INFLUENCE OF WATER LEVEL VARIABILITY ON ECONOMIC ACTIVITIES AND ADAPTATION STRATEGIES IN LAKE NAIVASHA, KENYA

MENGICH MAIBA BRENDA

A Thesis Submitted to the Graduate School in Partial Fulfilment of the Requirements for the Master of Arts Degree in Geography of Egerton University

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DECLARATION AND RECOMMENDATION

Declaration

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

Signature…….. Date...11/09/2024……

Mengich Brenda Maiba

NM13/04056/22

Recommendation

This thesis has been submitted with our approval as University supervisors

Signature…….. Date…..…….

Dr. Amon M. Karanja, PhD

Department of Geography,

Masinde Muliro University of Science and Technology

Signature……. Date…..…….

Prof. George M. Ogendi, PhD

Department of Environmental Science,

Egerton University.

DEDICATION

This thesis is dedicated to my parents Mr. Simon Mengich Sisimwo and Mrs. Linet Chesang Ndiema for their sacrifice and resources to educate me. Receive much blessings from God.

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ABSTRACT

Lake Naivasha's fresh water provides multiple services to the surrounding communities, and to a large extent explains the dense population around it. The lake is a Ramsar site and an important Bird Area, which has been experiencing a water variation cycle over the years causing direct and indirect effects on fishing, agriculture and tourism. Variation in water levels leads to flooding, and receding which has disrupted the ecology, functions and ecosystem services of Lake Naivasha. This study was conceptualised to: analyse the spatial and temporal variation of water levels between 1992 and 2022; determine the economic effects of water level variability; assess the adaptation strategies to water variability; and to establish a relationship between Surface area water level variability and fish yield and revenue in Lake Naivasha. The theoretical frameworks were based on the Socio-Environmental theory and the Drivers, Pressures, State, Impact and Response model. The study adopted a cross sectional research design. A Semi-Structured questionnaire was administered on a sample of 197 water users drawn from the fishing, agriculture and tourism sectors. Secondary data was collected using Landsat images that provided the temporal and spatial level of water variability and documentary analysis for the period 1992 and 2022. Satellite images was used to analyse the spatial and temporal variation of water levels between 1992 and 2022. Descriptive statistics, and inferential statistics were used for data analysis. The results indicated that there was a positive correlation between Surface area Variability and fish yield ($r= 0.6261$, $R^2= 0.3920$) and Fish revenue ($r= 0.5219$, $R^2= 0.2724$). Surface area variability explained 39% and 27% of the variation in total fish yield and fish revenue respectively. The study findings indicate that significant increase in water levels led to a 52% decline in the number of tourists thus affecting negatively the tourism and hospitality industry. On the other hand lake level increase led to a 45% increase in horticulture yields and reduction in lake water levels led to a 59% reduction in horticulture yields. In terms of adaptation measures to extremes in water variability, reduction of the household budget ranked highest among the households dependent on fishing with a mean of 3.47, while income diversification was the most preferred by tourism and hospitality industry workers (2.28), and horticulture workers (3.14). The study concludes that the selected economic activities were affected by water level variability. Therefore, there is need for continuous monitoring and surveillance of the lake level, and water quality by the relevant government agencies. This study recommends that the economic sectors should embrace the Lake Naivasha Water Basin allocation plan, as well as watershed management and conservation measures for the sustainability of this freshwater body.

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LIST OF ABBREVIATIONS AND ACRONYMS

ASAL	Arid and Semi-Arid Land
AEZ	Agro-Ecological Zones
BMC	Beach Management Committee
BMU	Beach Management Unit
C2L2	Collection 2 Level 2
CIDP	County Integrated Development Plan
ENSO	El Niño–Southern Oscillation
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
FBP	Flower Business Park
FD	Fisheries Department
GDP	Gross Domestic Product
GIS	Geographic Information System
GoK	Government of Kenya
HCDA	Horticultural Crops Development Authority
IBS	Important Bird Areas
ILO	International Labour Organization
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter Tropical Convergence Zone
KFC	Kenya Flower Council
Km^2	Kilometres square
KMD	Kenya Meteorological Department
KMFRI	Kenya Marine and Fisheries Research Institute
KNBS	Kenya National Bureau of Statistics
KRCS	Kenya Red Cross Society
KES	Kenya Shillings
KWS	Kenya Wildlife Service
LaNaWRUA	Lake Naivasha Water Resources Users Association
LNGG	Lake Naivasha Growers Group
LNRA	Lake Naivasha Riparian Association
LULCC	Land Use Land Cover Changes
m.a.s.l	Meters above sea level
Mil.	Millions

NACOSTI	National Commission for Science, Technology and Innovation
NEMA	National Environmental Management Authority
SAV	Surface Area Variability
SDGs	Sustainable Development Goals
TM	Thematic Mapper
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
US$	United States Dollar
USGS	United States Geological Survey
WLV	Water Level Variation
WRA	Water Resource Authority
WRMA	Water Resources Management Authority
WWF	World Wide Fund for Nature

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Globally, water resources have been affected by both anthropogenic and natural factors (Herrnegger *et al.,* 2021). Various anthropogenic activities such as agricultural operations, dam constructions and landscape modification are linked to variations in water levels of water bodies (Yuan *et al.,* 2015). Natural factors including climate and geological controls contribute to changes in water levels in aquatic ecosystems (Tawfeeq & Atasever, 2023). According to the Intergovernmental Panel on Climate Change (IPCC) report of 2023, human influence has caused variation in the average global rate of sea level change. Also, changes in patterns of temperature and precipitation recorded globally are mainly due to human activities (Jeppesen *et al.,* 2015). Over the years, there have been variations in lakes worldwide attracting global attention (Yuan *et al.,* 2015). Water volume in Lake Qinghai the largest closed basin in China decreased by 9.48 km^3 from 1975 to 2004 and increased by 15.18 km^3 from 2005 to 2020 (Yang *et al.,* 2022).

The distribution of freshwater systems in Africa is characterised by variation of water surface depending on the catchment hydrology (Papa *et al.*, 2023). Rainfall patterns in Africa are mainly influenced by El Nino Southern Oscillation (ENSO) in the tropical Pacific which vary extremely, exhibiting different scales of spatial and temporal variation therefore causing either extreme floods or drought (Muringai *et al.,* 2022). In sub-Saharan Africa, the majority of water resources support local economies and inland lakes are centres of blue economy through; fishing, agriculture, wildlife and tourism (Herrnegger *et al.,* 2021).

Lakes together with their wetlands provide valuable resources which have important roles such as climate modification, water quality regulation and provision of food to humans as well as other living organisms (Barasa & Wanyama, 2020). Lakes have various positive impacts ranging from environmental benefits to economic support especially for low-income families (Tawfeeq & Atasever, 2023). Inland lakes have exceptional universal values and therefore are considered as United Nations Educational Scientific and Cultural Organisation (UNESCO) World Heritage Sites, Ramsar sites and Important Bird Areas (IBS) (Barasa & Wanyama, 2020). Lake Naivasha's fresh water provides multiple services to the surrounding communities, and to a large extent explains the dense population around it. This lake that is a Ramsar site, and an Important Bird Area, has been experiencing a water variation cycle over the years and thus causing direct and indirect effects on fishing, agriculture and tourism.

The unique East African basin lakes are regarded as sensitive to change in hydro-climatic conditions (Odongo *et al.,* 2015). In 2019, the October- November- December rains were regarded as the highest in East Africa resulting in massive floods and landslides across the region (Wainwright *et al.,* 2021). Variations in Spatial and temporal water levels can result to changes in ecological, economic and hydrological consequences (Barasa & Wanyama, 2020). The anomalous precipitation has been extending due to frequent climate change causing soil saturation and further flooding (Wainwright *et al.,* 2021). Lake Beseka a volcanic lava dam in the Ethiopian Rift increased from 3 km^2 since 1960s to 40 km^2 causing detrimental effect on the surrounding hydrological and physical environment. The lake expanded to infrastructures such as the roads and railway that were once located far from its northern shore (Ayenew & Legesse, 2007).

The Eastern Rift Valley in Kenya has a series of lakes which were on the rise as from 2010 causing negative effects on the surrounding communities (Herrnegger *et al.,* 2021). Among the lakes that have been rising in the Eastern Rift Valley are Lakes Naivasha, Nakuru, Bogoria and Baringo. Lake Naivasha and Baringo are freshwater lakes while the rest have saline and alkaline waters. Increasing water levels in the geologically active terrain is changing the composition of water quality and quantity (Costa *et al.,* 2021). The ecology, salinity and lake water levels may change due to inflows and in-stream flow leading to an increase in sedimentation as well as nutrients downstream (Odongo *et al.,* 2015). Lake level rising results in floods which cause ecosystem degradation, wildlife dislocation as well as destruction of property and loss of lives. Water levels in lake Baringo increased from 143.6 km^2 in 2010 to a high level of 231.6 km^2 in 2013 disrupting a huge human dependency on economic activities and destroying critical infrastructure (Victor *et al.,* 2023).

Lake Naivasha has been experiencing an increase in economic activity since 1980s and high water demand (Odongo *et al.,* 2015). Lake Naivasha was declared a Ramsar site in 1995 after lake Nakuru (Maina *et al.,* 2018). Lake Naivasha's existence is a key component for profitability of the Kenyan economy as it is greatly valued for its reliable freshwater. The lake supports agro-based industrial economies such as horticulture farms, pastoralism, fisheries as well as geothermal industries. Also, the lake's water resource supports a variety of wildlife including bird species that live in the riparian zone and also has unique habitats such as Crescent Island (Maina *et al.,* 2018). Apart from the provisioning, regulating and supporting services Lake Naivasha provides high values of recreational and educational services and as a result, it is a tourist destination. Consequently the population in Naivasha town has more than doubled rising from 160,000 people in 1999 to 355,383 in 2019 (KNBS, 2019). The population growth is as a result of growth in the fishing, tourism and horticulture sectors that have created employment for thousands of workers.

The increased human population is slowly but steadily putting pressure on local water resources (Walker *et al.,* 2022). Such pressure is likely to affect various economic activities that are dependent on this freshwater body.

Lake Naivasha has a long history of water level fluctuations, the lowest was recorded in 1946 (1882.0 m.a.s.l), an increase in 1997 (1888.9 m.a.s.l) due to heavy rains and a large El Niño event and in 2019, the lake reached its ever highest level (Walker *et al.,* 2022). Awange *et al.* (2013) reported that Lake Naivasha water level dropped by 1.92 m from 2000 to 2006 and 1.38 m from 2006 to 2010. The water level reductions were as a result of evaporation, water abstraction and seepage which create dry land for more anthropogenic activities.

Despite the location of Lake Naivasha at the highest point in the Kenyan Rift valley it is still a flood risk. The rising water levels along the shores of lake Naivasha resulted in submergence of land, interfering with economic activities such as agriculture, tourism and fishing (Muita *et al.,* 2021). Furthermore, there were reported cases of human-wildlife conflicts due to displacement by water exposing both human and wildlife to loss of life. Human beings have generated suitable actions during catastrophic events to reduce vulnerability. Communities strive to minimise and mitigate flood impacts through flood adaptation actions that increases their resilience to risks (Alfieri *et al.,* 2015).

Water variability is affected by many factors including geographical location and level of preparedness. In developing countries, disaster management activities are poor and as a result, areas prone to flooding witness great destruction and damage to property and infrastructure as well as loss of human lives (Barasa & Wanyama, 2020). For instance, in East Africa the population has high levels of exposure and vulnerability to climate and weather extremes (Kilavi *et al.,* 2018). The prolonged La Niña drought of 2009 in conjunction with the over exploitation led to receding water level in Lake Naivasha causing ecological degradation (Harper *et al.,* 2011). Such variations in water levels in Lake Naivasha are likely to affect the different water users in the agriculture, fisheries and tourism sectors. Therefore, there was a need to assess the effects of rising and receding water levels on the various economic sectors around Lake Naivasha. It was also necessary to study the different adaptation strategies that were employed by the local communities to cope with the changes in water levels. Knowledge on Lake Naivasha water variability plays a key role in adopting critical mitigation and adaptation strategies in managing changes associated with rising and receding water levels. Furthermore, understanding these dynamics is essential for developing sustainable management practices that enhance livelihoods and environmental health in Lake Naivasha area.

1.2 Statement of the Problem

Water levels in Lake Naivasha have fluctuated over time, either receding in size causing a retraction or water levels rising causing floods. The lake has experienced numerous unprecedented pressures such as excess withdrawal of water and unsustainable resources management practices from different water users resulting in water variation. Agriculture, Fishing, Geothermal power generation, tourism and hospitality industry are some of the various economic activities practiced around Lake Naivasha. During the prolonged dry season of 2000 to 2009, Lake Naivasha watershed suffered from water variation due to human-induced land use changes and other factors such as evaporation, climate change and fluctuation of groundwater level among others. This decline irreversibly affected agriculture and fisheries. Nakuru 2018-2022 CIDP, records that flooding of the lake resulted in displacement of people, submerging of facilities and disruption of activities. The rising and receding water levels affect the economic activities in Lake Naivasha, a gap that necessitated the study. The study assessed the effects of water level variability on fishing, horticulture, tourism and hospitality industry and adaptation strategies adopted.

1.3 Objectives of the Study

1.3.1 Broad Objective

To examine the influence of spatial and temporal variation of Lake Naivasha water levels on economic activities and adaptation strategies in order to enhance livelihoods, and environment health.

1.3.2 Specific Objectives

i) To analyse the spatial and temporal variation of water levels between 1992 and 2022 in Lake Naivasha.
ii) To determine the influence of water level variability on economic activities in Lake Naivasha.
iii) To assess the adaptation strategies to water level variability in Lake Naivasha.
iv) To establish a relationship between Surface area water level variability and fish yield and revenue in Lake Naivasha.

1.4 Research Questions

The study was guided by the following research questions;

i) What are the spatial and temporal variations of water levels from 1992 to 2022 in Lake Naivasha?
ii) What are the influence of water levels variability to economic activities in Lake Naivasha?

iii) What are the adaptations strategies to water levels variability in Lake Naivasha?
iv) What is the relationship between Surface area water level variability and fish yield and revenue in Lake Naivasha?

1.5 Justification of the Study

Lake Naivasha is one of the most valuable tropical freshwater resources located in the central Rift valley of Kenya and is part of the Gregory Rift. Its water level responds to climate variability and river inflow hence it's recognised as a classic amplifier lake (Herrnegger *et al.,* 2021). Lake Naivasha experiences variability in surface area because it is shallow therefore experiencing high evaporation and it highly depends on the amount of rainfall. Adverse hydrological variability has increased the impacts of other major stresses such as change of economic activities, Land Use Land Cover Changes (LULCC), population growth and urbanisation (Kyambia & Mutua, 2015). Furthermore, in lake Naivasha water basin, the management practices are not adequate and therefore do not cope with the impacts of hydrological variability and resource reliability (Awange *et al.,* 2013). Rising water levels in Lake Naivasha results to flooding which have a direct effect on the environment and causes changes such as ill health, loss of lives and properties thus affect human activities along the lake.

The temporal and spatial water variations interfere with the achievement of a number of Sustainable Development Goals (SDGs) such as goal number one; (No poverty), goal number six, (Sustainable Water and Sanitation for all), goal thirteen on Combating climate change and its Effects, and goal fourteen on Life Below Water. By collecting data on variability of the lake, the state of the lake can influence implementation of water use, and conservation policies, and management (Yuan *et al.,* 2015). Findings from this study will contribute towards the attainment of Kenya's Vision 2030 on environment, water and sanitation by enforcing policies and institutional reforms. The findings will also be beneficial in identifying effective and efficient adaptation strategies to water level variability among water users in Lake Naivasha.

1.6 Scope and Limitations

The study was conducted in Naivasha sub-county in Lake Naivasha area. The study focused on analysing the economic activities that were affected by the variations of water levels from 1992 to 2022. A period of 30 years was long enough to show a trend in water level variability. The study assessed the effects of water level variability on agriculture, fishing and tourism which are the main economic activities around the lake. Data collection exercise was carried out between January and March, 2024 before the onset of long rains.

Data on the effects of water level variability was collected from people who had lived around the lake for more than 30 years. Total Fish yield data and revenue records were obtained from Kenya Marine and Fisheries Research Institute (KMFRI), Naivasha. Data on water level variability in m.a.s.l was based on the records kept by Water Resource Authority (WRA; formerly Water Resources Management Authority), Naivasha to validate the spatial extent of the lake. Total horticultural yields and number of tourist's data for the 30 years period were not available due to frequent changes in ownership and management structure. Therefore, Key Informants Interviews supplemented data collected using the semi-structured questionnaire. Fisher folks and Workers in the horticulture, tourism and hospitality industry were deemed sufficient to provide information on the economic effects of water level variability. Secondary data from Lake Naivasha Riparian Association (LNRA) was used to better understand the effects of water level variability on the three selected economic activities.

1.7 Assumptions of the Study

The study made the following assumptions;

i) The selected economic activities in Lake Naivasha were entirely dependent on the lake.
ii) The economic activities in Lake Naivasha were affected by the water level variations.
iii) The respondents recalled the events and provided accurate and updated information.

1.8 Definition of Terms

Economic activities- According to European Commission (2023), economic activities are characterised by input of resources, production processes and output of products (goods and services).

Economic effects- Consequences of water variation on economic activities.

Fisher folks- People who participate in harvesting fish especially for a living.

Flood risk- According to the European Union (EU) Floods Directive, it's the probability of a flood event to have adverse consequences to human health, economic activity and environment to the community.

Horticultural crops-refers to flowers, fruits, vegetables, spices, and ornamental and medicinal plants (Aseto *et al.*, 2022).

Hospitality operators-Services related to hotels such as Tourism, Accommodation, Travel and Transportation, Meetings and Events.

Off fish practices-Related water activities such as boat riding and businesses along the lakeshore.

Ramsar site- These are wetlands considered of international importance.

Riparian- A land zone owned by the government but can be cultivated by those having land adjacent to it. 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 and which falls below 1892.8 metres above sea level (6210 ft m.a.s.l).

Surface area Variations- Spatial changes in lake area over time.

Stakeholders- These are formal organised groups based on sectors that share a common interest. In lake Naivasha shareholders include: individual water abstractors, commercial users, water service providers, irrigators, pastoralists and tour operators (Ogada *et al.*, 2017).

Water users- People or companies who depend on lake water for economic purposes.

Water Level variation- Changes in meters above the sea level.

Wetlands- Article 1 of the Ramsar Convention states that "wetlands are 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".

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter contains an in-depth review of literature related to variations of water levels and economic activities practised in Lake Naivasha. Also there are influences of water variability on economic activities as well as adaptation strategies. Theoretical and conceptual frameworks are also included in the chapter.

2.2 Variations of Lake Water Levels

Generally, lake water levels respond to long-term wet and dry climatic cycles, with annual variations of the water levels superimposed on these long-term variations (Chevallier *et al.,* 2011). The water level can change several metres within few months, causing a horizontal change of several kilometres and therefore a shift of the shoreline. These hydrological dynamics add an extra dimension to the riparian ecosystem as well as to the water resource management issues and associated water use conflicts.

In north-western China, many closed inland lakes have experienced severe declines and among them is Lake Daihai in Inner Mongolia. The lake shrunk significantly from 1980s to 2010 by 9 m which is approximately 64% of the area therefore causing a serious concern on sustainable development of the surrounding (Wang *et al.,* 2022). Lake Urmia an endorheic lake with an average original surface of about 5,000 Km^2 in north-west of Iran experienced a strong decline in lake level between 1995 and 2013, the lake lost about 60% of area and even more than 90% of its volume (Schulz *et al.,* 2020).

Lakes in subtropical regions display variation in water levels due to large seasonal and inter-annual variation in rainfall and net evaporation (Havens *et al.,* 2005). The hydrology of Africa has a wide range of processes that are under the complex influence of climate change, geological controls and human interactions such as uncontrolled irrigation, extensive construction of reservoirs and poor agricultural water use (Aura *et al.,* 2023). African lakes experience strong climate variability across timescales leading to alternate periods of droughts and floods. The water levels in lakes have natural and unpredictable fluctuations resulting in either a drawdown or an increase of several metres.

In Africa, Lake Chad a freshwater resource, experienced extensive water fluctuations causing a dramatic shrinkage since the 1980s from a surface area of 25,000 km^2 to 2000 km^2 (Papa *et al.,* 2023). Lake Chad surface area is highly sensitive to stream flow and precipitation changes and in addition to the devastating droughts over the Sahel belt remarkably lead to declining water

levels. Also in Malawi, Lake Chilwa the second largest lake is mostly affected by seasonal rains and summer evaporation causing desiccation in dry seasons. In 2019 after heavy rains, Lake Chilwa increased by 60% after experiencing drying trends and low lake level (Muita *et al.*, 2021). Global climatic change affect the sea level causing floods in lagoons and in low lying lakes such as Lake Nokoue in southern Benin (Zandagba *et al.*, 2016). Flooding of Lake Nasser, in Egypt, result in deposition of large scale sediments which raise the turbidity levels.

Lake Naivasha in Kenya was postulated to have experienced a rapid decrease between the years 2002 to 2010 in spatial extent and water levels (Awange *et al.*, 2013). This decline was attributed to factors such as climate change, horticultural activities and Ol Karia geothermal power plant which pump substantial amounts of lake water for turbine operation. Also, the flower industry requires large inputs of water from Lake Naivasha. Being a semi-arid area, the operation of these commercial industries, though it is economically and socially important put great strain on this shared freshwater resource. As from 2010, there was a successive sharp increasing trend in Lake Naivasha water levels as a result of hydro-meteorological and climatic causes, geological and tectonic movements and also anthropogenic causes like land degradation (Muita *et al.*, 2021).

2.3 Agricultural Activities around Lakes

Lake Chapala the third largest lake in Latin America supports an important part of agricultural activities in Central Mexico where vegetables and other crops are cultivated on its shores (Maldonado *et al.*, 2020). Lake Chapala gives a high symbolic value and it generates significant revenue. In Tibetan plateau in Asia, Pastoralism is practised in the Qinghai Lake Basin in China since grassland vegetation is the largest terrestrial ecosystem (Song *et al.*, 2022). Grassland resources is the most important means of production for herders' livelihoods where animal husbandry is the source of primary livelihood. Lake Chad is an important source of freshwater for agriculture sectors in the Chad basin and its boundary trans-passes the countries of Chad, Cameroon, Nigeria and Niger (Papa *et al.*, 2023).

In Eastern Africa, Lake Tana the largest freshwater lake in Ethiopia is mainly used for agriculture and there is more development of large scale and smallholder irrigation to reduce food insecurity and poverty in Ethiopia (Taye *et al.*, 2021). Also in Ethiopia, there is excessive pumping of water from Lake Ziway for floriculture and expansion of commercial irrigation activity around the lake (Ayenew & Legesse, 2007). In Kenya freshwater from Lake Baringo is used for irrigation agriculture around Marigat area for production of crops like onions, watermelon and maize (Omondi *et al.*, 2016).

The adjacent land to Lake Naivasha plays a crucial role in developing both local and national economy despite having less water holding capacity. The area has rapidly transformed from a cattle ranching oriented area to rapid subdivision of land with labour-intensive agro-industrial centre. Naivasha town has experienced positive significant growth such as industrialization and infrastructure development (Tsimbiri *et al.,* 2015). Livestock ranching still exists in Lake Naivasha, as the area was originally dominated by Maasai grazing pastoralists who practised traditional farming and fishing activities before various economic actors and other population groups. The areas adjacent to the lake, especially the western portion of the basin tend to be much more arid and dry, with infertile soils unsuitable for growing crops and mostly used as pastures and private game ranches. Domestic stock and herdsmen wander without hindrance around the lake edge despite a 50 m buffer strip recommendation by the LNRA guidelines (Harper, 2004).

Lake Naivasha Basin is surrounded by small-scale subsistence farming together with cash crop plantations where flowers dominate and therefore serving as the home of the flower industry in Kenya (Sassi & Trital, 2022). Also there is integration of micro, small and medium-sized enterprises horticultural production (Aseto *et al.,* 2022). Other agricultural activities conducted along the lake's shore include livestock production and irrigated agriculture. The total irrigated commercial farm area is about 4450 ha with cut flowers accounting for 43%, vegetables 41%, and fodder 15% (Mekonnen *et al.,* 2012).

2.3.1 Horticulture in Lake Naivasha

Horticultural Crop Development Authority (HCDA) was established in 1967 by the government to regulate capacity and help in advisory over the years in developing this important sub-sector. The area around Lake Naivasha has become the main horticultural site in Kenya increasing the country's foreign exchange (Mekonnen *et al.,* 2012). It is a significant riparian activity producing tonnes of different vegetables, fruits and fresh cut flowers each year for the European market (Hellum *et al.,* 2015). The horticulture industry was established towards the end of 1980s attracting international flower companies along the lake shoreline and the flower farms have been expanding at a faster rate since the late 1990s.

In Kenya, the horticultural industry is among the largest foreign income earners having undergone tremendous development and providing direct and indirect employment (Tsimbiri *et al.,* 2015). There are about 220 flower farms registered by the Kenya Flower Council (KFC) where more than 150,000 people have been employed directly and about 70 farms are located near Lake Naivasha. At least 25 varieties of flowers are produced like roses, lilies, hypericums and spray

carnations and vegetables for the export market. According to the Food and Agriculture Organisation (FAO), horticulture is a vibrant sector contributing to 26% of Kenya's Gross Domestic Product (GDP) in agriculture and Lake Naivasha basin contributes almost 1.3% of the (GDP) (Aseto *et al.,* 2022). Horticulture farms in Lake Naivasha include; Flamingo, Wild fire, Aquila Longonot and Finlay farms. The flower sector is represented by a number of associations which are certified such as the KFC and the Lake Naivasha Growers Group (LNGG).

2.4 Lake Fisheries

Globally inland water sources have exhibited a steady yearly increase with high fish diversity and therefore supports food security, provides local income opportunities and employment. According to FAO, there are less marine captures compared to inland water fish captures in nations that have more important water bodies and river basins (Morara *et al.,* 2022).

Recreational fisheries constitute the dominant use of inland fishes in developed nations. In North America and Europe, there are a lot of inland recreational fisheries which has high economic worth and therefore contribute significantly as a source of food (Embke *et al.,* 2020). In developing countries, fishery resources are among essential economic components. Lake Albert a transboundary lake shared by Uganda (54%) and Democratic Republic of Congo (46%) supports a multi-species artisanal fishery that is of both subsistence and commercial (Nakiyende *et al.,* 2023).

According to Nakuru County statistical abstract, Lake Naivasha fishery plays an important role by supporting more than 4000 livelihoods in the economy of Nakuru County and surrounding urban areas in the catchment. Before 1959, commercial fishery in Lake Naivasha was limited, and permits were only provided for recreational fishing. After an open access to the lake, fishing has been highly dynamic over the years leading to overfishing (Morara *et al.,* 2022). Excessive fishing which leads to rapid decline in fish stocks is controlled by the Fisheries Department (FD) through prohibiting poachers and regulating the use of illegal boats and nets.

The dominant fish species in Lake Naivasha include: African sharp-tooth catfish *Clarias gariepinus* (Burchell), blue-bellied tilapia *Oreochromis leucostictus* (Trewevas), red-bellied tilapia *Coptodon zillii* (Gervais), large-mouth bass *Micropterus salmoides* (Lacépède), common carp *Cyprinus carpio* (Linnaeus) and the Nile tilapia *Oreochromis niloticus* (Linnaeus) (Njiru *et al.,* 2017). The target fish species which were either accidentally or intentionally introduced have evolved through different exploitation levels and fish yield phases. The exotic fish species were added to the native fish species to diversify and boost fisheries in the lake.

In developing countries fisheries suffer from overfishing and poor enforcement of existing fishery law (Nakiyende *et al.,* 2023). Fishing in Lake Naivasha has been under constant human

pressure due to the migrant workers mostly from the flower farms increasing fish market demands. The large numbers of employees provide incentives for illegal fishing. In 2000, the fish stock declined and the fisheries collapsed to unsustainable levels leading to a total fishing ban in 2001 to allow fish stock recovery. There have been significant changes in Lake Naivasha fishery since its reopening in 2003 for restoration and sustainable management and since then it has developed. There was formation of the Beach Management Committee (BMC) which necessitated the gazettement and enforcement of regulations in 2007 by the Government of Kenya.

According to Nakuru 2018-2022 CIDP, the lake has the following designated fish landing beaches; Karagita near crescent island on the northern side, Kamere on the southern side, Kasarani or Tarabete on the north-west and Central Landing Beach also known as Banda. The Fishing operations conducted daily are recorded at Kenya Marine and Fisheries Research Institute (KMFRI) and Fisheries Department (FD) (Morara *et al.,* 2022). There have been great fluctuations in the amount of fish landing from the fishery of Lake Naivasha, the minimum and maximum catch was reported in 2003 (38 metric tonnes) and 2019 (3087 metric tonnes), respectively.

2.5 Tourism in Lake Naivasha

Lake Naivasha provides a link of tourism as it falls within the major tourists attraction circuit of Maasai Mara Game Reserve and Lake Nakuru national park supporting a rich ecosystem. The tourist attraction sites include the lake region, Hell's Gate to the south of the lake, Longonot National Parks and several sanctuaries (Ogada *et al.,* 2017). To the west of Lake Naivasha, there is Lake Sonachi, a Crater Lake known as a small paradise with dense forest covering the steep walls of the crater providing a micro climate. Lake Sonachi is highly alkaline and often hosts the lesser flamingos (*Phoeniconaias minor).* About 200 meters from Lake Naivasha there is Lake Oloiden which is a breeding ground for the common and white necked cormorants (*Phalacrocorax lucidus*) and sometimes draws an impressive flock of flamingos depending on its alkalinity.

According to the County Abstract of 2015, despite Lake Nakuru having the highest number of tourists, Lake Naivasha has enormous potential for tourism development due to secure environs and its proximity to Nairobi, the capital city of Kenya. It receives thousands of visitors annually who flock the lake and this generates employment within the hotel industry (Njiru *et al.,* 2017). In the Nakuru County statistical abstract of 2017-2022, Lake Naivasha, Hells Gate and Mount Longonot national parks received 108,818 tourists in 2021. The southern lake shore hosts dozens of hotels of all categories suitable for domestic and international conferences and meetings. There are many private owned wildlife sanctuaries, boat rides and several high standard campsites that makes Naivasha one of the preferred destinations (Hellum *et al.,* 2015). Examples of Resorts,

lodges and hotels in Naivasha along Moi South Lake road are; Masada hotel, Burch's hotel, Lake Naivasha and Enashipai Resorts, Sawela, Sopa and Simba lodges, Crayfish Camp and Lake Naivasha Country Club.

Lake Naivasha has a wide range of terrestrial vegetation and aquatic flora and fauna. The flora is of diverse community with 43 plant families and 108 species (Harper, 2004). The dominant terrestrial tree species that forms the woodland around the lake is the Naivasha Thorn, or Yellow Fever Tree (*Acacia xanthophloea*). The acacia forests and wetlands provide an excellent aesthetic value for sightseers, also the Malewa River delta comprises of Acacia woodland and papyrus swamp.

There are many animals found in the neighbouring national parks and acacia woodlands on the shores. Lake Naivasha has over 350 bird species which have unique bird life and therefore a major tourist attraction site (Njiru *et al.,* 2017). The wildlife protected area are Eburru forest, Hells Gate and Longonot Park. The dense riparian papyrus zone provides a breeding and foraging ground for wildlife such as hippos, zebras, waterbucks, gazelles and buffalos. It is also a resting habitat for shore birds like the African fish eagles (*Haliaeetus vocifer*) and other migrant bird species. To promote tourism in Lake Naivasha, there are tourist associations within Naivasha including Lake Naivasha Tourism Group. Kenya Wildlife Service (KWS) is the general custodian of Lake Naivasha Ramsar site and several local youths are trained into ecotourism guides and biodiversity to reduce impacts of unsustainable modes of living like poaching.

2.6 Economic effects of Water level Variability

Large variations in water level can influence ecosystem dynamics if there is deep inundation of the littoral zone, causing flooding stress to aquatic vegetation, or at the other extreme, drying of a substantive portion of the littoral habitat (Havens *et al.,* 2005). As a consequence of water level reduction, the littoral zones are exposed leading to a reduction in the aquatic habitat such as papyrus (*Cyperus papyrus*), an important wetland ecosystem that has declined in acreage. Loss of water volumes reduces marginal swamps and this increases nutrients entry from the catchment area causing an upsurge in algal productivity which adversely affects fishery (Njiru *et al.,* 2017). Declining lake levels produces a series of environmental and socio-economic problems which include; deterioration of water quality, low fish production, crop water shortage and reduction in species diversion (Ye *et al.,* 2017). Lake Urmia's desiccation affected recreational, cultural heritage, ecotourism and educational services causing losses of more than US$ 1.6 million (2019) to Iran's economy (Wurtsbaugh & Sima, 2022).

In sub-Saharan Africa, floods and droughts are extreme climatic events that are perceived as challenging and therefore categorised as natural devastating hazards, causing property damage and claiming more lives (Herrnegger *et al.,* 2021). In Lake Chad, there was reduction of potable water and fish catches due to drought which increased cases of livelihood dependent communities on fishery (Zandagba *et al.,* 2016). Also during drought conditions, there is a drop in fishery production in arid and semi-arid regions of Sub-Saharan Africa due to fishery habitat loss (Muringai *et al.,* 2022).

Floods negatively affect the economic activities around the lake thus rendering residents more vulnerable and food insecure (Kilavi *et al.,* 2018). Rising waters in Lake Beseka Ethiopia led to loss of human lives, submerged grazing lands and displaced nomads who encroach the nearby Awash National Park. In Kenya, the 1997-1998 floods caused waterborne diseases, damage to crops, water, roads and communication systems, which affected more than half a million people (Njogu, 2021). In addition, the 2010 floods affected infrastructures in parts of North and South Rift, Upper Eastern and North Eastern regions. Sometimes flooding has subsequent societal benefits like in the Semian Mountains of Ethiopia, excessive rainfall provides a source of irrigation for crops in the drier lowlands (Takaoka, 2005). Muringai *et al.* (2022) suggests that flood events might create positive benefits such as, recharging both groundwater and wetlands and an increase in fish production as in the case of Mbita sub county, Homa Bay County.

2.7 Adaptation Strategies to Water Level Variability

According to United Nations Framework Convention on Climate Change (UNFCCC) 2015, adaptation refers to changes in processes, practices and structures to moderate potential damages. Adaptation strategies are important measures as it assesses the community ability to respond to hazards and to effectively reduce their vulnerability. The disruptions of economic activities force the water users around the lake to re-establish and adopt new ways of survival to sustain their lives and counter their losses. Adaptation strategies to counter Lake Urmia's disappearance in Iran and to enhance resilience include; prohibiting further withdrawal of water for irrigation and developing alternative water resources to avoid profound impacts on rural water users (Maleki *et al.,* 2022). Measures to protect Lake Daihai in China from drying include popularising water-saving irrigation technology and building a reservoir in the basin (Wang *et al.,* 2022).

In many Asian countries such as Sri Lanka, flood adaptation strategies are achieved through the following measures; Redistribution of losses through disaster relief, issuance of flood insurance and tax remission (Sivakumar, 2015). In southern Europe countries, increased complex technology is used such as mechanical wetlands and building of coastal barriers to prevent

Mediterranean waters from the mainland (Ciampa *et al.,* 2021). These strategies help to reduce both individual and community distress during or after the flood experience.

To adapt to recurrent annual flooding in Nyando basin, reservoirs have been proposed. The floods are always preceded by droughts which are a challenge to agricultural development and lead to bio-diversity alteration. According to the Kenya Meteorological Department (KMD), early flood warning systems is only operation in Nzoia river basin in Western Kenya that helps in mitigating the impact of flood events (Kilavi *et al.*, 2018). In Lake Baringo, flood walls were built around local lodges to control rising waters but the unprecedented floods breached the walls, and damaged the tourists hotels (Victor *et al.,* 2023). Several adaptation measures have to be undertaken to prevent lakes from flooding and from nearly drying up. Furthermore, maintaining reasonable lake water levels is critical for the purposes of social and environmental stability (Ye *et al.,* 2017).

2.8 Summary of knowledge Gaps

The summary of knowledge gaps has been presented on Table 2.1.

Table: 2.1: Summary of Knowledge Gaps

Theme	Authors	Key findings	Knowledge gap
Analyse the spatial and temporal variation of water levels between 1992 and 2022 in Lake Naivasha	Aura *et al.* (2023), and Ayenew and Legesse (2007)	Examined rising water levels in Afrotropical lakes which led to flooding from 2010 and 2020. Quantified the extent of flooding to guide management implications.	The focus was on the flooding and lacked information on fluctuating water levels and adaptation strategies.
Determine the economic effects of water levels variability in lake Naivasha	Awange *et al.* (2013), and Zandagba *et al.* (2016)	Climate change poses a threat to fisheries and therefore has an impact on the income of the riparian community.	The research didn't focus on other major economic activities like Tourism on riparian lands. Effects on economic activities in Lake Naivasha due to water levels variability hasn't been addressed.
Assess the adaptation measures to water levels variability in Lake Naivasha	Alfieri *et al.* (2015)	Provided flood adaptation measures in Mediterranean coastal regions.	Mainly focused on adapting to coastal flood hazards and not the adaptation measures to lake water levels variability.
Establish a relationship between Surface area water level variability and fish yield and revenue in Lake Naivasha.	Morara *et al.* (2022)	Analysed the changing composition of fish species in Lake Naivasha overtime.	The research didn't address the relationship between the Surface area water level variability, fish yield and revenue in Lake Naivasha.

2.9 Theoretical Framework

2.9.1 DPSIR Model

The theoretical framework was based on the Drivers, Pressures, State, Impact, Responses (DPSIR) model which is a relevant tool in assessing the interaction between society and environment. DPSIR model was developed by the European Environment Agency (EEA) from Pressure-State-Response (PSR) framework proposed by David Rapport and Anthony Friend in 1979. The PSR provides a logical framework for evaluating effects of water level variability on economic activities. The drivers which are either natural or anthropogenic factors exert pressure on the lake which changes its state by vertically increasing or reducing. This brings an impact to the water users around the lake and forces curative responses such as adaptation and mitigation.

In Lake Naivasha the natural and anthropogenic drivers include; hydrodynamic processes, water abstractors upstream, climate change and variability which causes a change in lake water levels. Pollution threats of waste from farmlands, settlements and industries lead to eutrophication, periodic blue-green algal blooms and fish kills. High rainfall combined with poor agricultural practices by small scale farmers in the lower, middle and upper catchment, increases siltation leading to rise in lake water levels. The impacts of either receding or rising water levels are faced by the environment, human and society such as displacement, loss of lives, and increase in wetlands which elicits societal response and therefore giving a feedback to the driving forces, state and impacts an effort to ensure sustainability and development.

2.9.2 Socio-Environmental / Ecological System Theory

Socio-environmental system theory was developed in the early to mid-1990s through collaboration of interdisciplinary areas (Biggs *et al.,* 2021). It was further developed by Elinor Ostrom to focus on local resource use and the relationships between the variables involved and the collective outcomes (Hinkel *et al.,* 2014). It defines a more complex system and broad characteristics of social and environmental subsystems that are interlinked and interact with each other. Each subsystems have many other components which also interact spatially, socially and ecologically with other elements across the parts of the system. Lake Naivasha has an intertwined system of strong connections between human, ecological nature and feedbacks. The many interrelations create feedback processes that bring about continuous adjustments such as controlling riparian encroachments and adaptations to the changing conditions. The ecological crises in wetland ecosystems such as siltation, algae blooms and changes in plant communities are often as a result of past actions. Various phenomena around the lake interact with one another which leads to multiple interventions that influence one another. Multiple actions that include; excess withdrawal of water from the lake, poor agricultural and industrial practices lead to multiple

interventions like government policy intervention across the various sectors. Environmental legal frameworks including water abstraction restrictions in Lake Naivasha have resulted to change in lake water levels.

2.10 Conceptual Framework

The interaction of independent and dependent variables is shown on Figure 2.1. The dependent variables were economic activities manifested by Agriculture, Tourism and Fishing. The independent variables are change in water levels and its spatial extent. The intervening variables are government policies, institutional frameworks and community associations which aim to reduce water variability effects. Water level is the basis for practising and supporting economic activities that facilitate continuous human activities. Extreme increase or decrease in Lake Naivasha water levels may affect economic activities dependent on it. The adaptation strategies determine how severe the water variability will affect the water users.

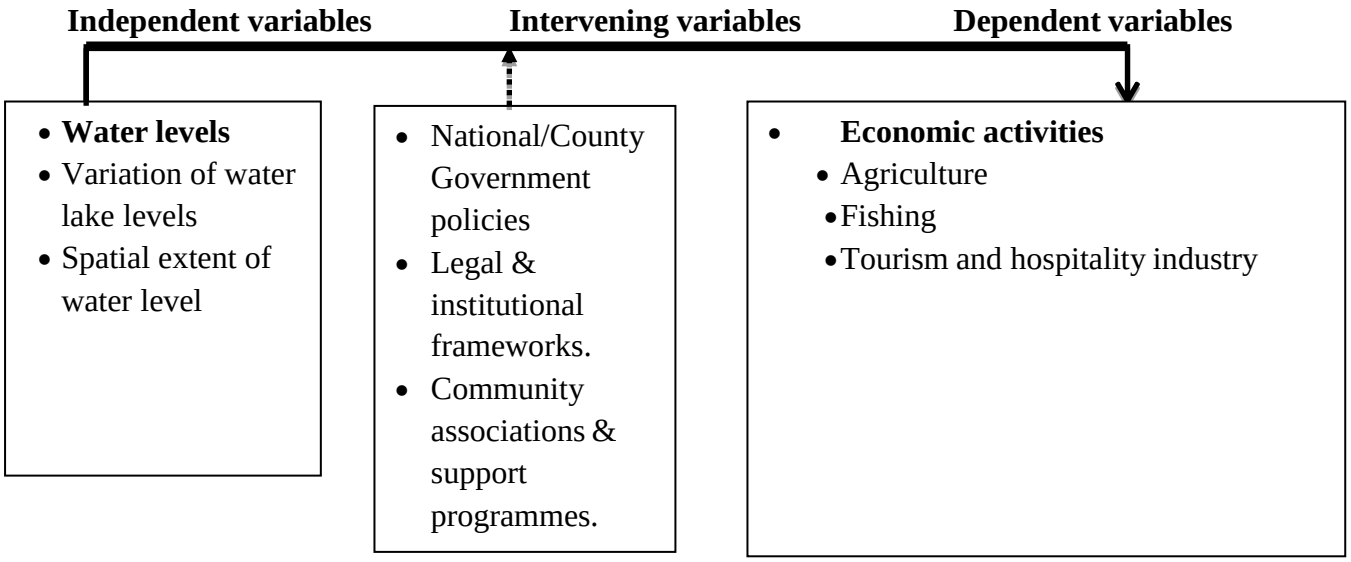


Figure 2.1: Conceptual Framework

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the procedures and methods that were used in the study. It entails the description of the study area, research design, sample size and sampling procedures, data collection, validity and reliability of data, data analysis and tools and ethical considerations.

3.2 Study Area

3.2.1 Location and Size

The study area is Lake Naivasha in Naivasha sub-County, Nakuru County in Kenya. Naivasha sub County has an area of 1685.8 km² and 8 administrative wards namely; Mai Mahiu, Naivasha East, Viwandani, Biashara, Hells Gate, Olkaria, Maiella and Lake View (KNBS, 2019). The name "Naivasha'' is derived from the Maasai word *"enaiposha"* meaning "rough water" or "moving waters''. Lake Naivasha is a closed basin of about 3400 km² and extends 60°north of the equator. It is bounded to the east by Kinangop plateau, north and north-east by Aberdare ranges, south by Olkaria, south-east by Mount Longonot and north-west by Eburru volcanic pile which separates Lake Naivasha basin from Lakes Elementaita and Nakuru. The basin is composed of four sub catchments which are Lake Naivasha, River Malewa, River Gilgil and River Karati (Ogada *et al.,* 2017). Lake Naivasha covers 5% of the total catchment area and is located at about 00°46'S and 36° 22'E of the Greenwich Meridian and 1890 metres altitude (Harper, 2004). The lake is shallow and has a surface area that varies between 130 km² and 160 km² as a result of fluctuating waters during the dry and wet seasons (Obegi *et al.,* 2021).

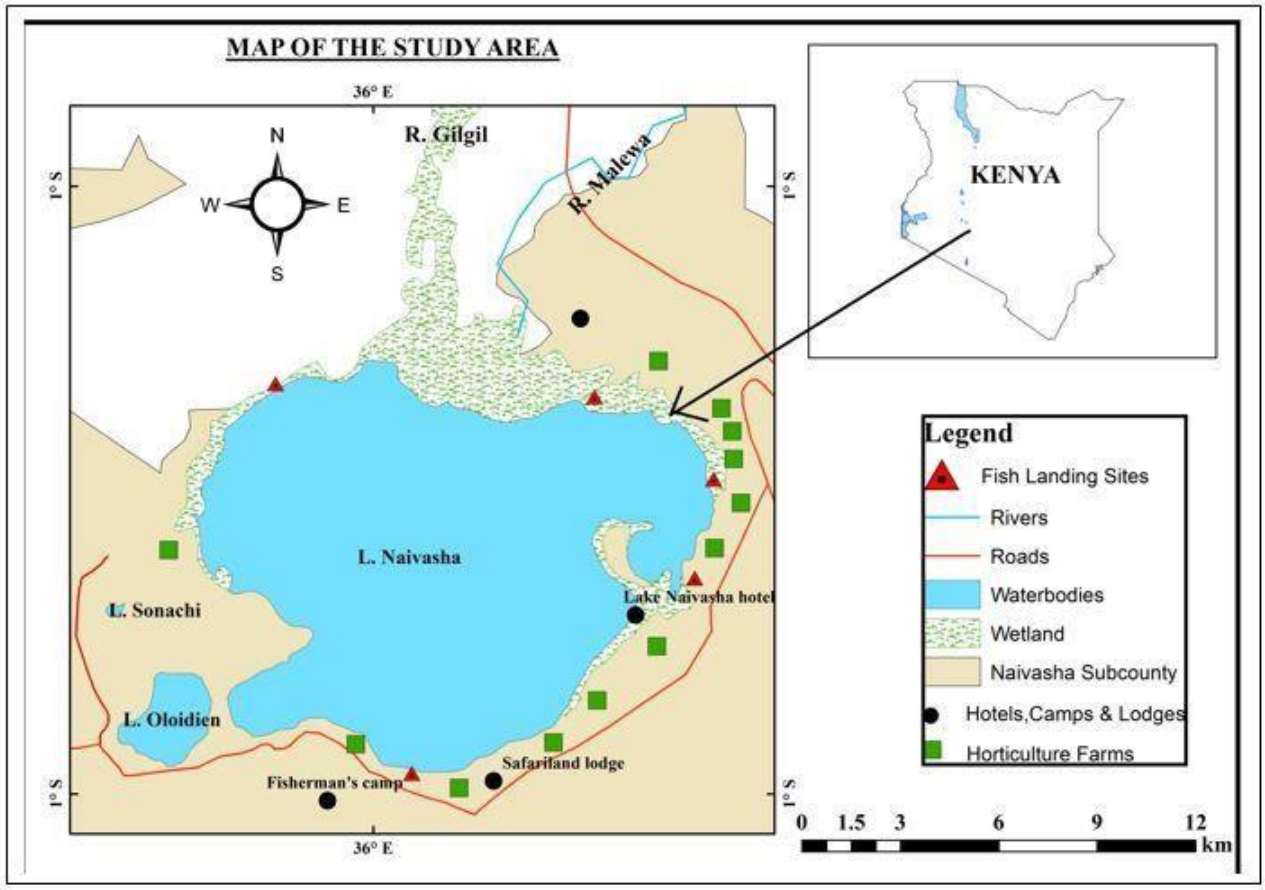


Figure 3.1: A Map of the study area showing study sites.

Source: Survey of Kenya (2022)

3.2.2 Climate

Lake Naivasha is located in a semi-arid environment despite being close to the equator and is located on the rain shadows of Mau Escarpment and Aberdare ranges. The average annual rainfall around the lake is about 650 mm year−1 while the upper catchment is approximately 2400 mm year−1 hence it is classified as Arid and Semi-Arid Land (ASAL) (Obegi *et al.,* 2021). The rainfall changes over a short distance and it rapidly decreases westward across the lake making the area partly sub humid and sub arid zone. The weather is typically tropical where the mean temperatures range from 23° C as the minimum in July to a maximum of 30° C in December (Mireri, 2005). Precipitation varies greatly due to seasonal movement of the Inter Tropical Convergence Zone (ITCZ) and hence it experiences bimodal annual rainfall seasons. The first wet season is during the long rains between March and May and the second wet season is during the short rains between October and November.

3.2.3 Hydrology

Lake Naivasha is an endorheic lake drained by two perennial rivers; river Malewa (1750km^2) from Kinangop plateau and north-western slopes of Aberdare ranges and river Gilgil (420 km^2) from Bahati highlands in the north (Mireri, 2005). Other seasonal and ephemeral rivers are Karati (70 km^2), Maraigushu and Marmanet from Eburru hills and Mau escarpment. Lake Naivasha is the main fresh water lake containing smaller satellite lakes which are Crescent Island Crater (CIC) along the eastern shore, Lake Oloiden and Sonachi Crater. Lake Naivasha surface fluctuations establish or disrupt connections with its satellite lakes which also fluctuate in water level as the main lake (Obegi *et al.,* 2021). Lake Oloiden at the south-west corner is sometimes connected to the main lake though it is separated by papyrus reef and a stretch of an elevated land. About 3 km west from Lake Naivasha there is Lake Sonachi or Greener Crater Lake which is saline (Cocquyt & Verschuren, 2023).

3.2.4 Topography and Geology

The rock structures in Lake Naivasha area are of volcanic origin and have a complex combination of volcanic lavas, lacustrine and sedimentary deposits of pyroclastic acid rocks (Maina *et al.,* 2018). The gentle slope extends to the greater plain surface area with highly permeable rocks. The southern part of the lake is within the Olkaria volcanic complex where numerous geothermal activities dominate including steam vents and hot springs (Shi *et al.,* 2021).

3.2.5 Soils

Lake Naivasha is situated between the lowland floodplain which is dry land and fertile upland soils. The soils vary resulting to different Agro-Ecological Zones (AEZ) of upper highlands, lower highlands and upper midland zones therefore having different range of agricultural potentials. The soils in Lake Naivasha sub catchment are composed of pumice from volcanic ashes and thus are highly porous (Boar & Harper, 2002). As a result irrigation activities are necessary to plants due to excess underground seepage.

3.2.6 Population and Settlement

The population of Naivasha sub-County has tremendously increased from 43,867 in 1969 to 355,383 where 179,222 are males and 176,132 are females (KNBS, 2019). Since independence, the land adjacent to Lake Naivasha has registered rapid population growth and multiple land use transformations. The Sub County has multiple ethnic communities with Maasai's and Kikuyus forming the largest portion, other communities include Kalenjin, Luos and European settlers. The Maasai community who were the original occupants of Lake Naivasha practised pastoralism before they were moved south during colonisation of Kenya (Mireri, 2005). The European settlers

named the basin 'white highlands' with higher parts used for wheat growing and around the lake, Lucerne, sisal and vegetables were grown. The Kikuyu community mainly practise rain-fed agriculture on the Lake's eastern and north-eastern sides while Luo community are mainly fishermen (Omondi *et al.,* 2016). The increase in population around the lake is due to migrants in search of employment from all regions of Kenya that has resulted in many informal settlements (Harper, 2004). There is Kihoto beside Naivasha town, Karagita and Kamere estates on the southern side of the lake and the south-east site close to the flower farms.

3.2.7 Economic Activities

A number of economic activities are practised around the lake to generate sources of income, these include; fishing, agriculture production, tourism and in geothermal power generation companies (Mireri, 2005). Agricultural practices include; mixed agro pastoralism to the west and south of the lake, irrigated smallholder farms closer to the lake's edge, to the north of the lake there is fodder for dairy cows. Other advanced economic activities include tourism, horticulture ventures and industrial sites. Fishing industry has continued to thrive as a result of the introduction of new fish species (Njiru *et al.,* 2017). Around Lake Naivasha there is Hells gate national park in its vicinity making it a tourist destination with a greater variety of birds and wildlife. Furthermore, there are many hotels and campsites suitable for both local and overseas tourists.

3.3 Research Design

The study adopted cross sectional research design which integrated both qualitative and quantitative approaches to achieve the research objectives. Descriptive data from key informant interviews and survey was used to assess the economic effects of water level variability and obtain the adaptation strategies. Landsat images from 1989 to 2022 were used to obtain the spatial variation of the water levels over thirty-year period. Additional data were obtained from documents obtained from KMFRI (for fisheries data) and WRA (for water level variations).

3.4 Target Population

The target population were the water users who included 801 licenced fishermen by KMFRI, 3,000 workers on flower and horticulture farms along the south lake shore, and 2,000 employees in the tourism and hospitality sector.

3.5 Sampling Procedure and Sample Size

The study used Nassiuma (2000) formula to obtain the sample size from a total of 5,801 water users. The formula gives an acceptable range of $21\% \leq C \leq 30\%$ for coefficient of variation and a range of $2\% \leq e \leq 5\%$ for standard error.

Nassiuma (2000) formula is written as;

$n = Nc^2 / (c^2 + (N-1)\, e^2)$.....(Equation 1)

Where:

n = sample size

N=Total Population

c= Coefficient of Variance (0.3 Higher Limit)

e= Margin error (0.02 Least)

Therefore $n = 5{,}801(0.3)^2/0.3^2 + (5{,}801-1)0.02^2 = 224.0388$

n=225

In the study proportionate method was used to select fisher folks, workers in the horticulture and hospitality industries within Moi North and South lake road. The study divided the respondents as follows; 100 Horticulture workers, 53 Fisher folks and 72 hospitality workers. Purposive sampling was used to identify nine Key Informants, three from the community associations, and six from National and County Government Departments and Agencies dealing with agriculture, tourism and hospitality, and Fisheries.

3.6 Data Collection

Both primary and secondary data was employed for the study. A semi-structured questionnaire was administered to selected respondents in the fishing, horticulture and tourism and hospitality industry sectors. This was used to obtain primary data on the economic effects and adaptation strategies associated with Lake water level variability.

A total of 197 questionnaires were administered and used for analysis. In the fishing sector, data was collected from 53 respondents in the four beaches of Lake Naivasha that is Kamere, Oloiden, Tarabete and Karagita. In the tourism and hospitality sector, data was collected from 64 respondents who worked in the hotels, camps and resorts along the lake's shore. Eighty workers were interviewed in the horticulture farms along Moi South lake road.

3.6.1 Surface Area Variability

Historical images from Landsat satellite from 1989 to 2022 were downloaded from the United States Geological Survey (USGS) Earth Explorer website. The USGS account was set to obtain the location of Lake Naivasha through the address and dates for each specific time of an image as shown in Figure 3.2. A cloud cover ranging from 0 to 10% was used to filter the available satellite images. High resolution image was obtained with band 1 to 7 from 1989 to 2010 and from 2010 to 2022, band 1 to 7 and 10 was used. The images from 1989 to 2010 were from Landsat 4-5 Thematic Mapper (TM) of collection 2 Level 2 (C2L2) while for 2010 to 2022 Landsat 8-9 (TM) of C2L2 was used.

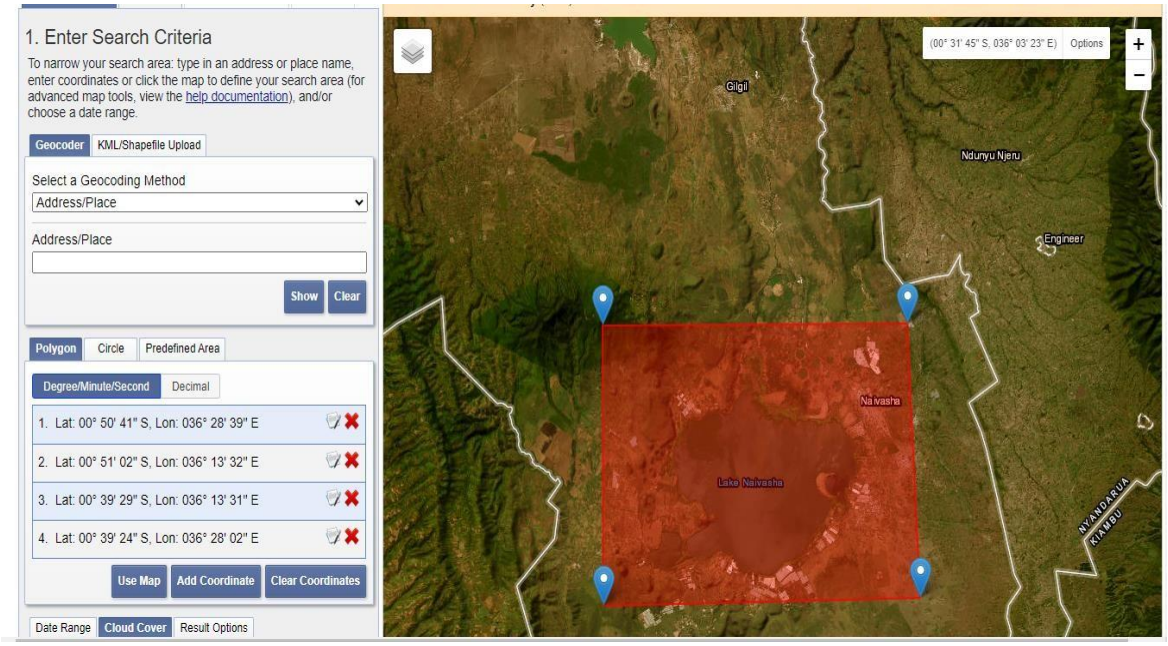


Figure 3.2: Lake Naivasha Satellite image

Source: USGS Earth Explorer (2023)

The images were connected to Arc Map, added into GIS fly and image analysis was done to obtain a composite of 3 bands (Red, Green and Blue). The band composition was used to visualise the true colour image that led to the production of unsupervised classified image of Lake Naivasha. Supervised classification was done on the unsupervised image to obtain a clear image and boundary between the water body and the land by use of training samples manager tool. The training sample manager included water, vegetation, soil and Agriculture classes. The measurement tool of Arc GIS map was used to obtain the area of the lake in km^2 for each year by clicking around the edge of the lake.

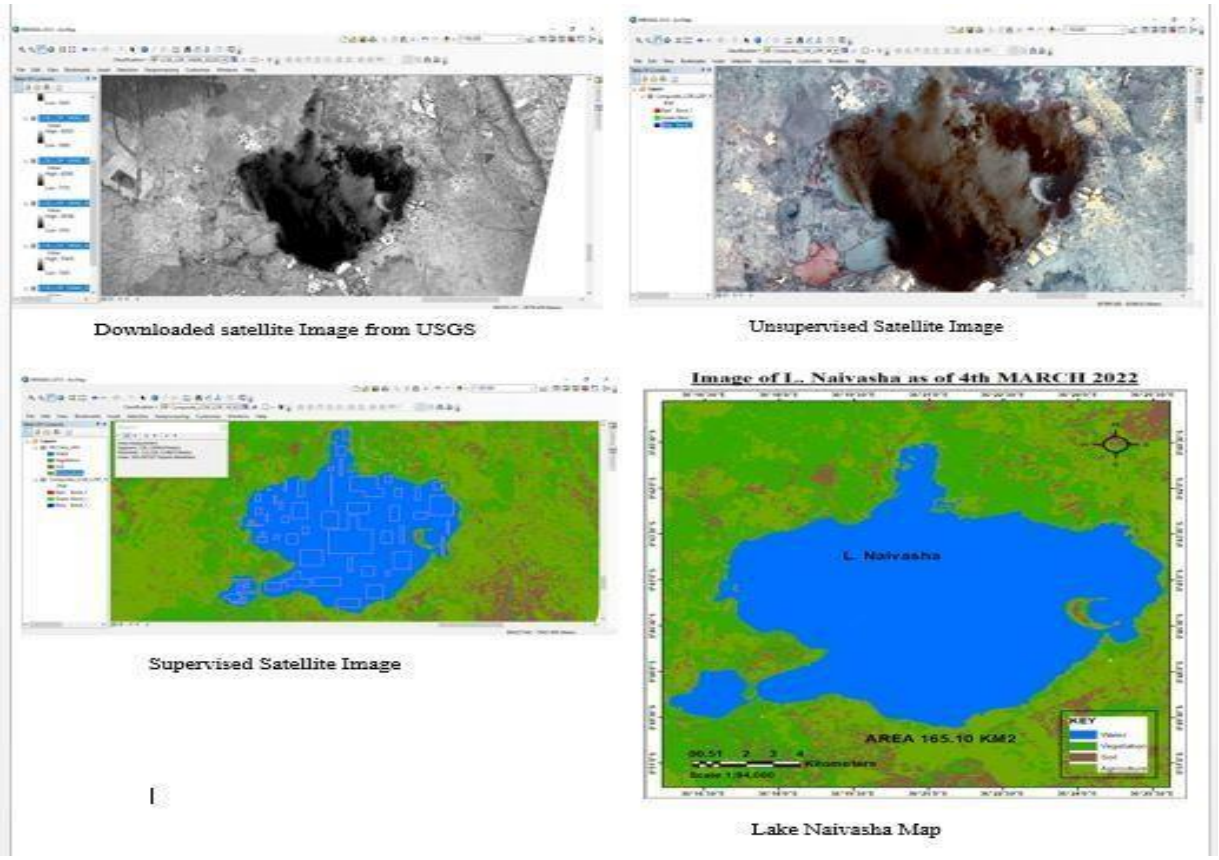


Figure 3.3: Lake Naivasha area measurement after image classification

Source: USGS Earth Explorer (2023)

3.6.2 Key Informants Interview

Nine key informants were selected from the various stakeholders associated with Lake Naivasha to obtain extensive information on the effect of water variability and the adaptation strategies over the years. Key informants' interviews supplemented the household survey. The Key Informants were from government and non-governmental organisations, they were officers from Kenya Wildlife Service, Fisheries Department, Kenya Marine and Fisheries Research Institute, Water Resource Authority, Lake Naivasha Water Resources Users Association, Beach Management Unit, Lake Naivasha Growers Group, Lake Naivasha Riparian Association and Lake Naivasha Tourism Group.

3.7 Validity and Reliability

Pilot study was conducted in Salabani and Kampi Samaki along Lake Baringo, in Baringo South Sub County to test for validity of the research instruments. Lake Baringo, is also a Ramsar site, and its water is utilised in the three selected economic activities, and thus was deemed a good site for a pilot study. According to pilot study sample size rule of thumb, 10 to 20% sample size of

the full scale survey is effective. A sample size of 22 respondents was used in the pilot study which was 10% of the total sample size for the main study. Seven fisher folks, 7 farmers and 8 workers in the tourism and hospitality were interviewed. After the pilot study, the questionnaires were reviewed by the supervisors and other experts to confirm their validity. Reliability was tested using Cronbach's Alpha Scale and the coefficient was found to be 0.73 which was above the recommended 0.7 and thus was a reliable instrument for data collection at Lake Naivasha. The questionnaires were revised after the pilot study and unclear questions modified. Further, reliability of the instruments was verified through pretesting of a small sample of respondents from the target population. Pretesting is a critical step in survey research as it ensures that all kind of errors associated with survey research are reduced (Grimm, 2010). This helped to improve the quality of the data significantly and aided in checking the accuracy and consistency.

3.8 Data Analysis

Data was analysed according to the different study objectives. Maps and graphs were used to show varying water levels and change in the lake's surface area therefore analysing the spatial and temporal variation of water levels between 1992 and 2022 in Lake Naivasha. Change detection process involves identifying differences in an object or phenomenon by observing it at different times therefore providing better understanding of various relationships and interactions (Lu *et al*., 2004).

Quantitative data collected on total fish catch and revenue were analysed using Simple linear regression model because the variables had the following assumptions; they were independent of each other, there were no outliers and there was a normal distribution among the variables. Pearson Correlation coefficient was used to find out whether there was a relationship between surface area water level variability and fish yield and revenue in Lake Naivasha. Fish yield and fish revenue were treated as dependent variables on water Surface Area Variations. The responses on the effects of water level variability to the fishing, tourism and hospitality industry and horticulture sectors were analysed using percentages.

Kendall rank coefficient was used to identify the preferred adaptation strategies to water level variability by the fisher folks, tourism and hospitality industry workers and horticulture workers in Lake Naivasha.

3.9 Ethical Considerations

An introduction letter to National Commission for Science, Technology and Innovations (NACOSTI) was obtained from Egerton University graduate school (Appendix 5). Research permit was obtained from NACOSTI before the commencement of data collection exercise and

further approval was sought from the administrative leadership and local authorities in the study area (Appendix 7). Research ethics were upheld throughout the research period as the information collected was strictly for the study and handled with utmost confidentiality (Appendix 6). Participants were informed about the objectives and the purpose of the study.

CHAPTER FOUR
RESULTS AND DISCUSSION

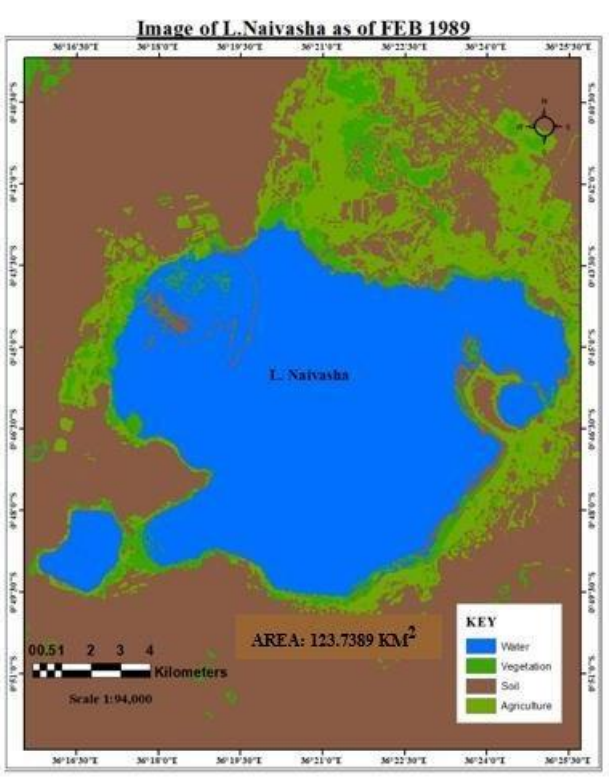
4.1 Introduction

This chapter presents results and discussion on spatial and temporal variation of Lake Naivasha and the various demographic and socio-economic characteristics of the respondents. Also, the results of the effects and adaptation strategies to water variation levels are presented and discussed.

4.2 The spatial and temporal variation of water levels in Lake Naivasha

4.2.1 Lake Naivasha Surface Area Variation

The yearly water level variations in Lake Naivasha depict frequent changes between 1989 and 2022 as shown in Figure 4.1. Due to its shallow depth, any change in water level is reflected on the margin area of the lake. The lowest water level since 1989 was in 2009 with 98.64 km^2 and the highest level was in 2022 with 165.10 km^2. Since 1989 to 2000 the lake was increasing with a smaller difference as compared from 2010 to 2022 which showed a steady high rise. Between 2000 and 2009 the lake surface area was decreasing.



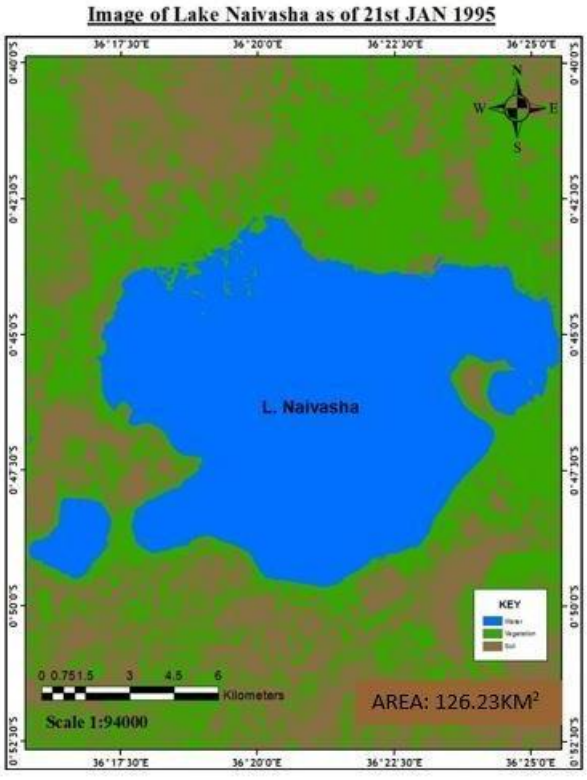


Image of L. Naivasha as of 27th JAN 2000

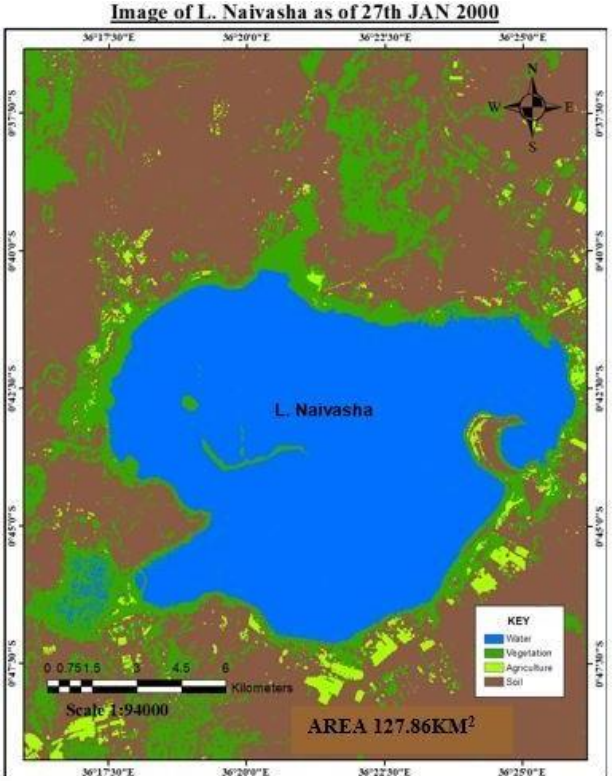


Image of L. Naivasha as of 30th JAN 2003

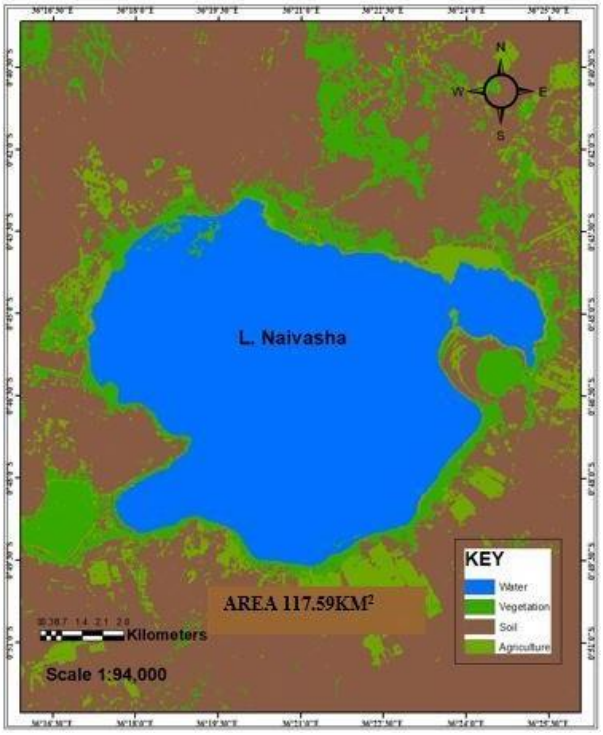


Image of L.Naivasha as of 11th NOV 2009

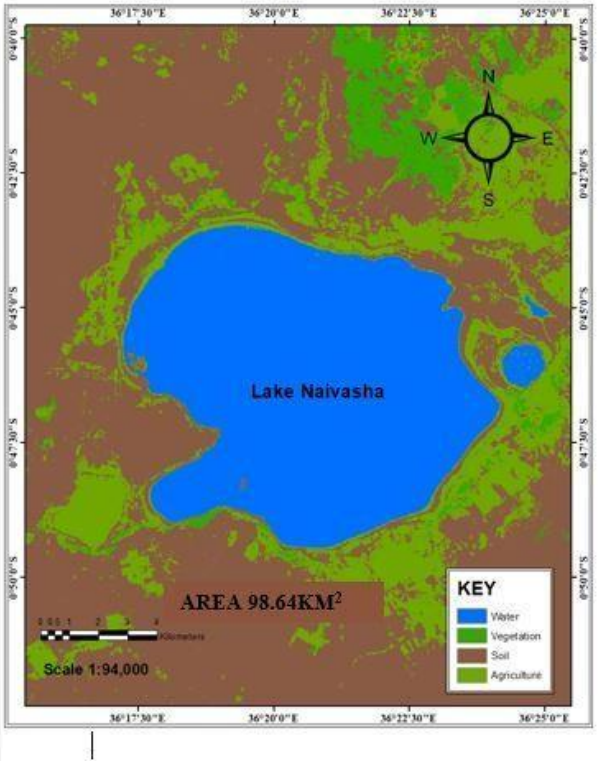
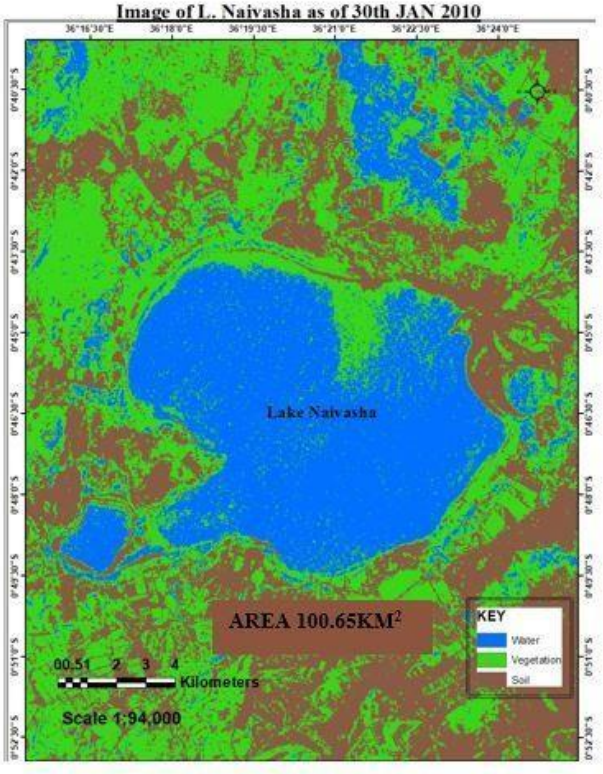


Image of L. Naivasha as of 30th JAN 2010



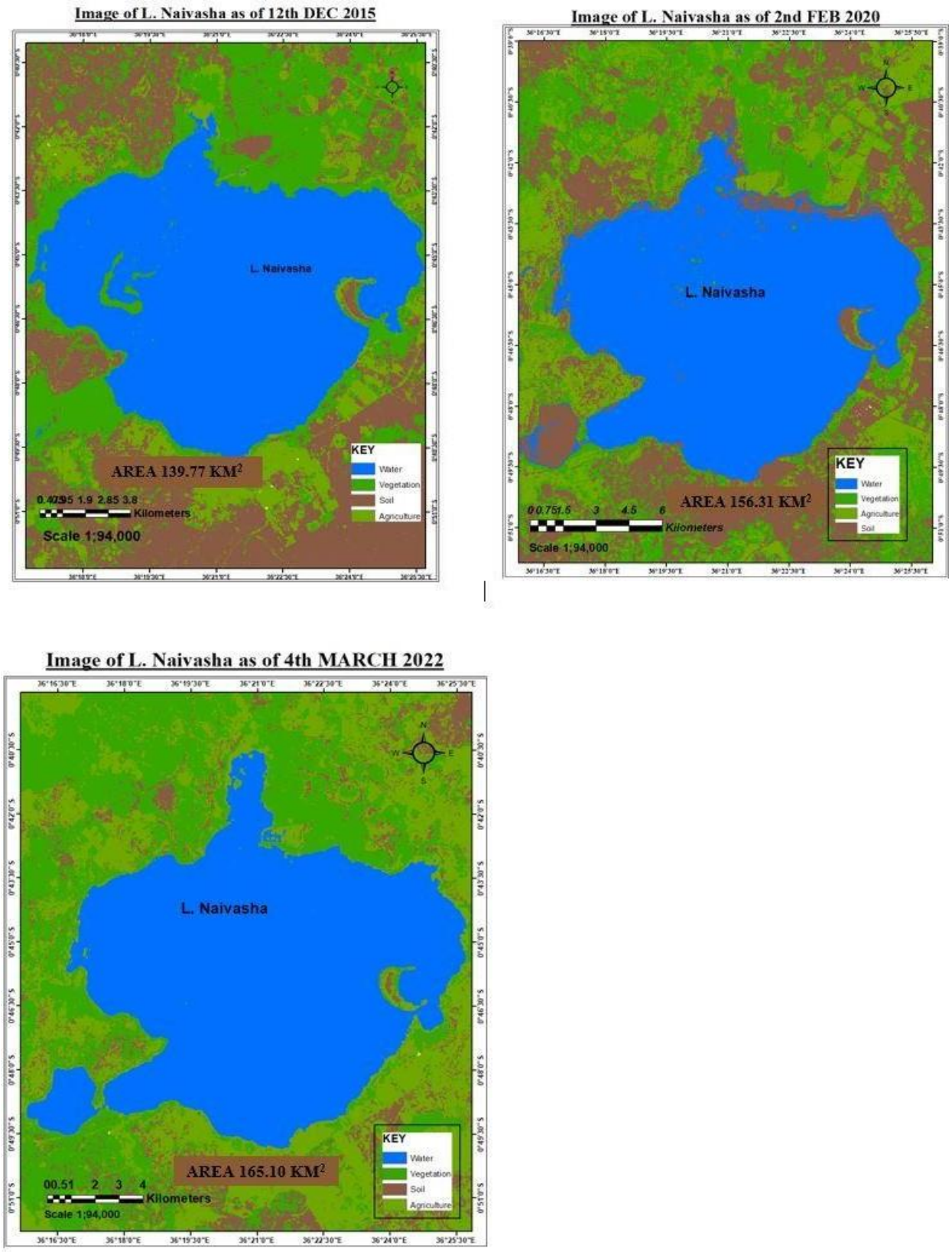


Figure 4.1: Images of Lake Naivasha surface area variability between 1989 and 2022

Source: USGS Earth Explorer (2023)

4.2.2 Lake Naivasha Water Level Variations

Surface Area Variations and Water Level Variations from time series data (Appendix 8) were plotted against the years using Microsoft Excel to visualize the trend of Lake Naivasha water variability from 1989 to 2022 in Figure 4.2. Agri-industrial abstraction since the 1980s led to papyrus (*Cyperus papyrus*) degradation causing river Malewa to run directly into the lake resulting to high siltation and nutrient loads. In 1992 river Turasha the main tributary of river Malewa was abstracted to the north for water supply in Gilgil and Nakuru towns (Odongo *et al.,* 2015). Also the Gilgil River has been abstracted for agriculture and therefore disappears in small swamps around the riparian boundary. Through abstraction the amount of water reaching the lake and recharging the underlying aquifers was reduced (Otiang'a-Owiti & Oswe, 2007). Also, since 1982 after the first KenGen OlKaria geothermal power plant became operational more others have been commissioned which abstracts a huge amount of water. The 2000 image showed increase in urbanization and infrastructure development on the land surrounding the lake therefore resulting to land use change which resulted to unregulated water abstraction.

Rapid growth in population around the lake catchment increased the need for more energy and therefore forests were cleared and trees were cut down for firewood, charcoal and timber for construction. In 2002, there was high level destruction of the Aberdares forest in the upper catchment through illegal activities which resulted to a marked effect on the hydrology of Lake Naivasha (Mireri, 2005). In 2009 the Crescent Bay receded and it was cut-off from the main lake forming an independent lake. Deforestation in the catchment area may partly explain the low rainfall received during this period, and thus the reduced lake levels, just like in all endorheic basins where any land use in the catchment has an effect downstream on the terminal lake (Walker *et al.,* 2022). The rivers flow became more extreme during wet season with intense flooding and low water volume during dry season. As the lake water level reduced, the riparian zone increased leading to further encroachment for water and pasture. Later electrical fences were erected during the rehabilitation process that allowed the reconstitution of the indigenous trees. More tree planting campaigns in the catchment led to the restoration of the degraded Aberdares and other forests such as Kinangop and Eburru.

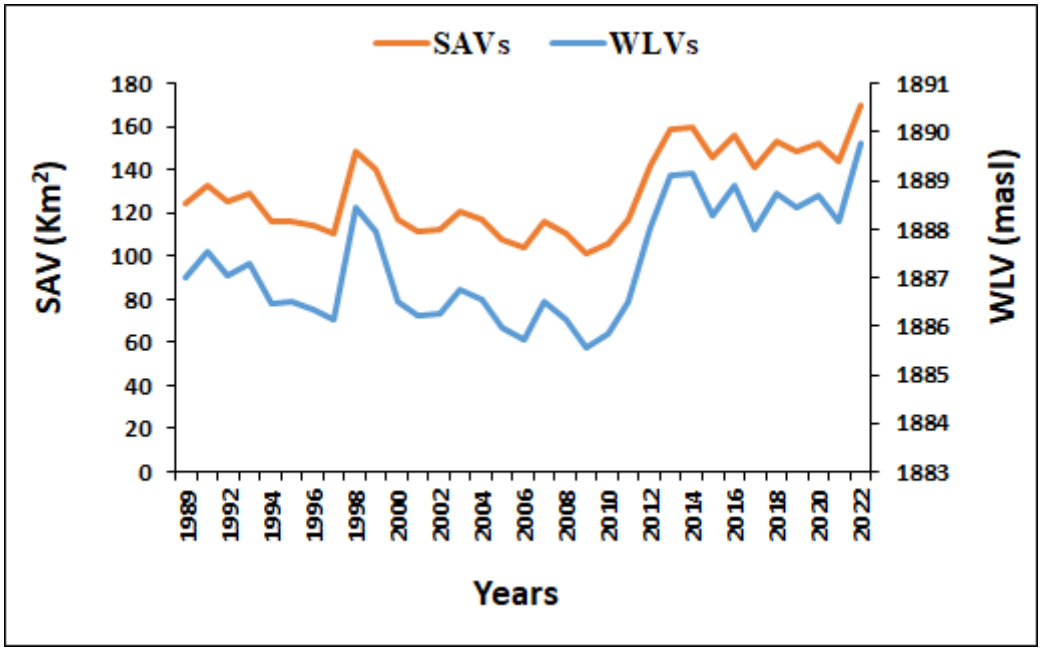


Figure 4.2: Lake Naivasha surface area (SAVs) and Water level variations (WLVs) between 1989 and 2022

4.3 Demographic and Socio-economic Characteristics of the Respondents

The different economic activities practised around Lake Naivasha attract different people of various socio-economic backgrounds and gender. The responses were classified and analysed on the basis of demographic (gender, age, marital status, dependants) and socio-economic (education level, monthly income, years of experience) characteristics.

4.3.1 Socio-economic Characteristics of Fisher Folks

Results in Figure 4.3 shows that, 89% of the fisher folk's respondents were male while the rest were female. This in agreement with Ogada *et al.* (2017) that women consider fishing more strenuous compared to other fishing related activities like processing. The few women in fishing is an indication that it is a male dominated activity just like in other African countries although in the man-made lakes of Nigeria women are involved in almost all aspects of fishing (Nwabeze *et al.*, 2012). Many countries consider fishing as a male centric sphere while preservation, processing and distribution of fish and its products are dominated by women. The few women involved in fishing in Lake Naivasha slightly varied from the study by Dittmann *et al.* (2016) who stated that there are only fishermen but no fisherwomen because fishing is hard work. The female presents in Lake Naivasha are boat owners and traders.

The fisher folk's age was ranging from over 18 years to 55 years with 83% of the respondents aged between ages 26 to 55 years. The majority of the fisher folk's age bracket was 26-35 which implied that they were youth and still in their active years. Eighty-one percent of the

fisher folks were married and 19% were single. Probably, due to access of income to meet obligations and food security, majority of the fishers were married and 81% of the fisher folks had between one to ten dependants within their families.

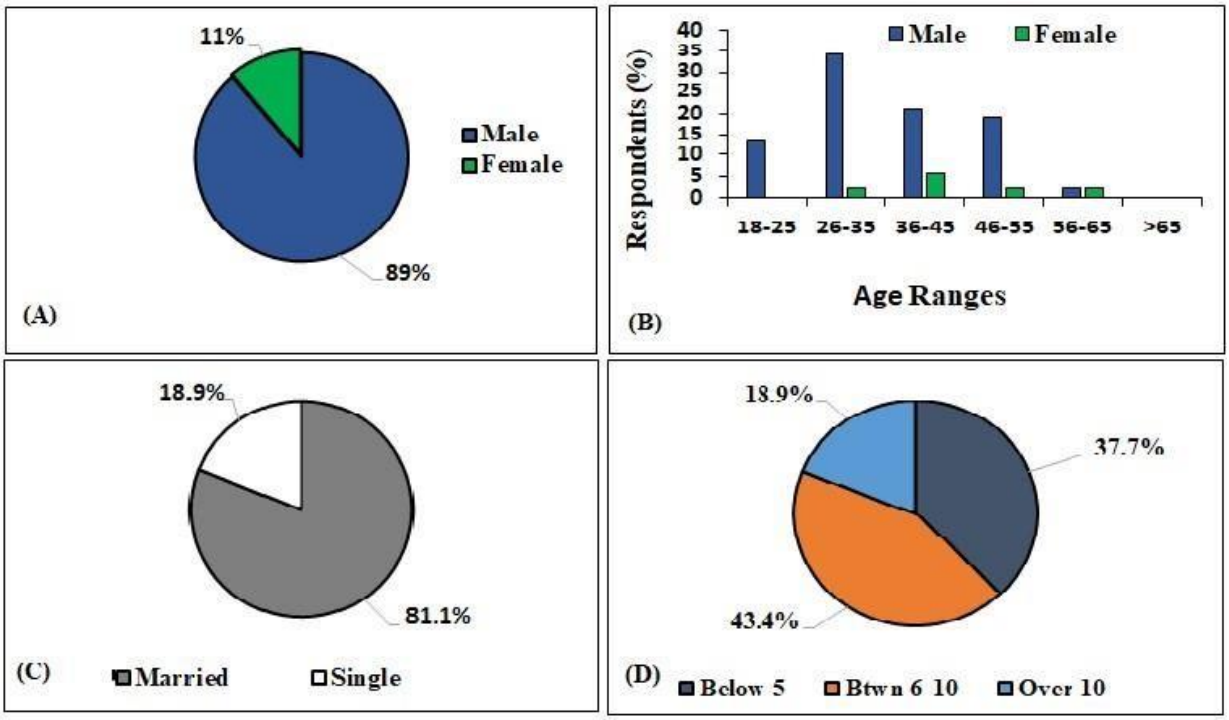


Figure 4.3: Demographic characteristics of Fisher Folks in Lake Naivasha

Results in Figure 4.4 (E) show that, education levels of the fisher folks interviewed ranged from informal education to tertiary education where primary and secondary education had the highest respondents at 38% and 32% respectively. Informal and tertiary education had the lowest number of fisher folks at 15% each. The findings were similar to Nwabeze *et al.* (2012) that the fishing community have a low education status and the less number of fisher folks with tertiary education could be attributed to the fact that the educated are interested in white-collar jobs. Results in Figure 4.4 also show that majority of the fisher folks had an income of less than KES.10, 000 which was perceived only to suffice the basic requirements and contribute to their survival. Thirty-four percent of the fisher folks had an experience of between 1 to 5 years, and 26% had an experience of between 6 to 10 years. This can be explained by the steady increase in Lake Naivasha's water level and surface area since 2010 and opening of Oloiden beach to allow fishing activities in 2019.

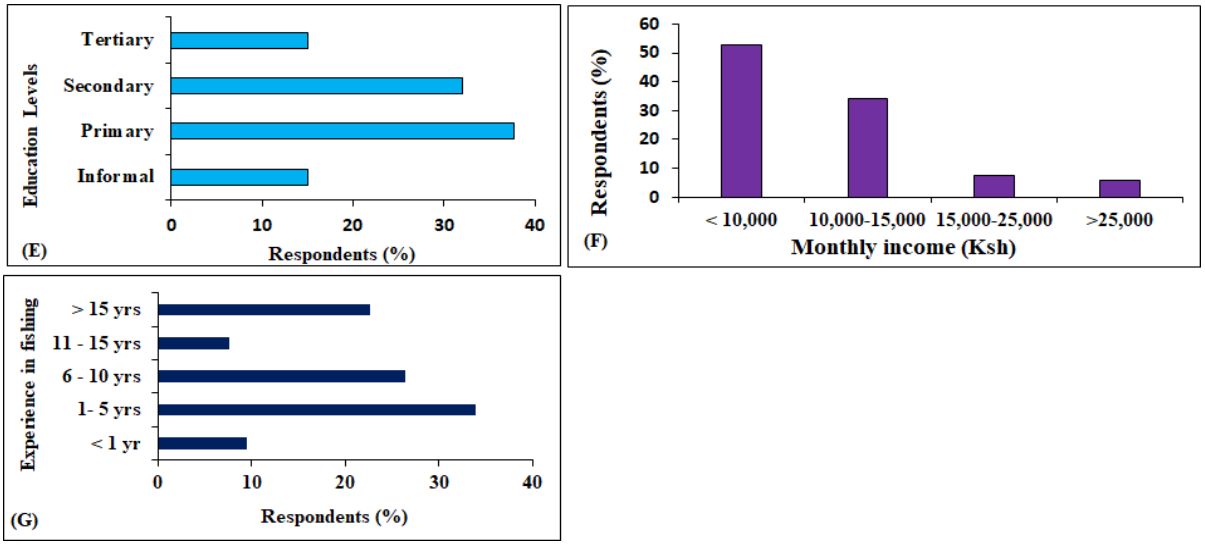


Figure 4.4: Socio-economic characteristics of Fisher Folks in Lake Naivasha

4.3.2 Socio-economic Characteristics of the Tourism and Hospitality workers

Results in Figure 4.5 show that, males (75%) dominated the tourism and hospitality industry. Seventy-four percent of the workers in the tourism and hospitality were between 18 to 35 years which accounted for the findings indicated that the young male hotel staff made up the majority. Seventy-eight percent of the respondents in the tourism and hospitality industry were married and almost 63% of the tourism and hospitality workers had less than 5 dependants.

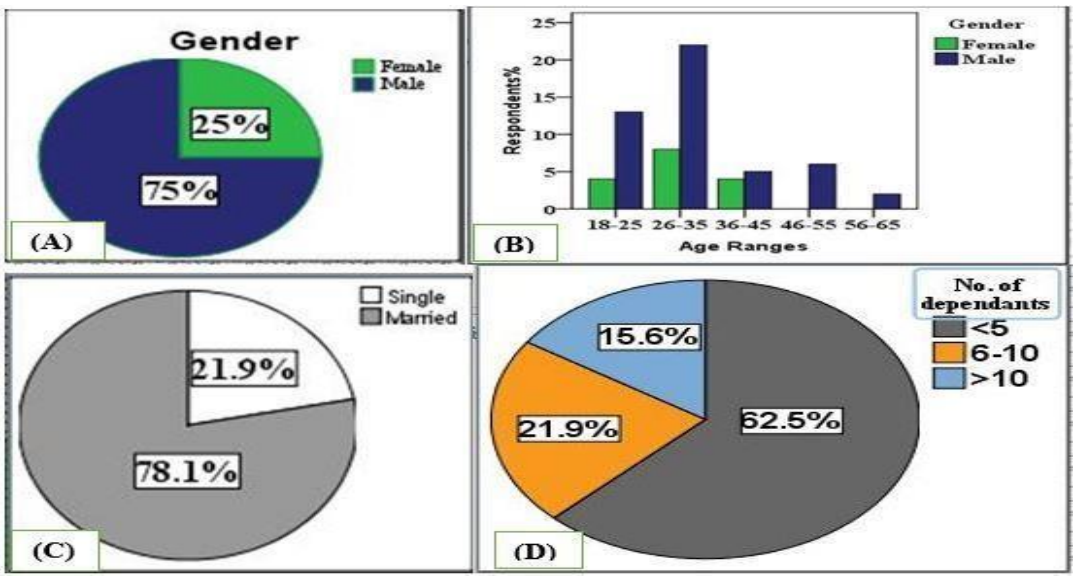


Figure 4.5: Demographic characteristics of Tourism and Hospitality workers in Lake Naivasha

Results in Figure 4.6 show that, majority of the respondents (48.4%) in tourism and hospitality industry workers had tertiary education, while 28.1% of the respondents had secondary

education. In general the literacy level was high because most of the hotels, resorts and lodges receive both international and local tourists. Forty-seven percent accounted for the hospitality industry workers who had a monthly income of between KES. 15,000 and KES. 25,000. This was followed by those who were earning below KES.10, 000 which was very low. Workers in the hospitality industry did not have the same length of attachment to employers. Seventeen percent of the respondents had below 1 year experience while 32.8% had experience of between 1 to 5 years. This could be accounted for by the fact that tourism sector is getting more established in Naivasha area.

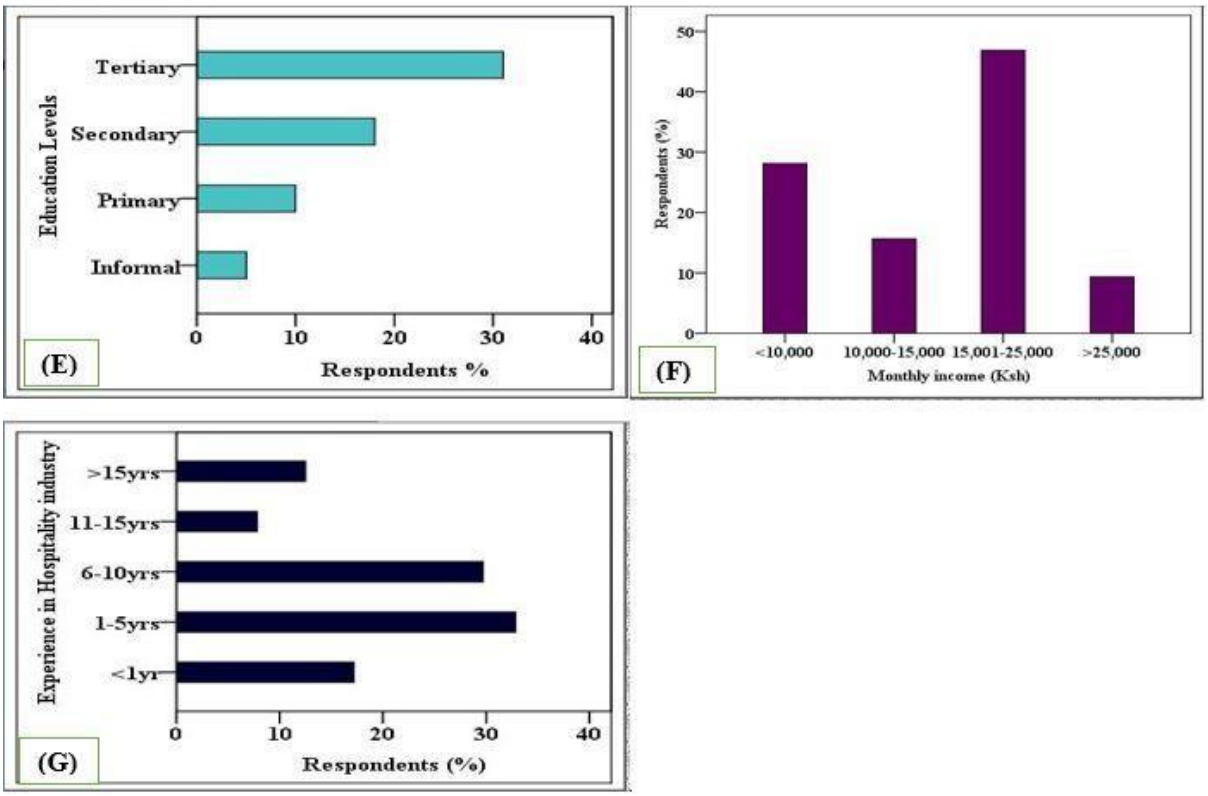


Figure 4.6: Socio-economic characteristics of Tourism and Hospitality workers in Lake Naivasha

4.3.3 Socio-economic Characteristics of the Horticulture workers

Results in Figure 4.7 show that, majority (61%) of the respondents in the horticulture sector were male while 39% were female. The age of majority of the respondents was between 26-35 years. The number of female respondents is due to the fact that in horticulture sector, workers have to perform a range of tasks like planting, irrigating, harvesting and packing. According to International Labour Organization (ILO) 2016, in the Kenyan horticulture industry women are concentrated at production level, and which was in line with the horticulture farms in Lake Naivasha. Women were confined in green houses and fields to labour intensive aspects of planting, weeding and picking activities. Seventy-nine percent of the horticulture workers were married as

indicated in many case studies of Chile and South Africa that majority of the workers were in their 30s and 40s with families (Tsimbiri *et al.,* 2015). Seventy-four percent of the horticulture workers had less than 5 dependants as shown in figure 4.7 (D).

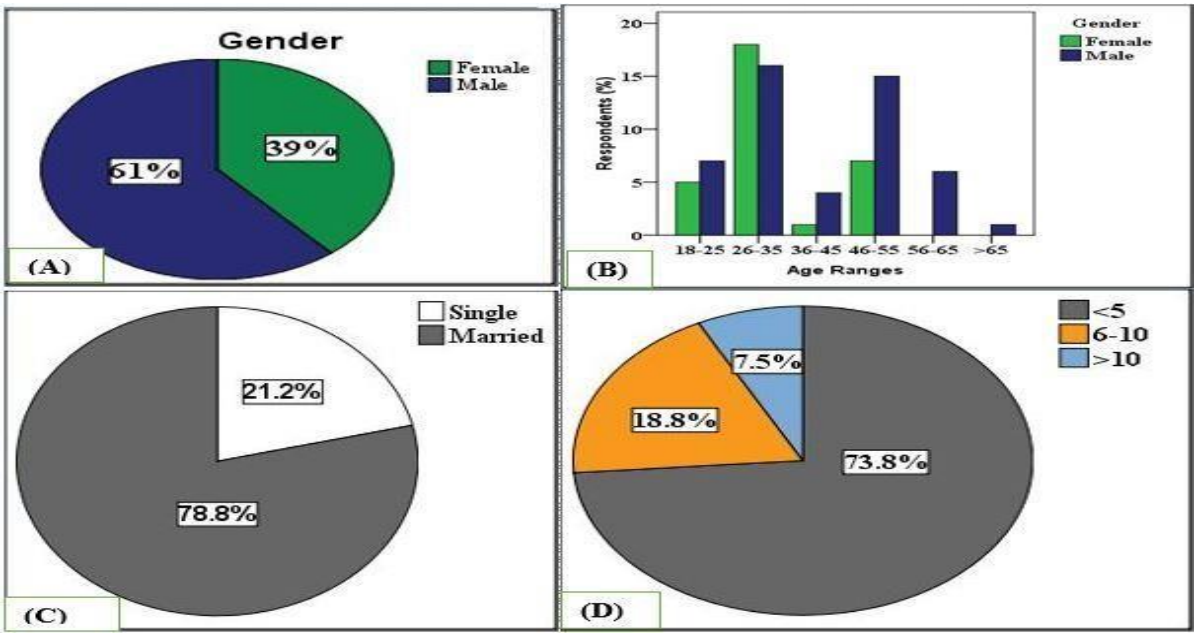


Figure 4.7: Demographic characteristics of Horticulture workers in Lake Naivasha

Results in Figure 4.8 show that, 40% of the respondents had attained tertiary education level, 18.8% of the respondents had primary education, while only 2.5% had informal education. The statistics on education clearly indicated that the horticulture workers within Lake Naivasha area had a fair education level. In farms a higher percentage of educated workers have a positive and significant effect on productivity and therefore continuous improvement on farm technological skills is necessary (Tsimbiri *et al.,* 2015). The results also show that, 31.2% of the farm workers were paid above KES. 25,000 while 30% of the horticulture workers were paid below KES. 10, 000. Since horticulture is a labour-intensive sector, both skilled and accessible labour is crucial for effective productivity on horticulture farms. There is hierarchy of employment in South African horticulture farms, where better incomes are experienced at the higher levels while non-permanent workers at the bottom of the hierarchy generally receive low wages (Barrientos *et al.*, 2005). In Kenya the temporary workers in the cut flower industry work long hours for a low pay. Further, the results show that 38.8% of the horticulture workers had worked in the sector between 6 to 10 years followed by 21.1% of the respondents who had worked in the sector for between 1 to 5 years. The respondents who had stayed longer could have moved from one horticulture farm to another as a result of collapsing and ownership changes.

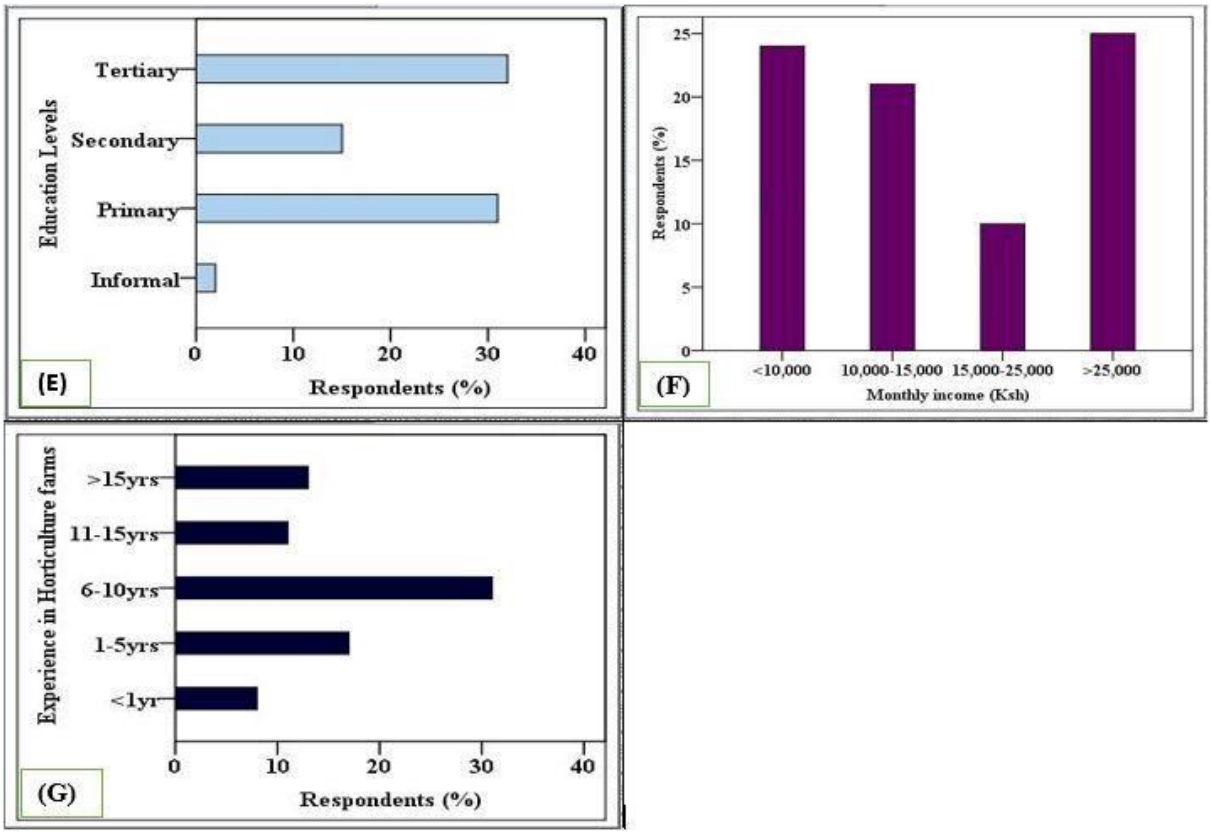


Figure 4.8: Socio-economic characteristics of Horticulture workers in Lake Naivasha

4.4 Effects of water level variability on economic activities in Lake Naivasha

Lake Naivasha water levels depend on the seasons and type of activities carried around the lake. The water level rises after every rainy and El Niño seasons and reduces during drought and La Nina seasons (Ndege, 2019; Otiang'a-Owiti & Oswe, 2007). Water levels in most lakes show positive associations with meteorological and hydrological factors (Muita *et al.*, 2021).

4.4.1 Effects of Water Level Variability on Fish yield and Revenue

Total fish yield from 1989 to 2022 and fish revenue from 2004 to 2021 were regressed against Surface Area Variations (SAV). Pearson's correlation coefficient was used to test the significance of association at 95% confidence level. The results showed a significant moderate positive relationship between Fish yield, Fish revenue and SAV. The Pearson correlation value of fish yield was 0.63 (Table 4.1) and fish revenue was 0.52 (Table 4.2). The R^2 value for fish yield was 0.39, and 0.27 for fish revenue, this indicating that 39% of the total fish yield and 27% of the fish revenue variation could be explained by SAV.

Table 4.1: Total Fish Yield against Surface area Variability

Regression Statistics

Multiple R	0.626102908
R Square	0.392004851
Adjusted R Square	0.371738346
Standard Error	659.1761253
Observations	32

ANOVA

	df	*SS*	*MS*	*F*	Significance *F*
Regression	1	8404570.431	8404570.431	19.342499	0.000126633
Residual	30	13035394.92	434513.1641		
Total	31	21439965.35			

Table 4. 2: Fish revenue against Surface area variability

Regression Statistics

Multiple R	0.521892
R Square	0.272371
Adjusted R Square	0.226894
Standard Error	103482.5
Observations	18

ANOVA

	df	*SS*	*MS*	*F*	Significance *F*
Regression	1	64136447493	6.41E+10	5.989236	0.026315
Residual	16	1.71338E+11	1.07E+10		
Total	17	2.35474E+11			

The total fish yield in Lake Naivasha has been varying with fluctuating water levels and it also depends on the fishery conditions and fishing efforts. The findings were similar to those

reported by Njiru *et al.* (2017) who identified that fish catches show a similar fluctuations as lake levels but habitat variability is one of the most important factors influencing fisheries. A study by Obegi *et al.* (2021) showed that water level fluctuations have dramatic impacts on fish yields as well as plant communities in Lake Naivasha. Also, the biological characteristics of the fish species as well as the interaction between the prey and the predators affect the fish yields.

Fish yield decreased from 238 metric tons in 1992 to 120 metric tons in 1998 but there was a slight recovery in 1999 to 446 metric tons following the previous year's long El-Niño phenomenon. Also another fish landing site was started in 1998, Tarabete beach due to increased water levels. Despite the water levels being high, there was no fish records in 2001 due to increased fishing efforts which led to over fishing in 2000 (Morara *et al.*, 2022). In 2001, the Department of Fisheries reintroduced Nile tilapia (*Oreochromis niloticus*) in Lake Naivasha to enhance the stocks. There was introduction of annual seasonal closure of fishing period between June and September for fish breeding since 2003 but was lifted by the County Government of Nakuru (Njiru *et al.*, 2017). Nile tilapia (*Oreochromis niloticus*) was reintroduced in 2011 and 2014 in Lake Naivasha after disappearing in 1971 to provide exploitable fisheries since it is the most preferred fish species.

Results in Table 4.3 show that reducing water levels led to few fish catch therefore impacting negatively on the fish yield. Yongo *et al.* (2013) pointed out that the relative abundance of tilapias and other fish catch depended on the lake level fluctuations despite any changes in fishing effort. Reduced fish stock directly resulted to reduced level of income among the fisher folks. Reduction in the size of the lake could result to increased number of fish catch as stated by the fisher folks because of fishing in a small area like in the case of 2009 which had 609 metric tons but affected the fish yields in the subsequent years.

Table 4. 3: Effects of reducing water levels on fishing activities

Responses	Yes (%)	No (%)
Increase in number of fish catch	30	70
Few fish catch	57	43
Increased distance to the fishing point	30	70
Increase in number of fisher folks	11	89
Reduced fish sizes	30	70
Increase in fish prices	21	79
Increased fish demand	30	70

Increased income	11	89
Reduced income	36	64
Restriction of fishing by the government	19	81

Results in Table 4.4 show that, when the lake water level increases, there is increase in number of fish catch and an increase in number of fisher folks but a decline in the fish prices. The increase in number of fisher folks is as a result of increased number of illegal fishermen due to the abundance of fish and increase in lake size. Rising lake levels displaced many people from their regular jobs in horticulture farms and tourism industry that they turned to fishing resulting to overfishing. The numbers of fisher folks in Lake Victoria increased during years of abundant rainfall and flooding due to availability of extensive nutrients from flood plains that provided growth in the fishery food chain (Muringai *et al.,* 2022).

According to the Fisheries Department key informants, different boat colours were introduced for identification according to the landing beaches. Tarabete beach has green boats, Karagita has blue boats, Kamere has light blue boats, and Oloiden has light green boats. This would help in identifying the new entrants into the fishing industry. Due to fluctuating water levels and overfishing, there is a change in the composition of fish catch, the tilapias are disappearing while Cat fish (*Clarias gariepinus*) and Common carp (*Cyprinus carpio*) are the most frequently landed fish species (Njiru *et al.,* 2017).

Table 4. 4 : Effects of increasing water levels on fishing activities

Responses	**Yes (%)**	**No (%)**
Increase in number of fish catch	53	47
Few fish catch	26	74
Increase in income	30	70
Increase in number of fisher folks	42	58
Increased boat accidents	2	98
Fishing restrictions	15	85
Low fish demand	23	77
Low fish prices	38	62

Due to increase in water levels in Lake Naivasha, the main lake connected with Lake Oloiden which was alkaline thus changing its water quality and becoming fresh (Ndege, 2019). The less saline water reduced the blue green algae which forced the flamingos to migrate to Lake Elementaita for a new habitat. According to the KMFRI officers, since 2019, fishing activities occurs at Lake Oloiden after the fisher folks were issued with license (Plate 4.1).

Plate 4.1: Fishing boats and nets along Oloiden beach in Lake Naivasha

There is increase in vegetation such as Water hyacinths (*Pontederia crassipes*), papyrus (*Cyperus papyrus*), and grasses due to increase in water level that provides a breeding place for fish. Results in Plate 4.2 show that, water hyacinths (*Pontederia crassipes*) covers a large portion of Lake Naivasha from the shore inwards especially around the mouth of River malewa in the northern and western part of the lake making it difficult for the boats to move. Water hyacinths in Lake Naivasha were reported since 1988 and spread throughout the littoral zones of the lake which affected access to fish zones and infested the lake ecosystem (Obegi *et al.,* 2021). The consequences of rapid spread of water hyacinths in Lake Victoria as reported by the Lake Victoria Environmental Management Project (LVEMP) were; reduction of fish through de-oxygenation but the hyacinths provided a nursery ground for smaller fish. Also, the hyacinths interfered with fishing and transportation of both modern ships and canoes (Kateregga & Sterner, 2007). The rapid increase in the number of catfish (*Clarias gariepinus*), a hardy and tolerant species could be facilitated by the spread of huge mats of water hyacinths in Lake Naivasha (Yongo *et al.,* 2013).

Plate 4.2: Water hyacinths in Tarabete fish landing site in Lake Naivasha

4.4.2 Effects of Water Level Variability on Tourism and Hospitality Industry

Results in Table 4.5 show that, boat ride activities reduces when Lake water level reduces because there is increased distance of pushing the boats from the shore. Sometimes, there are reduced hospitality services to those who entirely depend on the lake and some experience loss of employment. According to KWS officers, when the lake level reduced there was a decrease in the number of wildlife; the hippos got stuck in the mud and died while the grazers had difficulties in reaching the shoreline for water. Reduced bird watching activities is only affected by the decline of fish population therefore affecting the diversity of piscivorous bird communities around the lake (Harper *et al.,* 2011).

Table 4. 5: Effects of reducing water levels on Tourism and Hospitality industry

Responses	Yes (%)	No (%)
Increased employment opportunities	16	84
Loss of employment	34	66
Reduced hospitality services	34	66
Restriction of tourism activities	27	73
Increase in cases of hippopotamus attacks	23	77
Reduced boat ride activities	45	55
Increase in pushing boat distances	38	62
Reduced bird watching activities	27	73
Restructuring of workers	23	77
Increase in off days or leave	8	92

When the lake water level rises those in the tourism and hospitality industry are forced to change tourist sites and during severe rise there is closing down of hotels, lodges and campsites along the lake (Table 4.6). Buildings are submerged, properties are lost and structures are destroyed during extreme flooding of the lake. The massive destruction by rising water leads to staff reduction in hospitality industry. Retaining core personnel, restructuring and downsizing of workers are among the strategies used by hotels during crises to cut costs (Ghazi *et al.,* 2024). A larger section of Kamere and Karagita beaches were submerged forcing business owners to close while Cray fish camp was completely closed. The BMUs were forced to adjust their structures according to the water levels. For hoteliers, the rise and reducing water levels results to adjustments of water jetties and building of ramps during fluctuating water levels. Rising lake levels not only affected the infrastructure but also damaged the ecology on which the tourism industry depends on. Furthermore, there's increased costs of migrating, employing security personnel for safety and putting up electric fences to prevent the hippos from reaching the hotels and campsites.

Table 4.6: Effects of increasing water levels on Tourism and Hospitality industry

Responses	Yes (%)	No (%)
Reduced hospitality services	28	72
Reduced number of tourists	28	72
Reduced income for local business	33	67
Change of tourist sites	52	48
Closing down hotels, lodges and campsites along the lake	44	56
Increase in water related sporting activities	31	69
Increased bird watching activities	28	72
Restriction of tourists to the lake	20	80

The tourism and hospitality industry is vulnerable to a range of crises and disruptive events therefore posing a threat to their long term survival and operation (Ntounis *et al.*, 2022). This was evidenced by the devastation of the rising water calamity causing structures near the lake to be abandoned (Plate 4.3). According to Njogu (2021) replacing or repairing of infrastructure after disaster occurrence is often very costly and difficult to address.

Plate 4.3: Abandoned structures at Cray Fish Camp, Lake Naivasha

4.4.3 Effects of Water Level Variability on Horticulture

Commercial farms surrounding Lake Naivasha are mainly situated in South and North lake and in Flower Business Park (FBP) north of Lake Naivasha. The farms in FBP depends on groundwater (aquifers) while those in North and South lake highly depend on the lake surface water. When the lake water level reduces, the horticulture farms have to reduce their level of water abstraction therefore negatively affecting horticultural crop production and yields. Key informants revealed that during the 2009 drought, the cut-flower farms' were almost restricted from withdrawing of water from the lake. Loss of employment and re-deployment to other sectors in the farm was among the major effects of reduced water level as indicated in Table 4.7.

Table 4.7: Effects of reducing water levels on Horticultural activities

Responses	Yes (%)	No (%)
Increase in employment opportunities	11	89
Loss of employment	39	61
Reduced horticulture yields	59	41
Re-deployment to other sectors in the farm	23	77
Increase in off or leave days	8	92

Results in Table 4.8 show that, increasing water levels has a positive impact on horticulture yields because the farms are given freedom to withdraw more water for their production. Although, extreme rise in the water levels submerges some of the farms close to the lake therefore having a negative impact on horticulture yields and workers employed. Such devastating occurrences can result to withdrawal of existing investments as well as loss of future investment potential around the lake. Also, the rise in lake levels increases the turbidity of the water and therefore increasing the cost of removing the sediments by the farms.

Table 4.8: Effects of increasing water levels on Horticultural activities

Responses	Yes (%)	No (%)
Increase in employment opportunities	30	70
Increase in horticulture yields	45	55
Reduced horticulture yields	33	67
Downsizing of workers	4	96

Loss of employment	28	72
Increase in income for horticulture farms	14	86

4.5 The Adaptation Strategies to water levels variability in Lake Naivasha

To solve Lake Naivasha's frequent water variability, several acts by the national and county governments have been implemented. National Environmental Management Authority (NEMA) created Water Resources Management Authority (WRMA) through the 1999 legislation (Environmental Management and Co-ordination Act) revised 2015, and 2002 Water Act, revised 2015. The water Act 2002 had some radical changes in the management of water resources in Kenya which gave authority to WRMA. It was mandated to conserve, regulate and manage surface and groundwater resources in Kenya, therefore enforcing the Water Act 2002. Water Resources Management Authority (WRMA) was reviewed in 2010 during the new constitution under Section 11 of the Water Act and in 2016 WRMA was changed to Water Resources Authority (WRA) under the counties.

Before 2010, abstraction was not well regulated and in response to the receding water levels and major drought of 2009, there was review of the water allocation plan and abstraction was based on the fluctuation zone. All the stakeholders were involved and LNGG initiated the water balance study. Since 2009, there was lake wide monitoring of abstractions and lake-basin level by WRA with the use telemetry device (Plate 4.4). There is minimisation of water wastage and controlling of unnecessary activities around the lake to ensure proper regulation and management of the water resources for it to be sufficient and clean water for everyone. According to the telemetric device, the green zone allows abstraction of water level up to the limit permitted when the lake levels are high. At the yellow or amber zone, the abstraction level drops by 25% and at the red zone, abstraction for domestic and public water supply is at 75% while others is 50% of the permitted volume. At the black zone, commercial users are stopped and only domestic and public water supplies are allowed at 25 litres per person or livestock per day.

Plate 4.4: A Telemetric device showing the water level of Lake Naivasha along Moi South Lake road

4.5.1: Adaptation strategies of water level variability in the fishing sector

The adaptation strategies in Table 4.9 were ranked using Kendall rank test to identify the most preferred adaptation strategies by the fisher folks in Lake Naivasha. The results showed that majority of the fisher folks (3.47) were reducing the household budget during extreme water variability. Also changing sources of income and setting of emergency funds were among the highly practised adaptation strategies. The findings were in agreement with N'Souvi *et al.* (2024) who identified diversification of economic activities and changes in the fishing ground as adaptation strategies used by majority of the fishermen. Targeting new species, changing fishing gear, relying on social networks and migration are some strategies adopted by fishers (Muringai *et al.*, 2022). Alternative businesses by the fisher folks in Lake Naivasha included looking for temporary work and doing casual jobs like selling of charcoal and firewood to those residing in towns.

Table 4.9:Ranked Fisher folk's Adaptation Strategies to water levels Variability

	Mean Rank
Use of a different fishing method	3.93
Involving in alternative businesses	4.07
Change source of income	3.67
Source fish outside the lake	4.53

Set emergency funds	3.93
Temporary relocation	4.40
Reducing the household budget	3.47

For future sustainability of the fish stock during extreme water variability, BMUs chairpersons suggested that more fish should be brought from hatcheries and fishing methods should be controlled. This response were similar to the findings of Yongo *et al.* (2013) who suggested that restocking will increase the levels of fish catches and the lake water levels would be maintained by encouraging horticulture farms to have their own boreholes. To maintain the fish population in Lake Naivasha, the fisheries management and stakeholders have identified and demarcated critical habitats for fish spawning. These are Crescent Island, at the mouth of river Malewa, Korongo in the northwest and Oserian bay in the Southwest. The fisher folks avoid fishing near the shore so that juvenile fish are not caught and the environment around the beach is being conserved. Mismanagement of fisheries is widely believed to be the primary cause of fisheries collapse as well as ignoring the habitat and other ecosystem components (Morara *et al.,* 2022).

In Lake Naivasha, each beach has a chairperson who mobilises planting of trees and building of gabions to prevent soil erosion and to minimise soil entry to the lake. Maintenance of healthy riparian area is important as the vegetation sieves aquatic pollutants therefore reducing the nonpoint source pollutants received in the lake (Odongo *et al.,* 2015). Also, there is restocking programme to assist in the recovery of fish stocks where the fish fingerlings are sourced from Sagana and other private hatcheries. New fish species can be introduced for production when the lake water level reduces. Common carp is a profitable fish species when fish catch returns from other target species in the lake decline (Njiru *et al.,* 2017).

4.5.2: Adaptation strategies of water level variability in the Tourism and Hospitality industry

Results in Table 4.10 show that, change of income activity and diversification were the most preferred adaptation strategies among Tourism and Hospitality industry workers with a mean rank of 2.28. Setting of emergency funds was the least preferred adaptation strategy. Increase of insurance cover is a must in the tourism and hospitality industry to protect businesses from anticipated increased droughts, flood risk damages and associated weather extreme events (Dube *et al.,* 2021). There were several adaptation strategies challenges to water level variability which included; Inadequate funds, unskilled labour force and poor networking among local citizens and

the disaster management team. Trained skilled personnel's in the rescue team with all necessities in the rescue boats are needed for safety.

Table 4.10: Ranked Tourism and Hospitality industry workers Frequency on the Adaptation Strategies to water levels Variability

	Mean Rank
Income diversification	2.28
Personal insurance	2.66
Set emergency funds	2.78
Change income activity	2.28

Most of the hotels have an insurance cover that compensates the damages in case of extreme water variability. Also, electric fences are used to prevent hippos from the hotels and also trenches have been dug by those close to the lake. To maintain water availability in the hotels, there's water harvesting system from hotel rooftops resulting to less water abstraction from the lake which is for primary use. According to the Rainwater connection (2006), collecting rainwater directly through the gutter system and storing in tanks is an effective method of building freshwater and ensuring no water is lost. Furthermore, the hoteliers treat the waste water in sewers and use the recycled water for other activities like cleaning and irrigating the lawns (grasses, flowers and gardens). Close to the lake the hotels and lodges structures are of semi-permanent materials that are raised and can be moved easily during extreme water level variability. An example of such a structure is shown on Plate 4.5.

Plate 4.5: Tented camps in Lake Naivasha Crescent Camp hotel

4.5.3: Adaptation strategies of water level variability in the Horticulture sector

Several adaptation strategies to water level variability are practised at farm and off-farm levels. Results in Table 4.11 show that, income diversification was the common adaptation strategy among the horticulture workers so as to earn additional income. Income diversification is a prompt security strategy and widely understood to reduce vulnerability (Tofu & Wolka, 2023). Also temporary relocation was highly practised during extreme water variability and leasing of land which was another best practice. Some of the horticulture workers sought employment in Naivasha town for alternative sources of income.

Table 4.11: Ranked Horticulture workers Adaptation Strategies to water levels Variability

	Mean Rank
Income diversification	3.14
Set emergency fund	3.89
Depend on family members	3.78
Temporary relocation	3.22
Lease farms	3.41
Look employment in Naivasha town	3.56

To reduce vulnerability of the horticulture farms around Lake Naivasha, there are various bodies and associations that guide them. The Lake Naivasha Growers Group (LNGG) is a commercial farming body that has its own code of practice relating to water use and environmental impacts that its members have to follow. The horticulture farms are given information on water levels weekly, furthermore there are regular seminars and workshops, impromptu checks and awareness. According to the interviewed farm managers, all farm have installed water meters and are required to reduce water consumption every year by setting a target to improve water management. Also the commercial farms have to compulsory follow the different certification requirements of the consumers.

The horticulture farms have invested in research to reduce water usage where better irrigation technology and closed looped hydroponic systems are used. Some farms are applying computerised irrigation systems to check soil moisture and using coco-peat to improve the soil characteristics. In some greenhouses flowers are grown on trays containing local pumice as substratum which does not retain water unlike soils and all the water is collected back. Hypericum (*Hypericum perforatum*), Gypsophila (*Gypsophila paniculata*) and statice (*Limonium sinuatum*) flower varieties are grown outside green houses and use drip irrigation instead of overhead sprinklers. Also, most farms have a diverse water sources such as lake water, boreholes and rainwater. There's water harvesting system from the greenhouses roof runoff and thus reducing water abstraction from the Lake (Plate 4.6).

Plate 4.6: Water Harvesting from Greenhouses at Florensis Farm in Lake Naivasha

The rain water is collected to a central point and no reverse osmosis or salts are removed as compared to the lake water. Although rainfall in Naivasha is short and erratic, it is economically good to use rain water since it is not treated (Ndege, 2019). Every horticulture farm has a small artificial wetland to clean the waste water to control it from running directly to the lake and avoiding political discourse of fish-kill in the lake like that of around 2010. High volumes of effluents produced by the floricultural industry have been blamed for the decline of fish as well as the African fish eagle (*Haliaeetus vocifer*) around the lake (Njiru *et al.*, 2017).

Plate 4.7: Water Collection at Shalimar Maitri Farm, Lake Naivasha

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Water levels in Lake Naivasha has been varying from 1992 to 2022 depending on the rainy seasons and therefore increasing or decreasing in size. The water levels were increasing from 2010 to 2022 after a decrease from 2000 to 2009. The year 2009 was identified with having a severe decrease in water level. Reduced water levels were as a result of high levels of abstraction, evaporation and deforestation while increased water levels was due to increased precipitation and too much siltation.

The fishery sector was the most affected with variations in water levels as compared to the horticulture and hospitality industry. The fishing sector directly depends on the lake water quantity and quality for sustainability. Hotels, lodges and beaches in the hospitality industry were second most significantly affected by the variation in lake water levels due to increased costs of relocation. Lake Naivasha water level variability does not directly affect the number of visitors. The horticulture sector is less affected by water level variations as they continue to draw the exact amount of water required for production.

The economic sectors exhibited different effects and adaptation strategies to water level variability. Reducing the household budget and changing the source of income was the most preferred water level adaptation strategy among the fisher folk's. The least preferred adaptation strategy by the fisher folks was to source fish outside the lake while in the tourism and hospitality industry setting of emergency funds was the least preferred adaptation strategy. Most of the horticulture workers are immigrants who work in the farms without taking into considerations the variations in water levels and therefore having few adaptation strategies.

There was a positive significant relationship between the fish yield, fish revenue and Lake Naivasha surface area variation. The shrinking water levels resulted to decrease in fish catch which in turn led to decrease in fisher folk's income and total fish revenue. The fish yields reduced in the subsequent years after a decrease in the water levels. Increase in lake water levels led to an increase in the number of fish catch.

5.2 Recommendations

The study recommends the following:

i. The government agencies should continue with monitoring and surveillance of the lake level and quality and riparian zones should be conserved as per the existing wetland act.

We recommend enforcement of the Lake Naivasha Catchment Area Protection Order 2012 so as to protect the Lake's riparian zone and by extension its water quality.

ii. Each economic sector should adhere to the Lake Naivasha Water Basin allocation plan. Awareness should be created on the effects of high water abstraction to economic activities and management guidelines to Lake Naivasha should be reviewed and implemented. Sensitisation should be increased on the need for rainwater harvesting and soil conservation including afforestation and re-afforestation in the area.

iii. The national and county governments should support alternative livelihoods for enhanced food and environmental security. Also, national and county governments should invest in horticulture since it is among the country's top foreign exchange earner and the fourth largest export.

iv. Lake Naivasha water levels should be closely monitored to maintain the high fish catch and revenue collected. Increasing number of fisher folks should be controlled to reduce pressure on the existing fish species and to enhance the fish stock.

5.2.1 Policy Recommendations

The study made the following policy recommendations:

i. Water resource managers should collaborate with other government ministries in maintaining the quality and quantity of Lake Naivasha. Also, the Beach management leaders should encourage the water users the need of conserving the lake riparian zones.

ii. The fisheries, Tourism and Agriculture sectors together with other Non-Governmental agencies associated with Lake Naivasha should build and maintain strong partnership with the locals to support the sustainability of the lake.

iii. Local public response is required for more insights before implementations of the laws governing the lake. Measures to maintain the lake water levels should be diverse to accommodate the livelihoods around the lake.

iv. The State Department for Fisheries should educate those involved in fishing to have a wider scope of aquaculture so as to control the extinction of some fish species in Lake Naivasha.

5.3 Suggestions for Further Research

The following recommended areas of study would help enrich the understanding of the effects of water level variability.

i. Further research is suggested on the impacts of Lake Naivasha catchment practices on water quality.
ii. A study is recommended on the role of groundwater in Lake Naivasha water level variability.

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APPENDICES

Appendix I: Questionnaires for Fisher Folks

I am Mengich Maiba Brenda, a student at Egerton University, pursuing a Master of Art's Degree in Geography, in the Faculty of Environment and Resource Development. I'm conducting a study on 'Assessment of the effects of water level variability on Economic activities and Adaptation Strategies in Lake Naivasha, Kenya'. I seek your consent to participate as one of the respondents in this study. The information collected will be handled with utmost confidentiality and used for academic purposes only.

SERIAL NO ……. DATE ……

SECTION A: Demographic Information and social economic characteristics

1. Gender? Male ☐ Female ☐
2. Age in years? 18-25 ☐ 26-35 ☐ 36-45 ☐ 46-55 ☐ 56-65 ☐ Above 65 ☐
3. Marital Status? Single ☐ Married ☐
4. Number of dependants in your family? Below 5 ☐ 6-10 ☐ Over 10 ☐
5. Education level? Informal schooling ☐ Primary education ☐ Secondary education ☐ Tertiary education ☐
6. Total monthly income? Below KES. 10,000 ☐ Between KES. 10,001-☐,000 Between 15,001-25000 ☐ Above KES.25,000 ☐
7. For how long have you been fishing in the lake? Below 1 year ☐ 1-5 years ☐ 6-10 years ☐ 11-15 years ☐ Above 15 years ☐

SECTION B: Effects of water variability

8. (a) How often do you observe increasing water levels? After every rainy season ☐ During El nino ☐ Constantly increasing ☐ Can't tell ☐

(b) How often do you observe reducing water levels in the lake? During drought ☐ During La nina ☐ During increased farming activities on the shore ☐ Can't tell ☐

9. How can you describe the observed changes in the water level as indicated in question 8? Extremely severe☐ Severe ☐ Moderate ☐ Normal ☐

10. (a) What are the effects of reducing lake water levels to the fishing activities?

Increase in number of fish catch ☐

Few fish catch ☐

Increased distance to the fishing point ☐

Increase in number of fisher folks ☐

Reducing fish sizes ☐

Increase in fish prices ☐

Increased fish demand ☐

Increased income ☐

Reduced income ☐

Restriction of fishing by the government ☐

(b) What are the effects of increasing lake water levels to the fishing activities? Increase in number of fish catch ☐

Few fish catch ☐

Increase in income ☐

Increase in number of fisher folks ☐

Increased boat accidents due to high waves ☐

Fishing restrictions ☐

Low fish demand due to market flooding ☐

Low fish prices due to increase supply ☐

SECTION C: Adaptation strategies

11. As a stakeholder in the fishing industry, how have you responded to changes in lake water levels?

Use of a different fishing method ☐

Involving in business ☐

Change source of income ☐

Source fish outside the lake ☐

Set emergency fund ☐

Temporary relocation ☐

Reducing the household budget ☐

12. Are there any measures put in place by the Government or non- governmental organisations to respond to changes in lake water levels?

Restriction on the fishing methods ☐

Banning of all fishing activities in the lake ☐

Relocation of the people along the lake ☐

Provision of emergency aid to those affected ☐

Deployment of coast guards to monitor the water levels ☐

Continuance surveillance on the lake ☐

13. In your view which measures are suitable in adapting with the effects caused by variations in lake water levels?

Desilting of the lake regularly ☐

Introduction of fish hatcheries in the nearby ponds ☐

Standardisation of the fishing methods and equipment ☐

Restriction on drawing water during dry season ☐

Appendix II: Questionnaires for Horticulture Workers

I am Mengich Maiba Brenda, a student at Egerton University, pursuing a Master of Art's Degree in Geography, in the Faculty of Environment and Resource Development. I'm conducting a study on 'Assessment of the effects of water level variability on Economic activities and Adaptation Strategies in Lake Naivasha, Kenya'. I seek your consent to participate as one of the respondents in this study. The information collected will be handled with utmost confidentiality and used for academic purposes only.

SERIAL NO ……. DATE ……

SECTION A: Demographic Information and social economic characteristics

1. Respondent's gender? Female ☐ Male ☐
2. Age in years? 18-25 ☐ 26-35☐ 36-45 ☐ 46-55 ☐ 56-65 ☐ Above 65 ☐
3. Marital Status? Single ☐ Married ☐
4. Number of dependants in your family? Below 5 ☐ 6-10 ☐ Over 10 ☐
5. Education level? Informal schooling ☐ Primary education ☐ Secondary education ☐ Tertiary education ☐
6. Total monthly income? Below KES. 10,000 ☐ Between KES. 10,0001-15,000 ☐ Between KES 15001-25000☐ Above KES.25,000 ☐
7. For how long have you been working in the horticulture farms? Below 1 year ☐1-5 years ☐ 6-10 years ☐ 11-15 years ☐ Above 15 years ☐

SECTION B: Effects of water variability

8.(a) How often do you observe increasing water levels? After every rainy season ☐ During El nino ☐ Constantly increasing ☐ Can't tell ☐

(b) How often do you observe reducing water levels in the lake? During drought ☐ During La nina ☐ During increased farming activities on the shore ☐ Can't tell ☐

9. How can you describe the observed changes in the water level as indicated in question 8?

Extremely severe ☐ Severe ☐ Moderate ☐ Normal ☐

10. (a) What are the effects of reducing lake water levels to the horticultural activities?

Increase in employment opportunities ☐

Loss of employment ☐

Reduced horticulture yields ☐

Re-deployment to other sectors in the farm ☐

Increase in off or leave days ☐

(b) What were the effects of increasing water levels to the horticultural activities?

Increase in employment opportunities ☐

Increased horticulture yields ☐

Reduced horticulture yields ☐

Downsizing of workers ☐

Loss of employment ☐

Increase in income for horticulture farms ☐

SECTION C: Adaptation strategies

11 .As a stakeholder in horticulture how have you responded to changes in lake water levels?

Income diversification ☐

Set emergency fund ☐

Dependent on family members ☐

Temporary relocation ☐

Lease farms for crop cultivation ☐

Look for employment in Naivasha town ☐

12. Are there any measures put in place by the Government or non- governmental organisations to respond to changes in lake water levels?

Restriction on drawing water from the lake ☐

Minimising horticultural activities around the lake ☐

Drawing water from other sources ☐

Provision of modern irrigation equipment's ☐

Provision of information on the expected water level changes ☐

Relocation of horticulture workers around the lake ☐

Provision of emergency aid to those affected ☐

Deployment of coast guards to monitor generator oil leakage and pollution ☐

Continuance surveillance on the lake ☐

13. In your view which measures are suitable in adapting with the impacts caused by variations in lake water levels?

Introduction of check dams ☐

Building of terraces and trenches ☐

Provision of education by Agriculture Extension officers on modern irrigation methods and tools ☐

Educating the workers on the need for savings ☐

Appendix III: Questionnaires for Workers in Tourism and Hospitality Industry

I am Mengich Maiba Brenda, a student at Egerton University, pursuing a Master of Art's Degree in Geography, in the Faculty of Environment and Resource Development. I'm conducting a study on 'Assessment of the effects of water level variability on Economic activities and Adaptation Strategies in Lake Naivasha, Kenya'. I seek your consent to participate as one of the respondents in this study. The information collected will be handled with utmost confidentiality and used for academic purposes only.

SERIAL NO ……. DATE ……

SECTION A: Demographic Information and social economic characteristics

1. Respondent's gender? Female ☐ Male ☐
2. Age in years? 18-25 ☐ 26-35☐ 36-45 ☐ 46-55 ☐ 56-65 ☐ Above 65 ☐
3. Marital Status? Single ☐ Married ☐
4. Number of dependants in your family? Below 5 ☐ 6-10 ☐ Over 10 ☐
5. Education level? Informal schooling ☐ Primary education ☐
   Secondary education ☐ Tertiary education ☐
6. Total monthly income? Below KES. 10,000 ☐
   Between KES. 10,001-15000 ☐Between KES 15001-2500☐ Above KES.25,000☐
7. For how long have you been working in the hospitality industry? Below 1 year ☐
   1-5 years ☐ 6-10 years ☐ 11-15 years ☐ Above 15 years ☐

SECTION B: Effects of water variability

8. (a) How often do you observe increasing water levels? After every rainy season ☐
During El nino ☐ Constantly increasing ☐ Can't tell ☐
(b) How often do you observe reducing water levels in the lake? During drought ☐ During La nina ☐ During increased farming activities on the shore ☐ Can't tell ☐
9. How can you describe the observed changes in the water level as indicated in question 8?
Extremely severe ☐ Severe ☐ Moderate ☐Normal ☐
10. (a) What are the effects of reducing lake water levels to the tourism and hospitality industry?
Increased employment opportunities ☐
Loss of employment ☐
Reduced hospitality services due to reduced tourists ☐
Restriction of tourism activities ☐
Increase cases of hippopotamus attacks ☐

Reduced boat ride activities ☐

Increase in pushing boat distances ☐

Reduced bird watching activities ☐

Restructuring of workers ☐

Increase in off days or leave ☐

(b) What are the effects of increasing water levels to the tourism and hospitality industry?

Reduced hospitality services ☐

Reduced number of tourists ☐

Reduced income for local business ☐

Change of tourist sites ☐

Closing down hotels, lodges and campsites along the lake ☐

Increase in water related sporting activities ☐

Increased bird watching activities ☐

Restriction of tourists to the lake ☐

SECTION C: Adaptation strategies

11 .As a stakeholder in the tourism and hospitality industry how have you responded to changes in lake water levels?

Income diversification ☐

Personal insurance due to increased boat accidents and hippo attack ☐

Set emergency fund ☐

Change income activity ☐

12. Are there any measures put in place by the Government or non- governmental organisations to respond to changes in lake water levels?

Restriction of access to the lake during high water levels ☐

Sensitization forums and workshops on safety measures ☐

Continuance surveillance on the lake ☐

Provision of Financial literacy trainings for workers ☐

13. In your view which measures are suitable in adapting with the impacts caused by variations in lake water levels?

Introduction of entrance fee to improve tourism industry ☐

Introduction of safety measures to the boat users ☐

Licencing of tour operators in the lake ☐

KWS should educate workers on dealing with hippopotamus ☐

Appendix IV: Key Informant Interview Schedule

The objective of this interview is to 'Assess the effects of water level variability on economic activities and Adaptation Strategies in Lake Naivasha, Kenya.' The target populations are government and non-governmental organisation heads such as KWS, BMU, LNRA, LNGG and KMFRI officers.

Date……. Institution……. Position……..

Scheduled Questions

1. How can you describe the changes in lake water level?
2. What are the effects of lake water levels receding and rising?
3. What are the roles of your office during extreme changes in lake water levels?
4. What are the costs incurred during extreme changes in lake water levels?
5. How do fisher folks, horticulture workers and hospitality industry workers respond to extreme water variability?
6. What are the Adaptation strategies adopted by fisher folks, horticulture workers and hospitality industry workers in the lake?
7. How are the different water users prepared for extreme water variability?
8. What are the County and National government water level variability preparedness strategies?
9. What are some of the activities undertaken to enhance water level variability preparedness strategies?
10. What are the adaptation challenges strategies facing water users in the lake?
11. What can be done to enhance water variability adaptation strategies in the lake?

Appendix V: Introduction Letter NACOSTI

EGERTON UNIVERSITY
Tel: Pilot: 254-51-2217620
254-51-2217877
254-51-2217631
Dir line/Fax: 254-51-2217847
Cell Phone
P.O. Box 536 - 20115
Egerton, Njoro, Kenya
Email: bpgs@egerton.ac.ke
www.egerton.ac.ke

OFFICE OF THE DIRECTOR GRADUATE SCHOOL

NM13/04056/22 — 21st December, 2023
Ref:..... Date:.....

The Director General
National Commission for Science Technology and Innovation,
P. O. Box 30623-00100
NAIROBI.

Dear Sir,

RE: REQUEST FOR RESEARCH PERMIT – MS. BRENDA MAIBA MENGICH REG. NO. NM13/04056/22

This is to introduce and confirm to you that the above named student is in the Department of Geography, Faculty of Environment & Resources Development, Egerton University.

She is a bona-fide registered M.A student in this University. Her research topic is **"Assessment of the Effects of Water Level Variability on Economic Activities and Adaptation Strategies in Lake Naivasha, Kenya."**

She is at the stage of collecting field data. Please issue her with a research permit to enable her undertake the studies.

Your kind assistance to her will be highly appreciated.

Yours faithfully,

22 DEC 2023

Prof. George M. Ogendi, PhD
DIRECTOR, DIRECTORATE OF POSTGRADUATE STUDIES

GMO/vk

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Appendix VI: Egerton University Ethical Clearance

EGERTON UNIVERSITY

TEL: (051) 2217808
FAX: 051-2217942

P. O. BOX 536
EGERTON

EGERTON UNIVERSITY INSTITUTIONAL SCIENTIFIC AND ETHICS REVIEW COMMITTEE

EU/RE/DIR/009
Approval No. EUISERC/APP/308/2024 ***20th February* 2024**

Mengich Maiba Brenda,
P.O Box 536-20115,
Egerton
Telephone: +254(0)795014592
brendamengich@gmail.com/mengich.0405622@student.egerton.ac.ke

Dear Brenda,

RE: ETHICAL APPROVAL: ASSESSMENT OF THE EFFECTS OF WATER LEVEL VARIABILITY ON ECONOMIC ACTIVITIES AND ADAPTATION STRATEGIES IN LAKE NAIVASHA, KENYA

This is to inform you that the ***Egerton University Institutional Scientific and Ethics Review Committee*** has reviewed and approved your above research proposal. Your application approval number is ***EUISERC/APP/308/2024***. The approval period is ***20th February 2024 – 21st February, 2025***

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by ***Egerton University Institutional Scientific and Ethics Review Committee***.
iii. Death and life-threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to ***Egerton University Institutional Scientific and Ethics Review Committee*** within 72 hours of notification
iv. Any changes, anticipated or otherwise that may increase the risks or affect safety or welfare of study participants and others or affect the integrity of the research must be reported to ***Egerton University Institutional Scientific and Ethics Review Committee*** within 72 hours.
v. Clearance for Material Transfer of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to ***Egerton University Institutional Scientific and Ethics Review Committee***.

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

Date. 20/02/2024

Yours sincerely.

Prof. Raphael M. Ngure
CHAIRMAN, EGERTON UNIVERSITY INSTITUTIONAL SCIENTIFIC AND ETHICS REVIEW CTTEE
RMN/BK/

Appendix VII: NACOSTI Research License

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **184694**

Date of Issue: **12/January/2024**

RESEARCH LICENSE

This is to Certify that Miss.. BRENDA MAIBA MENGICH of Egerton University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Nakuru on the topic: ASSESSMENT OF THE EFFECTS OF WATER LEVEL VARIABILITY ON ECONOMIC ACTIVITIES AND ADAPTATION STRATEGIES IN LAKE NAIVASHA, KENYA for the period ending : 12/January/2025.

License No: **NACOSTI/P/24/32435**

184694

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

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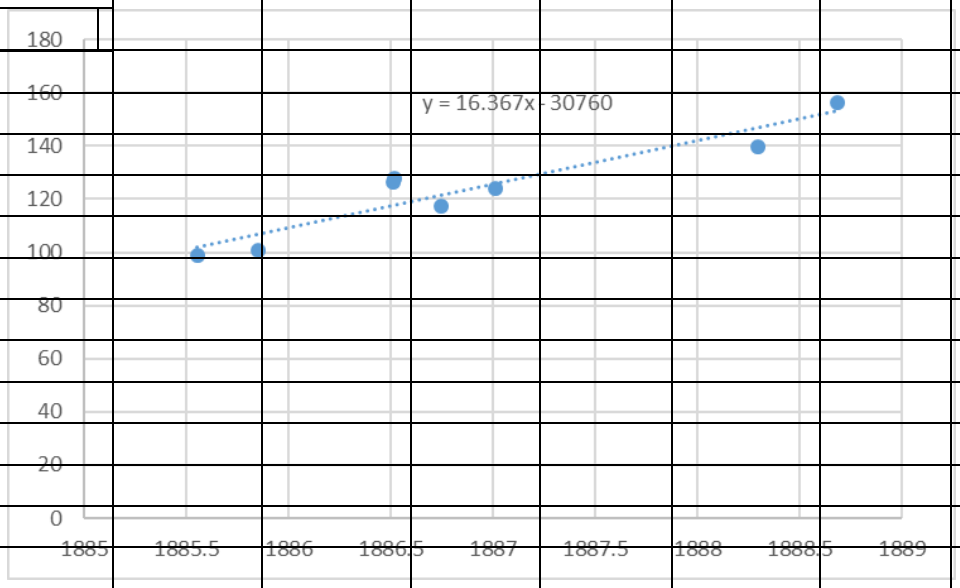
See overleaf for conditions

Appendix VIII: Lake Level (m.a.s.l) – Surface Area (Km^2) Correlation model

								Years	WLF	SAV	
								1989	1887.011	124.7009	
								1991	1887.526	133.1353	
Year	WLF	SAF						**1992**	1887.054	125.4155	
1989	1887.011	123.7892						**1993**	1887.285	129.1936	
1995	1886.51	126.2326						**1994**	1886.487	116.1273	
2000	1886.521	127.8649						**1995**	1886.51	116.5092	
2003	1886.746	117.5872						**1996**	1886.357	113.9996	
2009	1885.555	98.6358			*Column 1*	*Column 2*		**1997**	1886.145	110.5352	
2010	1885.855	100.6259		Column 1	1			**1998**	1888.464	148.4882	
2015	1888.297	139.7736		Column 2	0.937923	1		**1999**	1887.956	140.1723	
2020	1888.68	156.3125						**2000**	1886.521	116.6842	
2022								**2001**	1886.207	111.5457	
								2002	1886.264	112.4802	
								2003	1886.746	120.3688	
								2004	1886.555	117.2385	
								2005	1885.971	107.6831	
								2006	1885.725	103.6644	
								2007	1886.511	116.5237	
								2008	1886.118	110.0858	
								2009	1885.555	100.883	
								2010	1885.855	105.7964	
								2011	1886.517	116.628	
								2012	1888.055	141.7984	
								2013	1889.096	158.8407	
								2014	1889.17	160.0517	
								2015	1888.297	145.7639	
								2016	1888.912	155.8249	
								2017	1887.998	140.866	
								2018	1888.737	152.9565	
								2019	1888.47	148.5885	
								2020	1888.68	152.0256	
								2021	1888.17	143.6784	
								2022	1889.78	170.0293	



Appendix IX: Fish Yield Vs Surface Area Variability

Regression Statistics	
Multiple R	0.626102908
R Square	0.392004851
Adjusted R Square	0.371738346
Standard Error	659.1761253
Observations	32

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	8404570.431	8404570.431	19.342499	0.000126633
Residual	30	13035394.92	434513.1641		
Total	31	21439965.35			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*L 9*
Intercept	-2840.723631	800.453441	-3.548893022	0.0012967	-4475.467647	-1205.979616	-
SAV	26.81257212	6.096522578	4.398010797	0.0001266	14.36181198	39.26333226	1

FISH REVENUE VS SAV

Regression Statistics	
Multiple R	0.521892
R Square	0.272371
Adjusted R Square	0.226894
Standard Error	103482.5
Observations	18

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	64136447493	6.41E+10	5.989236	0.026315
Residual	16	1.71338E+11	1.07E+10		
Total	17	2.35474E+11			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*
Intercept	-283691	155663.7716	-1.82246	0.087129	-613683	46301.94	-613683
Sav	2846.9	1163.285806	2.447292	0.026315	380.8438	5312.955	380.8438

Appendix X: Research Pictorials

Fisher folks interview in Oloiden Beach, Lake Naivasha.

Ecotourism boats in Karagita beach, Lake Naivasha.

Destroyed horticulture water pump house due to rising water levels in Lake Naivasha

Encroached Macrophytes in the Northwest of Lake Naivasha

Appendix X1: Publication

Effects of Surface Area and Water Level Variability on Fisheries Production in Lake Naivasha, Kenya

Brenda M. Mengich[1], Amon M. Karanja[2], George M. Ogendi[3], & George N. Morara[4]

[1]*Department of Geography, Egerton University, Kenya (mengich.0405622@student.egerton.ac.ke)*

[2]*Department of Geography, Egerton University, Kenya*

[3]*Department of Environmental Science, Egerton University, Kenya*

[4]*Kenya Marine and Fisheries Research Institute, Kenya.*

https://doi.org/10.62049/jkncu.v4i2.132

Abstract

Lake Naivasha is a freshwater, a Ramsar site and an Important Bird Area. It provides multiple services to the surrounding communities such as Fishing, Tourism and Agriculture. Lake Naivasha has been experiencing a water level variation cycle over the years as a result of it being shallow and experiencing high evaporation. Variation in water levels leads to flooding, and receding which disrupts the Lake ecosystem thus causing direct and indirect effects on fishing. The study was conducted to establish the relationship between Surface area and water level variability and fish yield and revenue in Lake Naivasha. Primary data was collected using a semi-structured questionnaire, and Key informant interviews. Secondary data was collected using Landsat images that provided the temporal and spatial water level variability and documentary analysis between 1989 to 2022. Both descriptive statistics and inferential statistics were used for data analysis. The results show a positive correlation between Surface area Variability and fish yield (r= 0.6261, R2= 0.3920) and fish revenue (r= 0.5219, R2= 0.2724). Surface area variability accounts for 39% of the variation in total fish yield, and 27% of the fish revenue. The study recommends continuous monitoring and surveillance of the lake level, and water quality by the relevant government agencies, as well as watershed management and conservation measures for the sustainability of the Lake's fishery.

Keywords: Fish Yield, Fish Revenue, Lake Naivasha, Surface Area Variations, Satellite Images, Water Level Variability