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

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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

Introduction

Lake Water Level Variability

Lake water levels respond to long-term wet and dry climatic cycles, with annual variations superimposed on these long-term variations (Chevallier *et al.,* 2011). Water level can change several meters within few months, causing a horizontal change of several kilometers 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. Variations in lakes worldwide attract 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). 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).

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 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).

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 led 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 affects the sea level causing floods in lagoons and in low lying lakes such as Lake Nokoue in southern Benin (Zandagba *et al.*, 2016).

Lake Naivasha in Kenya was postulated to have experienced a rapid decrease between 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. 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). 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.

Lake Fisheries

Globally inland water sources have exhibited a steady yearly increase with high fish diversity and therefore support 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.

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.

Objective of the Study

The objective of the study was to contribute to the understanding of the effects of Surface area and water level variability on fishery in Lake Naivasha.

Materials and Methods

Description of the Study Area

The study was conducted in Lake Naivasha, Nakuru County, Kenya. 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 Eburu 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).

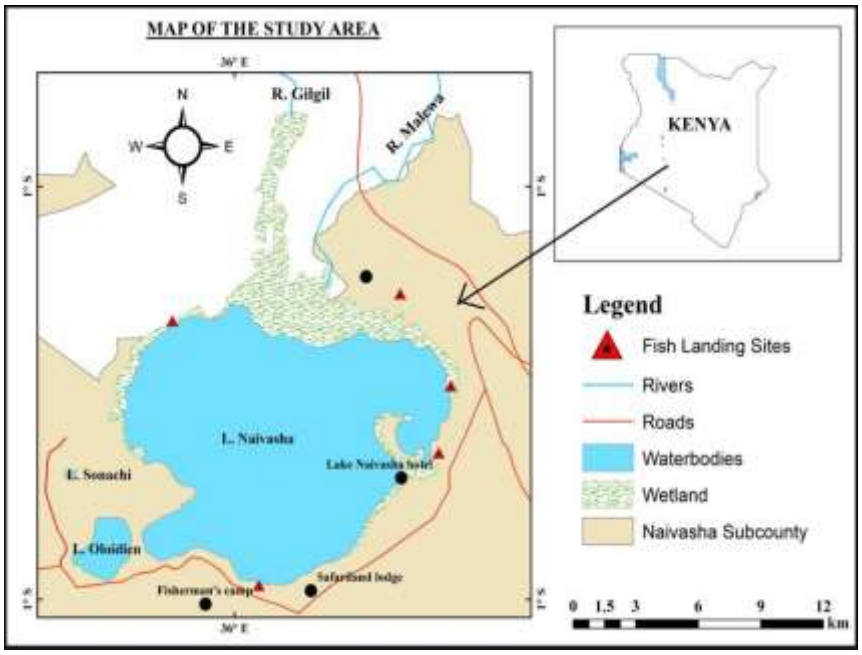

Figure 1: Map of the study area showing study sites.

Source: *Survey of Kenya (2022)*

Data Collection and Analysis

Landsat images from 1989 to 2022 were used to obtain the spatial variation of the water levels over study-year period. The Landsat images were downloaded from the United States Geological Survey (USGS) Earth Explorer website. The measurement tool of Arc map was used to obtain the area of the lake in km^2 for each year by clicking around the edge of the Lake. Data on water level variability in m. a.s.l was based on the records kept by Water Resource Authority, Naivasha to validate the spatial extent of the lake.

Total Fish yield data and revenue records were obtained from Kenya Marine and Fisheries Research Institute (KMFRI), Naivasha. Additional primary data was collected from 53 fisher folks using a semi-structured questionnaire. Pearson Correlation coefficient at 95% confidence level was used to find out whether there was a relationship between surface area and water level variability and fish yield and revenue in Lake Naivasha. Fish yield, and fish revenue were treated as dependent variables whereas water Surface Area and water level variability was the independent variable.

Results and Discussions

Lake Naivasha Surface Area and Water Level Variability

Due to Lake Naivasha shallow depth, any change in water level is reflected on the margin area of the lake hence showing a variation on the lake size. 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 (Otiang'a-Owiti & Oswe, 2007; Ndege, 2019). Water levels in most lakes show positive associations with meteorological and hydrological factors (Muita *et al.*, 2021).

Surface Area and Water Level Variability were plotted against the years using Microsoft Excel to visualize the trend of Lake Naivasha water variability from 1989 to 2022. The yearly water level variations in Lake Naivasha depict frequent changes between 1989 and 2022 as shown in Figure 2.

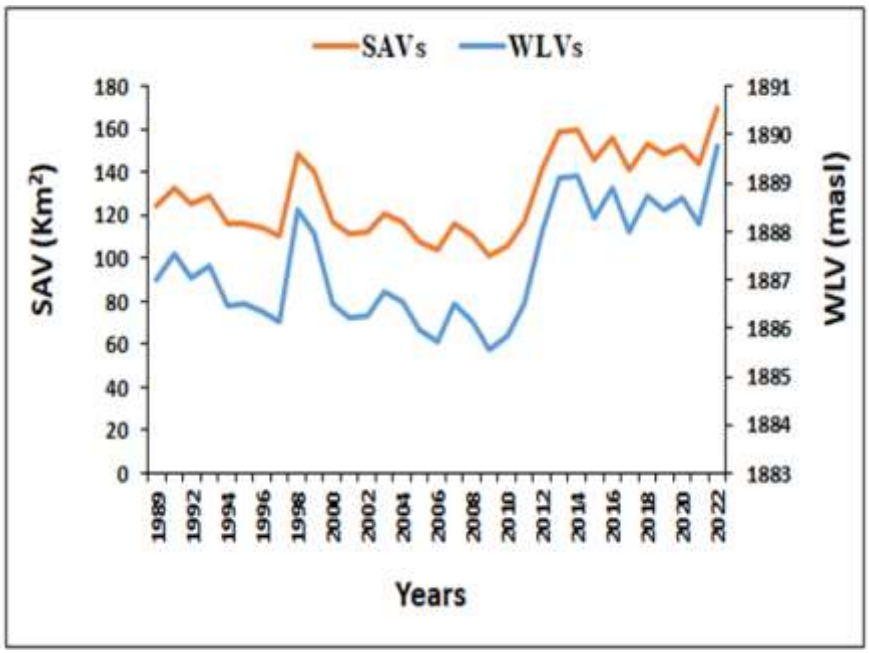

Figure 2: Lake Naivasha surface area and Water level variability between 1989 and 2022

Source: Author (2024)

Socio-Economic Characteristics of The Respondents

The fishing activity in Lake Naivasha attracts different people of various socio-economic backgrounds and gender. The fisher folks' respondents were classified and analysed on the basis of demographic (gender, age, marital status, dependents) and socio-economic (education level, monthly income, years of experience) characteristics.

Results in Figure 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.\

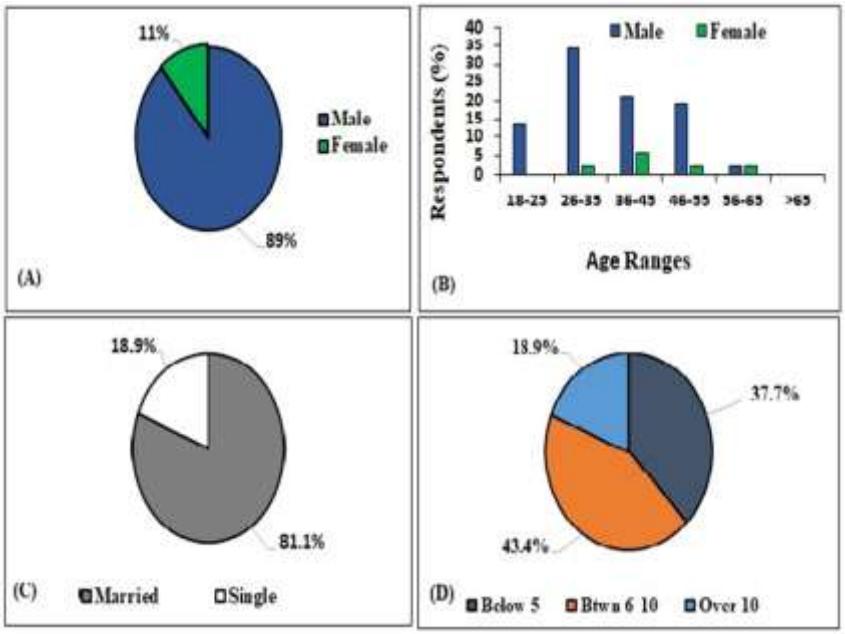

Figure 3: Socio-economic characteristics of fisher folks in Lake Naivasha

Source: Author (2024)

Results in Figure 4 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 fishing 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 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.

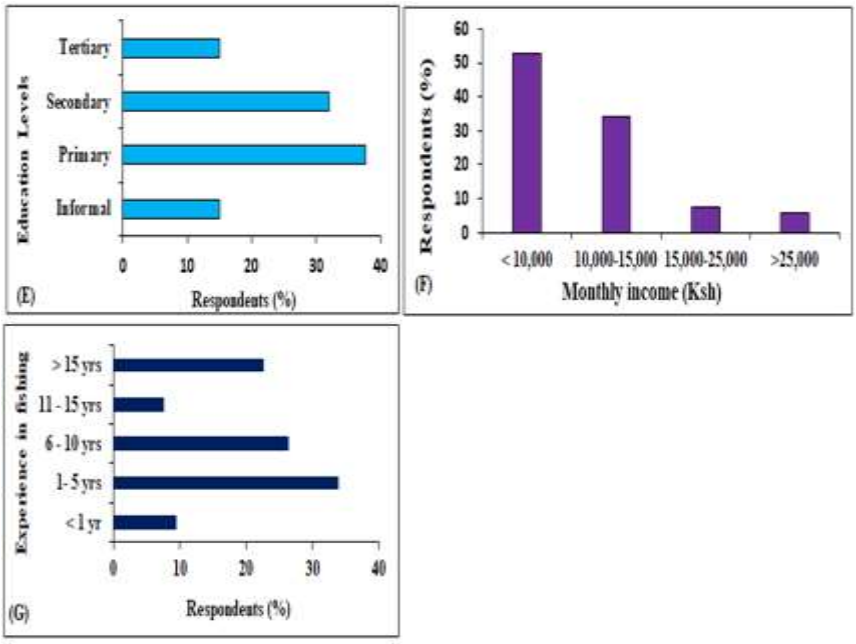

Figure 4:Socio-economic characteristics of Fisher Folks in Lake Naivasha

Source: Author (2024)

3.2 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). The results in Figure 5 showed a moderate significance positive relationship between Fish yield, Fish revenue and SAV. 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 explains 39% of the variation in total fish yield, and 27% of the fish revenue.

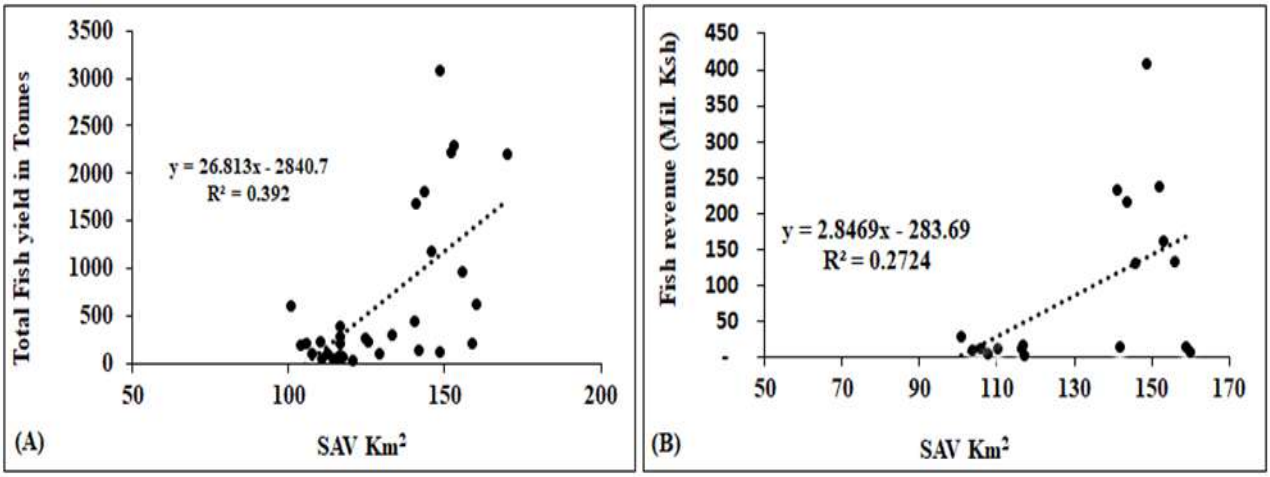

Figure 5: Total Fish yield and Fish revenue against Surface area variability

Source: Author (2024)

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 that 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. Further, the biological characteristics of the fish species as well as the interaction between the prey and the predators affect the fish yields.

In Lake Naivasha, 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.

Decline in fish yield as a result of reducing water levels were concurrent with other studies globally. 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). Furthermore, 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).

Results in Table 1 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 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 1: Cross Tabulation of the 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

Source: Author (2024)

Results in Table 2 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 2: Cross Tabulation of the 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

Source: Author (2024)

Due to increase in water levels in Lake Naivasha, the lake was 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 Kenya Marine and Fisheries Research Institute officers, since 2019, fishing activities occurs at Lake Oloiden after the fisher folks were issued with license (Plate 1).

Plate 1:: Fishing boats and nets along Oloiden beach in Lake Naivasha

Source: Author (2024)

There is an 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 2 show that, water hyacinths (*Pontederia crassipes)* cover 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 2: Water hyacinths in Tarabete fish landing site in Lake Naivasha.

Source: Author (2024)

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).

Conclusion

There was a positive significance 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. There is need for 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.

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Conflict of interest

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