1888.92**	Aug-89	**1886.80**	Aug-95	**1886.30**	Aug-'01	**1886.33**	Aug-'07	**1886.76**	Aug-13	**1889.32**
Sep-77	**1888.06**	Sep-83	**1888.97**	Sep-89	**1886.77**	Sep-95	**1886.30**	Sep-'01	**1886.39**	Sep-'07	**1886.82**	Sep-13	**1889.35**
Oct-77	**1887.95**	Oct-83	**1889.08**	Oct-89	**1886.75**	Oct-95	**1886.40**	Oct-'01	**1886.41**	Oct-'07	**1887.11**	Oct-13	**1889.38**
Nov-77	**1888.03**	Nov-83	**1889.19**	Nov-89	**1886.92**	Nov-95	**1886.45**	Nov-'01	**1886.50**	Nov-'07	**1886.99**	Nov-13	**1889.36**
Dec-77	**1888.26**	Dec-83	**1889.15**	Dec-89	**1887.13**	Dec-95	**1886.56**	Dec-'01	**1886.52**	Dec-'07	**1886.76**	Dec-13	**1889.49**
Jan-78	**1888.31**	Jan-84	**1889.09**	Jan-90	**1887.32**	Jan-96	**1886.50**	Jan-'02	**1886.42**	Jan-'08	**1886.63**	Jan-14	**1889.56**
Feb-78	**1888.29**	Feb-84	**1888.97**	Feb-90	**1887.48**	Feb-96	**1886.40**	Feb-'02	**1886.27**	Feb-'08	**1886.51**	Feb-14	**1889.42**
Mar-78	**1888.45**	Mar-84	**1888.79**	Mar-90	**1887.49**	Mar-96	**1886.30**	Mar-'02	**1886.16**	Mar-'08	**1886.33**	Mar-14	**1889.32**
Apr-78	**1888.96**	Apr-84	**1888.69**	Apr-90	**1887.60**	Apr-96	**1886.20**	Apr-'02	**1886.00**	Apr-'08	**1886.34**	Apr-14	**1889.23**
May-78	**1889.28**	May-84	**1888.37**	May-90	**1888.02**	May-96	**1886.07**	May-'02	**1886.66**	May-'08	**1886.30**	May-14	**1889.06**
Jun-78	**1889.16**	Jun-84	**1888.26**	Jun-90	**1888.43**	Jun-96	**1886.00**	Jun-'02	**1886.53**	Jun-'08	**1886.09**	Jun-14	**1888.91**
Jul-78	**1889.15**	Jul-84	**1888.14**	Jul-90	**1888.40**	Jul-96	**1886.10**	Jul-'02	**1886.40**	Jul-'08	**1886.70**	Jul-14	**1888.85**
Aug-78	**1889.20**	Aug-84	**1888.02**	Aug-90	**1888.35**	Aug-96	**1886.24**	Aug-'02	**1886.32**	Aug-'08	**1885.86**	Aug-14	**1888.82**
Sep-78	**1889.25**	Sep-84	**1887.91**	Sep-90	**1888.30**	Sep-96	**1886.30**	Sep-'02	**1886.21**	Sep-'08	**1885.85**	Sep-14	**1888.85**
Oct-78	**1889.42**	Oct-84	**1887.90**	Oct-90	**1888.25**	Oct-96	**1886.50**	Oct-'02	**1886.08**	Oct-'08	**1885.92**	Oct-14	**1888.76**
Nov-78	**1889.47**	Nov-84	**1887.88**	Nov-90	**1888.19**	Nov-96	**1886.50**	Nov-'02	**1886.09**	Nov-'08	**1885.97**	Nov-14	**1888.64**
Dec-78	**1889.44**	Dec-84	**1887.87**	Dec-90	**1888.14**	Dec-96	**1886.56**	Dec-'02	**1886.09**	Dec-'08	**1885.94**	Dec-14	**1888.58**
Jan-79	**1889.36**	Jan-85	**1887.76**	Jan-91	**1888.09**	Jan-97	**1886.50**	Jan-'03	**1886.32**	Jan-'09	**1885.81**	Jan-15	**1888.52**
Feb-79	**1889.52**	Feb-85	**1887.81**	Feb-91	**1888.04**	Feb-97	**1886.40**	Feb-'03	**1886.15**	Feb-'09	**1885.59**	Feb-15	**1888.34**
Mar-79	**1889.51**	Mar-85	**1887.57**	Mar-91	**1887.85**	Mar-97	**1886.30**	Mar-'03	**1885.94**	Mar-'09	**1885.44**	Mar-15	**1888.19**
Apr-79	**1889.57**	Apr-85	**1887.56**	Apr-91	**1887.66**	Apr-97	**1886.20**	Apr-'03	**1885.78**	Apr-'09	**1885.28**	Apr-15	**1888.07**
May-79	**1889.64**	May-85	**1887.61**	May-91	**1887.52**	May-97	**1886.21**	May-'03	**1886.56**	May-'09	**1885.12**	May-15	**1888.12**
Jun-79	**1889.73**	Jun-85	**1887.67**	Jun-91	**1887.44**	Jun-97	**1886.09**	Jun-'03	**1886.66**	Jun-'09	**1884.96**	Jun-15	**1888.45**
Jul-79	**1889.79**	Jul-85	**1887.72**	Jul-91	**1887.48**	Jul-97	**1886.06**	Jul-'03	**1886.65**	Jul-'09	**1884.80**	Jul-15	**1888.47**
Aug-79	**1889.79**	Aug-85	**1887.78**	Aug-91	**1887.53**	Aug-97	**1886.07**	Aug-'03	**1886.64**	Aug-'09	**1884.60**	Aug-15	**1888.37**
Sep-79	**1889.73**	Sep-85	**1887.83**	Sep-91	**1887.48**	Sep-97	**1885.97**	Sep-'03	**1886.97**	Sep-'09	**1884.44**	Sep-15	**1888.31**
Oct-79	**1889.61**	Oct-85	**1887.81**	Oct-91	**1887.43**	Oct-97	**1885.85**	Oct-'03	**1886.93**	Oct-'09	**1884.33**	Oct-15	**1888.20**
Nov-79	**1889.55**	Nov-85	**1887.72**	Nov-91	**1887.39**	Nov-97	**1885.80**	Nov-'03	**1886.92**	Nov-'09	**1884.30**	Nov-15	**1888.38**
Dec-79	**1889.46**	Dec-85	**1887.64**	Dec-91	**1887.34**	Dec-97	**1886.84**	Dec-'03	**1886.87**	Dec-'09	**1884.12**	Dec-15	**1888.91**

	2016 to 12 2020
Jan-16	**1889.04**
Feb-16	**1888.95**
Mar-16	**1888.78**
Apr-16	**1888.66**
May-16	**1888.95**
Jun-16	**1889.11**
Jul-16	**1889.16**
Aug-16	**1889.17**
Sep-16	**1889.09**
Oct-16	**1889.06**
Nov-16	**1888.96**
Dec-16	**1888.86**
Jan-17	**1888.66**
Feb-17	**1888.48**
Mar-17	**1888.30**
Apr-17	**1888.11**
May-17	**1888.00**
Jun-17	**1887.84**
Jul-17	**1887.78**
Aug-17	**1887.79**
Sep-17	**1887.88**
Oct-17	**1887.93**
Nov-17	**1888.04**
Dec-17	**1887.92**
Jan-18	**1887.68**
Feb-18	**1887.49**
Mar-18	**1887.50**
Apr-18	**1887.86**
May-18	**1888.93**
Jun-18	**1889.50**
Jul-18	**1889.50**
Aug-18	**1889.41**
Sep-18	**1889.39**
Oct-18	**1889.26**
Nov-18	**1889.17**
Dec-18	**1889.07**
Jan-19	**1888.94**
Feb-19	**1888.74**
Mar-19	**1889.26**
Apr-19	**1888.30**
May-19	**1888.22**
Jun-19	**1888.45**
Jul-19	**1888.39**
Aug-19	**1888.33**
Sep-19	**1888.36**
Oct-19	**1888.36**
Nov-19	**1888.47**
Dec-19	**1889.13**
Jan-20	**1889.45**
Feb-20	**1889.70**
Mar-20	**1889.68**
Apr-20	**1889.90**
May-20	**1891.01**
Jun-20	**1891.26**
Jul-20	**1891.38**
Aug-20	**1891.39**
Sep-20	**1891.44**
Oct-20	**1891.42**
Nov-20	**1891.53**
Dec-20	**1891.47**

Past high levels	
	m.a.s.l.
Nov 1983 = 3.93	**1889.19**
Dec 1982 = 4.15	**1889.41**
Oct 1981 = 4.39	**1889.65**
July 1979 = 4.53	**1889.79**
Jun 1968 = 4.56	**1889.82**
April 1965 = 4.65	**1889.91**
Dec 1964 = 4.96	**1890.22**
May 1932 = 5.72	**1890.98**
1906 = 7.54	**1892.80**
1917 = 10.24	**1895.50**

Key Colors scheme	
(green)	Highest months of each year
(red)	Lowest months of each year
xxxxx	Extremely highest months to be recorded for sometime
xxxxx	Extremely lowest months to be recorded for sometime