AN ASSESSMENT OF THE EFFECTS OF CANALIZATION ON THE WATER QUALITY AND BIRDLIFE IN LAKE NAIVASHA

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A PROJECT REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF ARTS IN ENVIRONMENTAL PLANNING AND MANAGEMENT (EPM) OF THE DEPARTMENT OF GEOGRAPHY & ENVIRONMENTAL STUDIES, UNIVERSITY OF NAIROBI, KENYA

2016

DECLARATION

This project report is my original work and has not been presented for examination in any other university.

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C50/9146/2004

This project report has been submitted for examination with my approval as university supervisor

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DEDICATION

This work is dedicated to all those who have worked tirelessly in public service to aid in environmentally sound and sustainable practices. For your leadership and nurture that has often times been overlooked and your persistence in the midst of significant odds; I salute you! A day will come when you efforts will be recognized and your labour rewarded. God will not allow a good deed or sacrifice to be offered in vain. “So be steadfast and immovable always abounding in good deeds knowing your labour will be rewarded by God” I Corinthians 15:58

ACKNOWLEDGEMENTS

This research would not have been realized without the assistance and moral support of many. I am most thankful to Dr. Francis Mwaura, my Supervisor, who gave me new insights to academic thinking and for his altruistic support at every stage, having accompanied me on two trips into Lake Naivasha. Madam Belinda Rego, the other supervisor is now retired but is equally appreciated. I wish to thank the Government of Kenya and especially the Ministry of Fisheries staff who labored along us by both availing transport within the lake and giving technical advice and information that has been invaluable in this research. I will single the District Fisheries Officer Mr. Vincent Kinyua, Mr. John Kamau a Fisheries Assistant and Coxswain and Euster Agamara for your tremendous input. I also wish to appreciate staff at WRMA as they were most helpful in availing requested data. Last but not least, Tiffany Mwake, the quiet but very helpful assistant. May the good God bless you.

Repeat fieldwork would not have been possible without the support from my friends. I almost gave in after the adversity of losing two laptops and a computer with my data in a span of just a week. I am indebted forever for their encouragement and appreciate the University of Nairobi and supervisors for granting me an extension of registration which enabled me to complete this work.

However, I owe the biggest thank you and appreciation to God Almighty and to my family. To my lovely wife Nancy Mwabili for her support and patience, especially on learning of our dangerous escape from a Hippo attack in Lake Naivasha, when we got stuck in mud at nightfall in the middle of the lake!

ACRONYMS AND ABBREVIATIONS

CSOs	Civil Society Organizations
CoP	Convention of the Parties
DDC	District Development Committee
DO	Dissolved Oxygen
DRSRS	Department of Resource Surveys and Remote Sensing
EAC	East African Community
EIA	Environmental Impact Assessment
EMCA	Environmental Management and Coordination Act
FD	Fisheries Development
ha	hectares
GIS	Geographical Information Systems
IBA	Important Bird Area
IMP	Integrated Management Plan
IUCN	International Union for Conservation of Nature
KARI	Kenya Agricultural Research Institute
KEMFRI	Kenya Marine Fisheries Research Institute
KENGEN	Kenya's Electricity Generation Company of Kenya.
Kshs	Kenya Shillings
Km^2	Kilometers Squared
LN	Lake Naivasha
LNGG	Lake Naivasha Growers Group
LNIMP	Lake Naivasha Integrated Management Plan
LNRA	Lake Naivasha Riparian Association
LNROA	Lake Naivasha Riparian Owners Association
M&E	Monitoring and Evaluation
masl	Metres above sea level
mg/l	Milligram/litre
ORP	Oxygen Redox Potential
µs cm-1	Microsiemens per centimeter
MoA	Ministry of Agriculture
WAP	Water Allocation Plan
WAS	Water Abstraction Survey
WRB	Water Regulatory Board
WRMA	Water Resources Management Authority
WRUAs	Water Resource Users Associations

ABSTRACT

Lake Naivasha which is approximately 150 km^2, supports large scale production of flowers for the European market. This has significantly raised the water abstraction levels with the horticulture farms around the lake digging canals with which to draw irrigation water from the lake. The aim of the study was to assess whether canalization of the shoreline significantly affects water quality and birdlife distribution in Lake Naivasha.

The specific objectives of the study were to assess the intensity of shoreline canalization and the canal density around the lake. To demonstrate whether unique patterns of in shore canalization exhibited within the lake significantly impacted the water quality and correlate this to wetland birdlife. The method used to achieve the objective, was first to map all the canals on the shoreline using GPS, analyse water quality parameters at every canal point and assess lakeshore birdlife distribution at these canals. The canals were then grouped according to the aggregation pattern observed into a Southern, Northern and Eastern Zone.

The findings of the study revealed that the southern part of the lake had 60% of shoreline canals, 26 in number, some with a width of up to 25 and 30 meters. The northern part of the lake had one canal, with four others on the northwestern side; all these were between 5-10 meters wide. 13 canals on the eastern side of the lake exhibited the highest density in terms of proximity of canals with the widest canals measuring 20 meters. The true western side had no canals. Water quality means for the Eastern, Southern and Northern side were: TDS at 184 mg/l, 166 and 160mg/l for the DO, 73.7, 89.9 and 83.7, whereas pH 9.1, 8.7 and 8.8 respectively during low water levels. The width of canals and their proximity to one another had significant impact on the water quality and on birdlife distribution on the shoreline. Bird counts were highest on the northern side and lowest on the eastern side and there was a distinguishable water quality pattern in the different zones.

The study revealed an inverse relationship between canalization and birdlife distribution on the shoreline. Low water quality was observed from data collected in areas with the highest canal density, which was postulated to impinge negatively on the biotic factors that sustain birds within the lake leading to fewer bird counts in areas of high canal density. It was also observed that canalized areas disrupted the pristine and tranquil ecosystem that birds need. There is an urgent need to get policy makers to enact regulations that limit inshore abstraction canal numbers and sizes. Horticultural farms should be limited to only one canal per farm to aid in improving the ecosystem integrity. It is apparent, Lake Naivasha risks suffering irreparable degradation in the next prolonged drought season if canalization effects are left unmitigated.

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CHAPTER ONE
INTRODUCTION

1.1 Background of the Study

Lake Naivasha is the backbone of Kenya for the floriculture industry. Due to its socio-economic and ecological factors, the lake was designated as a Ramsar site in 1995 making it the second Wetland of International Importance (Ramsar, 1996) in Kenya after Lake Nakuru. Under the designation, the lake management is expected to undertake wise usage for sustainability of the resource in accordance with the Ramsar Convention. In their study, Roughgarden and Diamond (1986) posited that in every environment, there are three factors that influence the structure of animal communities, namely; competition, predation and disturbance. These are factors that have affected Lake Naivasha, this study makes an assessment of disturbances to water quality and birdlife caused by canalization within the lake shore line.

With the increased canalization to support horticultural farming, it has become apparent that the ecosystem integrity may be sacrificed at the altar of economic expedience. There has been a hue and cry on the deterioration of the water quality on the lake of which the floriculture industry is partly responsible. Apart from the use of pesticides and fertilizers that leech into the lake, digging canals and abstracting water severely threatens the ecosystem integrity. The lake which is a designated Important Bird Area (IBA) has borne the brunt of reduced water quality caused by increased canalization to satisfy the water needs of the lucrative flower farms. The land use in the immediate vicinity of IBA's has the potential to disrupt the nesting and feeding patterns of birds. In Kenya studies have not been carried out on the effect of canalization of rivers and lakes, yet the construction of irrigation canals continues to be on the increase. In the Yala swamp, the Mwea irrigation scheme canalization has continued to increase no doubt with long term consequences.

1.2 Statement of the Research Problem

According to Lincer *et al.* (1981), the Lake Naivasha had over 350 bird species which was one of the reasons that led it to be designated as a Ramsar site in 1995 (Everard and Harper 2002), it therefore, is a wetland of international importance. Over the years the overall richness of the lake has been maintained though it has been bedevilled by multiple challenges. The lake has been under multiple, and rapidly increasing pressures which include; increasing reduction of lake levels, deterioration of lake and river water quality, soil erosion and siltation, fish mortalities and decreased fish yields, encroachment and transformation of the lake shore riparian zone. By the year 2011 around 200 bird species could still be easily recorded though some with much lesser frequency (IUCN, 2011). It is apparent that the bird numbers have been dwindling over the years.

In earlier studies, Taylor and Harper, (1988) noted that birds that would number in tens of thousands like the Red-knobbed Coot, *Fulica cristata* had reduced to single thousands while the Jacana, *Actophilornis africana*, which was in thousands dwindled to hundreds. Changes in vegetation, turbidity, floating mats of exotic vegetation have invariably taken a heavy toll on the lake. The studies have, for example, indicated the decline in the population of the African Fish Eagle (*Haliaeetus vocifer*) and the *Red-knobbed Coot* (*F. cristata*) which for a long time have been considered as the flagship species for Lake Naivasha.

The lake's ecology has been compromised by cultivation of its immediate shoreline, dredging and digging of canals, these change water chemistry, which inevitably affects the nutrient status (Harper, 1992). Water abstraction also accounts for significant losses in the lakes water volume (LNBIMP, 2012; Becht & Harper, 2002). Water abstraction from the Naivasha catchment is not very well known and can only be estimated from abstraction permits or from the known area of cropland and known requirements of the crops.

There is need to understand the impact of canalisation and have an properly articulated water balance of Lake Naivasha. Similarly, there is the necessity of scientifically and logistically establishing the relationship between water abstraction canals, and their effect on the food web. The integrity of the aquatic vegetation has an effect on the fishery and on the birdlife distribution.

In Kenya, studies have not been carried out on the effect of canalization of rivers and lakes, yet the construction of irrigation canals continues to be on the increase. The lake that was designated a part time Ramsar site in 1989 from the months of October to April is a significant tourism site. The lake suffered almost irreparable water quality challenges with negative effects on its biodiversity. At the time of doing the research (2007 to early 2010) all signs pointed to the fact that if nothing was done to check water abstraction and canalization then the inevitable was going to happen; irreconcilable degradation and severe loss.

Studies by Betch and Harper (2002) have shown that the water level and aquatic vegetation of the Lake Naivasha has been continuously changing. The rising and declining water levels have influenced the vegetation. By extension, water quality, turbidity and transparency affects fish eating birds and their distribution. The birds also depend on the riparian environment for feeding and nesting. This research sought to understand how canalization affects the water quality and bird life distribution within the immediate shoreline of Lake Naivasha.

The driving research questions for this study were as follows:

a) How many irrigation water canals have been established around the lake and are the canals distributed equally around the lake?
b) Is there a unique pattern in lake water quality attributable to the canalized sections of the lake shore?
c) Does the lakeshore canalization have any significant impact on the distribution of wetland birdlife?

1.3 Objectives of the Study

1.3.1 Overall Objective

The overall objective of this study was to assess the effects of canalization on water quality and birdlife in Lake Naivasha.

1.3.2 Specific Objectives

1. To assess the intensity of canalization on the shore line of Lake Naivasha and the pattern of canal distribution around the Lake
2. To determine whether the canalized areas exhibited unique patterns in lake water quality
3. To determine if canalization within the lakeshore has significant impact on the distribution of wetland birdlife.

1.4 Hypothesis

The working hypothesis for the study was as follows:

Ho: "Lakeshore canalization has not significantly affected the water quality and birdlife distribution in the Lake Naivasha".

Hi: "Lakeshore canalization has significantly affected water quality and birdlife in the Lake Naivasha".

1.5 Justification and Significance of the Study

During CoP 10 of the Ramsar Convention which was held in Changwon, Republic of Korea, in 2008 there was a proposal by the Contracting Parties to delegate Lake Naivasha to the Montreux Record by the Ramsar Convention. The Ramsar Convention's Montreux Record is a register of wetlands that are on the List of Wetlands of International Importance. It keeps track of changes in ecological character that have occurred, are occurring, or that are likely to take place as a result of technological interruptions, pollution or other anthropological interference. Changes that have occurred in Lake Naivasha and resulted in the lake being put on the Montreux list include:- a) habitat degradation, b) nutrient enrichment, c) decreased river flow, d) land use conversion, and e) biodiversity alteration. Lakeshore canalization can contribute to the above challenges which are likely to jeopardize the status of the lake as a wetland of international importance. (Ramsar, 2008)

Canalization adds further disruption of the natural lake environment through dredging, digging and drawing of water. The periodic clearing and repairs of water canals continue to cause additional challenges to the aquatic environment. Apart from creating several surface water outlets, they extend the surface area cover of water around the lake, which affects how the biotic and abiotic factors interact. Several stakeholders blame changes in fish production on increased turbidity, water abstraction and general decline in water quality (KMFRI, 2001). The shallow canals also aid turbidity by sediment re-suspension in the case of wading animals and birds, swimming fish or blowing winds (Harper *et al.*, 2011).

For all its vast potential for a dominant economic good, the degradation of this lake through population expansion, over-fishing, agricultural production with irrigation water, biodiversity loss and pollution are among the major but diverse challenges that have arisen. Though the lake environment is fragile it is quite dynamic and resilient, continuing to support tourism and geothermal power generation from deep-rooted stream jets among other economic activities. The biodiversity of Lake Naivasha is critically threatened by human induced factors, including: habitat destruction, pollution (from pesticides, herbicides and fertilizers), sewage effluent, and livestock feeding and water abstraction.

1.6 Scope of the Study

This study sought to consider whether shoreline abstraction canals significantly affect the water quality of the lake and wetland bird life. The study therefore concentrated mainly on the shoreline and the immediate lake water up to about 20 meters from the shore. It is within this area, at canal points for water abstraction that the water quality parameters were measured in situ using a multivariable hand held meter. The parameters measured included, Dissolved Oxygen D.O, Temperature, Turbidity, Conductivity, Resistance, pH, Salinity and Oxygen Redox Potential (ORP). The number of birds around the canals were counted from within the boat. The bird counts were only made in the area where there was a canal. This was used to determine whether the canal width, canal density and water quality had an effect on bird distribution.

The main thrust was to determine the effect of canalization and resultant water abstraction on water quality by measuring the different parameters separately and then comparing, contrasting and making conclusions taking note of the prevailing anthropogenic factors and attempting to prescribe remedial actions to the same. The aim of the study is to grasp the impact of canalization and how this ultimately affects bird life distribution in the Lake Naivasha. In this regard, therefore, this study relied mainly on primary data collected. Primary data was obtained for the key water quality parameters within the water abstraction canals. These were done and the coordinates of the lake canals plotted by GPS, to show the canal density in the specific regions of the lake. The study targeted the shoreline area from inside the waters of the lake. The canal point's water parameters were measured aboard the boat.

1.7 Limitations of the Study

Owing to the water levels at the time of the study (2009) the researcher could not get beyond 20 meters towards the shoreline in several points. The receded waters made much of the area closer to the shore very muddy, and there was genuine concern of the outboard engine stalling, this was experienced in areas of very low water levels around the lake. Further to this, during one of the trips the calibration of the hand held GPS meter was faulty. The canals were identified by the name given by the fish scouts and fisheries assistant officers whose experience within the lake was deemed to be impeccable owing to their experience of over 20 years patrolling the lake.

1.8 Definition of Terms

Birdlife: This refers to the birds within the immediate vicinity of the inshore water section only. These were either foraging on the shore or swimming around the waters 20 meters close to the canal. Birds in flight were not considered.

Canalization: Refers to canals on the shoreline of the lake that were used to draw water out of the lake. The canals ranged in size from 5-30 meters. The canals were constructed in a way to aid water flow by gravity as much as was feasible.

Piscivorous Birds: This is a general reference to birds that prey on and eat fish.

Ramsar site: This is a wetland of International importance, as defined by the Ramsar Convention for the conservation and sustainable utilisation of wetlands.

Receded water: Refers to lowered water levels due to evaporation, irrigation and seepage leading to retraction of the lake and reduced lake surface area.

Shoreline Canals: These are canals directly drawing water from the main lake body. Most were constructed to draw water by gravity by deepening the canals. In low water levels the canal water stagnated and pumps were introduced.

Water Quality: For a fresh water system variance from potable water value ranges of dissolved oxygen, total dissolved solids, pH, conductivity, turbidity and other pollutants are a sign of diminishing quality.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

The possible changes to the water quality of Lake Naivasha have been brought to the light by various authors (Harper, *et al.*, 1990 and 1993; Gaudet and Muthuri, 1981) and the risks posed by such changes discussed. Of great concern, has been the increased water quality changes. This can lead to alteration of the ecology of the lake through the elimination of species sensitive to changes in water characteristics at the expense of opportunistic species capable of adapting to such changes. It was not clear how the increased modification of the lake shore environment was affecting the water quality and biodiversity status in the lake hence the need for this study (Harper *et al*., 2011).

For instance, studies on the eutrophication of Lake Balaton in Hungary revealed the impact of human activities on a water body and its biodiversity. Closer to home, the quality of surface waters in the Nile Basin has also been significantly influenced by both natural and human factors, the human factors taking a higher toll on the ecosystem integrity. The Sudd region acts like a filtering body for all suspended sediment and definitely all the bed load settles there. There has been inevitable depreciation in the water quality as a result of pollution and canalization (Timmerman, 2005).

Water bodies are classified as either oligotrophic, mesotrophic or eutrophic; this is based on the lake's productivity status that is influenced by water quality, especially nutrients. Such lakes have waters with lower total ionic concentrations, with conductivity less than 600µS cm-1. According to Talling and Talling (1965) classification of inland African lakes, Lake Naivasha is mesotrophic with a tendency to being eutrophic, especially in seasons of low water. In close proximity to the lake, there are over 100 commercial farms, of which some are large, medium and small which do irrigated floriculture, and dairy production. These are produced mainly for export, to international markets. As demonstrated by (Harper, Mavuti & Muchiri 1990) lake resources are of critical importance, especially for geothermal electricity generation, fisheries, wildlife, tourism and conservation

The expansion of irrigated agriculture mainly took place from the mid-1980's. Lake Naivasha is the centre for the horticulture economy in Kenya where the first flower farm was established in the 1970s by the Dansk Chrysanthemum Kultur (DCK) Company after which the market centre of DCK near Hell's Gate is named. The inordinate use of Lake Naivasha's water continuously for agriculture has lead to a drop in the water levels in the lake (Betch, 2007). The lake has been the horticulture hub of Kenya for many years as a result of the fertile and permeable soils, reliable supply of good quality water, high temperatures, availability of cheap labour and easy, smooth and safe access to international airports in Nairobi. The Naivasha Region has previously produced over 75% of all horticultural produce in Kenya, the country is nowadays recognized as one of the most important "offseason" suppliers to Western Europe. The industry is estimated to have a net annual income of over 63 million US dollars making flower and vegetable farming a leader in the regional economy. Consequently, over 45 km^2 or 7% of the Naivasha basin is currently under irrigation and recent studies have shown that abstraction for irrigation farming contributes 20% of the water out flow from the lake (Harper *et al.*, 2011).

The region has a large number of large and small commercial farms including over 645 hectares of riparian environment. The annual average abstraction estimate in some farms is above 5,000,000 cubic meters which translates to a total abstraction of almost 50 million cubic meters of water directly from the lake per year excluding riverine and groundwater abstraction. Water abstraction canals some of which are larger than some of the smaller rivers entering the lake currently besiege the lake.

Significant impacts associated with over-abstraction of water from the lake and the significant growth of its population became apparent only in the 1990s, the first geothermal power plant was built in the late 1970s, and the nascent horticultural trade was then established at the lake at about the same time. As highlighted above, the lake's ecology deteriorated as a result of the introduction of alien species in the 1980s (Harper *et al.*, 1990). The Lake Naivasha Riparian Owners Association (LNROA), concerned over the continued decline of the lake, became active from 1990, with the commissioning of two consultants' reports which articulated the scientific status of the lake (Khroda, 1994; Goldson, 1993). These were used to lobby for the declaration of Lake Naivasha as a Ramsar site, a goal ultimately achieved in 1995. LNROA later altered its name to the Lake Naivasha Riparian Association (LNRA) and later opened up its membership to include non-riparian persons whilst encouraging broad stakeholder representatives (e.g. fishers) to join.

Over the years, based on research, action to halt the deteriorating ecosystem have been put in place, amongst these: restoration of vegetation; at the lakes boundaries; the removal of illegal developments within the riparian zone; setting and enforcement of abstraction limits; expanding the municipal sewage treatment works; and also fast-tracking development of the Lake Naivasha Basin Integrated Management Plan (LNBIMP), through 'ensuring comprehensive stakeholder involvement to give legitimacy to the process and ownership' (KMFRI, 2010). Within the same period (October 2010), the Prime Minister of Kenya, Hon. Raila Odinga, released a communication towards the launch of 'Imarisha Naivasha' (Swahili: this means 'stabilise Naivasha') this was developed with some assistance from the International Sustainability Initiative, with complements from the Prince of Wales. This was appreciated as a pivotal all-embracing attempt to harmonize and integrate the activities of all agencies, starting from the central government, local government, international NGOs, local and international businesses and local stakeholders.

According to Betch (2007) the increasing irrigated agriculture has led to reduced river flows, lake levels and overall depletion of underground aquifers due to over abstraction. Horticultural farms around Lake Naivasha have undoubtedly significantly increased the demand for water. Estimates have been made that show the total area under commercial irrigation around the lake to be between 3000 and 5000ha. Studies have also raised concern that the horticultural farms have contributed towards the noted deterioration of water quality in the lake (Kitaka *et al.*, 2002). With there being such large numbers of flower farms and land owners around the lake, this led to gross encroachment and transformation of the fragile environment in the riparian zone to farm land. This clearly presents serious threats to the future water quality of the lake.

The single most importantant riparian activity on Lake Naivasha has been the large scale production of flowers for the European market with at least 50% of the lakes' perimeter under agriculture. Formerly, the stock-rearing, ranching and sisal cultivation has been replaced by irrigated horticulture. The past three decades have seen the growth of the horticultural industry with huge usage of pesticides. Further to this, cultivation closer to the lake has become more rampant. This development of the labour intensive flower industry as noted by Enniskillen (2002) led to the increased need for, housing, water and latrines. Fig 2-1 shows the calculated actual water abstraction levels in the lake in the year 2011. It is apparent that water abstracted from the Lake Naivasha shoreline is twice as much as all other sources combined.

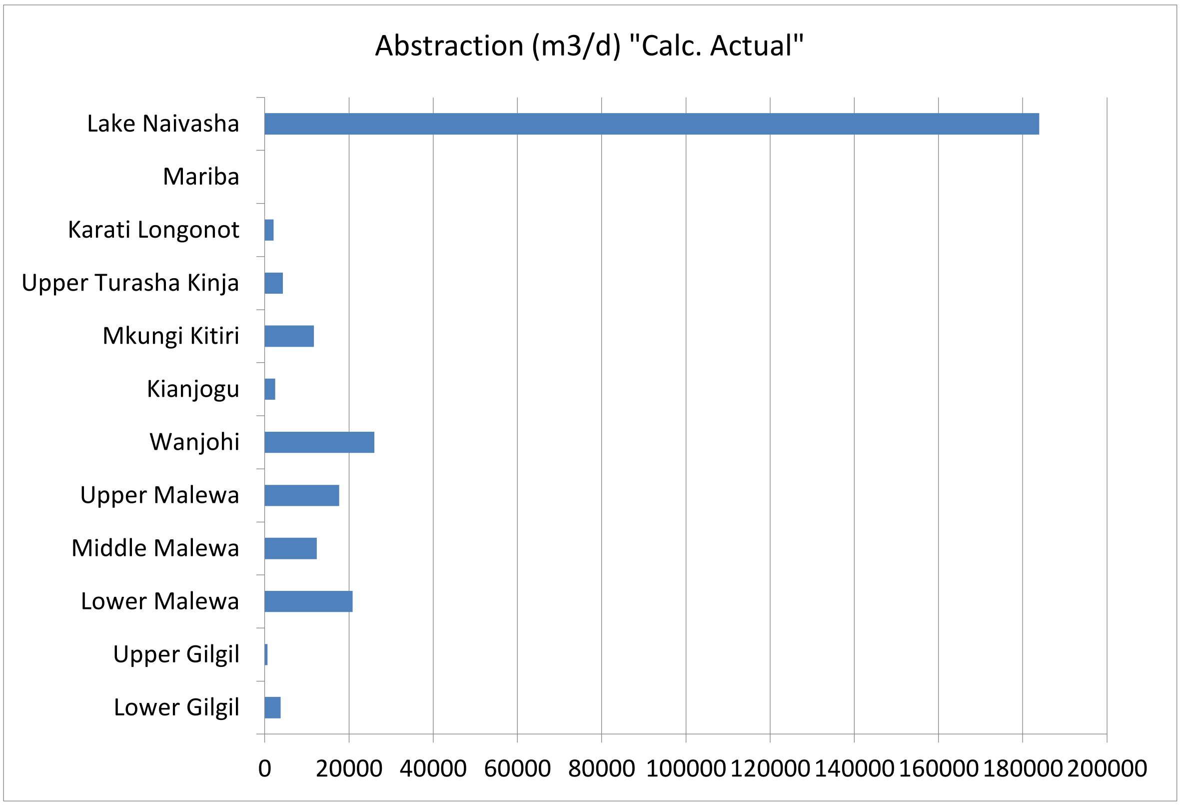

Figure 2-1: Water Abstraction from the Lake Naivasha Basin (WRMA, 2011)

In a survey carried out by Water Abstraction Survey (WAS, 2010) water abstractions in the area closer to the lake are most dense and also account for ± 2/3 of the total abstractions of the lake basin. The Lake Naivasha catchment presents a generally complex hydrological system that comprises of surface water, and groundwater systems. The actual water resources within Lake Naivasha catchment is yet to be established due to lack of vital information of the groundwater system.

2.2 Lake Naivasha Water Quality

At the time of carrying out this research data collection (2008 to early 2010), many newspapers in Kenya, plus several websites, were focused on highlighting the Lake Naivasha water quality crisis. There was a hue and cry concerning the ecosystem and communities as being in peril. References were made of the lake becoming a contemporary tragedy, and a bog as was epitomized in one of the local dailies (Riungu, 2009) noted, 'Lake Naivasha is

Dying'. These types of analysis were in sharp contrast to the celebrations, just 10 years before with its notable successes (Ramsar, 1999), the lake was among the leading global examples of community-based initiatives for the management of a Ramsar wetland, lead by the Lake Naivasha Riparian Association (LNRA)

In lake Naivasha, data and information on potential contaminants in the various aquatic compartments is limited, despite the great demand of the lakes freshwater and associated impacts from human activities within the catchment and near shore areas (Harper, *et al.*, 1993). Therefore, a water quality assessment of Lake Naivasha and the canalization processes and its environs was not only necessary, but vital, in terms of its contribution to ecohydrology debates in and also in spurring initiatives for policy development. The increased nutrient input from increased application of agro based fertilizers in the catchment area and the farms surrounding the lake and breakdown of the municipal sewage treatment plant may contribute to the addition of raw sewage into the lake further enriching the water body with nutrients. Algal blooms witnessed in the lake have served to reinforce such fears on the deterioration of the water quality (Mavuti, 1990; Njuguna, 1982). Table 2-1 gives the water parameters from 1962-1998 on conductivity, pH, turbidity measured using a secchi disc, temperature and dissolved oxygen.

Year	**Actual site**	**EC mS/ cm**	**pH**	**Secchi (m)**	**Temp (°C)**	**DO (mg/l)**	**Source**
1978-80	Main Lake	200-300	8.0 - 9.0	0.5-2.5 (mean 1.5)	18-26.5 (22.2)	9.0 - 10.0	Mavuti (1983)
1965	Main lake	345	8.9				Talling & Talling (1965), in Gaudet 1976.
1984	Main lake						Harper *et al* (1990)
1989	Main lake						
1997	Main lake (heavy rain)			0.57			
1998	Main lake (normal rain)			1.26			
1962	Main lake	370					
1970		260-					

		350					
1983		280					
1988		380					
1992		320					
1997	Main lake	374	8.64				Hubble (1987)
1997	Crescent Isl.						"
1997	Oloidien	2780	9.52	0.25			"
1997	Main lake	374	8.35		23.5	4.91	"
1997	Crescent Is	401	8.39		22	6.1	"
1997	Malewa mouth	365	8.64		24	4.85	"
1996	Main lake			0.5			"
1996	Malewa mouth			0.4			"
1998	Lake Naivasha	200	8.9	0.45	22.5	4.9	Donohue & Thenya (1998)
73-75	Main lake	363					Hubble (2000)
"	Crescent Isl.	457					
"	Oloidien	983					
1997	Main lake	372					
"	Crescent Isl. Bay	401					
"	Oloidien	2780					
Jan. 1998	Main lake	260					
"	Crescent Isl. Bay	331					
"	Oloidien	2830					
"	Malewa mouth	215					

Table 2-1:Water Quality Parameters1962-1998

(WRMA 2011)

Agriculture is a major cause of degradation as it is one of the single largest users of groundwater resources and there is cause to be concerned about the implications of water quality. The lake is of considerable economic potential, hence the escalating demands on its water resources and a resultant decline in the fishery potential and increasing pollution. Previous limnological information indicates a changing lake environment, as evidenced by past lake water level fluctuations (Gaudet & Melack, 1981; Gaudet, 1979).

The first recorded sampling of Lake Naivasha for its physical and chemical characteristics was made in 1929 (Jenkins, 1934), followed by Beadle in 1930 (Beadle, 1932). Other studies (Gaudet & Melack, 1981; Gaudet, 1979; Milbrink, 1977, Melack 1976, Kilham 1971,) have been made in addition to numerous short-term studies by students from the Netherlands (ITC) and Earthwatch. Kitaka *et al*. (2002) indicated that the lake became 'hyper-eutrophic' this was a result of excessive phosphorus loading subsequent to the 'El Niño' rains in 1998, and it reverted back to its 'eutrophic state' in 1999. This latter study emphasized that the increase in the lake's trophic state originated from the wider catchment, this resulted from absence of buffering that was previously provided by the North Swamp as the river inflows. Since past studies did not consider the impact of canals originating from within the lake, their influence on the ecosystem was not factored into the big picture.

Lake sampling with the express purpose to assess the water quality is a generally complicated process, as is analysis of the obtained data. One of the challenges encountered in assessment of anthropogenic activities around Lake Naivasha is a tendency to rationalize deteriorating scenarios, until they near extinction. The water quality of lakes is essential as it maintains recreation, fisheries and also provision of clean drinking water (Harper *et al.*, 2011). These uses are definitely in conflict with consistent polution of water induced by agricultural use which degrades water quality, besides the additional industrial and municipal waste effluents. Studies done have illustrated that nowhere in the world are there foolproof and successful lake management practices.

The core issues relating to water resource management within the basin are focused around catchment degradation, the rampant encroachment of riparian lands and non-compliance to natural resources management laws which have led to the recorded decline in water quantity and quality. Plate 2-1 is a photo of a typical shoreline canal, most of which were between 10-30 meters wide. The greenish water reveals high levels of eutrophication of the water. Back flow of water is more notable when the lake levels are lower. Canals inevitably increase the surface area for evaporation, contact with soil and seepage, which affects the water quality.

Plate 2-1: Typical canal point in Lake Naivasha

Source Researcher 2009

2.3 Lake Naivasha Bird life Studies

There are sixty areas designated as Important Bird Areas (IBA) in Kenya and Lake Naivasha is one of the very significant ones (Bennun & Njoroge, 1999). In the year 2008, it was agreed that the worst threats to bird life in these IBA's was human settlement and urbanization, agricultural encroachment, illegal cultivation, vegetation destruction overgrazing and illegal logging. All these are especially true of the Lake Naivasha basin. The threat to Lake Naivasha stems from over-exploitation, mainly through canalization and over abstraction of water, habitat degradation and destruction, drainage pollution and alien invasive species. Lake Naivasha, one of Kenya's most valuable ecosystems played host to 350 species of birds (Anderson *et al,* 2005). As alluded to earlier in this report, Lake Naivasha was designated as a Ramsar site, based on it bird species richness. The number of terrestrial birds at Lake Naivasha has been on the decline, mainly because of the changing ecosystem. The birds which include many waterfowl species like herons, storks, ibises, grebes, pelicans, cormorants, African darters, flamingos, multiple species of ducks spoonbills, and geese, waders, gulls and terns. (Adams *et al.*, 2002)

It is apparent, birds that were very common and could be counted and numbered in many tens of thousands, such as: – *F. cristata* and Yellow-billed Duck *Anas undulate,* were now counted in the lower single thousands at most when submerged aquatic plants return. According to Taylor & Harper (1988), Jacana or Lily Trotter, *Actophilornis africanus*, previously present in several thousand on water lily beds can now only be counted in a few hundred at most, concentrated on the water hyacinth (*Eichornia Crassipes)* fringes which are found more extensively in northern parts of the lake. It is the view of this researcher that bird numbers would have gone very low if the heavy rains of 2010 delayed by a year. Overall, there is increased pressure even within the designated IBA's of Kenya. Human settlement and urbanization contribute 71% of the threats to birds in 2008. Disruptions of ecosystems through water abstraction has significant effect on birdlife, by disturbing nesting and feeding. The clearing of forests and discharge of wastes into lakes also presents additional challenges (IBA, 2008). It is therefore apparent that the Lake Naivasha has suffered significant human encroachment over the years.

The lake hosts important raptors, like the fish eagle *H. vocifer*. It has also been observed that the lesser flamingo populations have been on the increase in the Lake Naivasha. During the study period flamingos were sighted at the lake. The Lake Oloidien at the western tip of Lake Naivasha has increasingly become alkaline which tends to favour Lesser Flamingos which have at times arrived in thousands (IBA, 2008). This alkalisation is a concern as it threatens the lakes precious fresh water.

Studies have shown that Oloidien water has been progressively increasing in conductivity with evaporation leaving it more concentrated year by year; Harper *et al*., (2006) also noted that the conductivity fluctuates by about 350 µS cm-1 in the main lake and started at this level in Oloidien in 1982, had reached 500 µS cm-1 by mid-2006, when hundreds of thousands of lesser flamingos came to the lake for the first time to feed on dense *Spirulina* (*Arthrospira fusiformis*) which had developed Since 2006 large populations of lesser flamingos have been seen at the Oloidien (National Museums of Kenya, unpublished annual water bird censuses, 2006–10).

Plate 2-2 shows dredging works in progress to deepen a canal and enable water to flow by gravity. This disrupts bird life, especially in some cases where heavier machinery and dredging tractors were used.

Plate 2-2: Canal dredging and repair works in the southern zone of Lake Naivasha

(**Researcher 2009**)

According to Brown, (1980) The ‘umbrella’ indicator species, within the Lake Naivasha is the African fish eagle (*H. vocifer*), it began to decline in the mid-1990s to 70 birds; this was about 50% of the former maximum with no courtship or nesting observed for most of the decade. This was during a time when there was significant decline of the lake waters. The cause, as Harper *et al.* (2002) postulated, was as a result of food shortage; there was enough for the birds to stay alive, but not enough food for the birds to breed. The decline in the prey–fish species and coot – had occurred over the preceding decade and feeding conditions were worsened by the increased turbidity in the lake, rampant floating mats of invasive vegetation and lagoons lost over the years behind the fringing papyrus.

Prior to the heavy ‘El Niño’ rains of 1998, the lake had receded considerably with reduction of *H. vocifer* numbers being noticeable. With the setting in of the rains, it brought about a rapid lake level increase of three vertical meters. A study done by *Harper et al.*, (2002) revealed that flooding of new lagoons behind formerly-stranded papyrus, became the breeding grounds for tilapias. *H. vocifer* breeding re-commenced, leading to 17–24 fledgling juveniles in a population of over 100 by 1999. This population continued rising in the next decade to 150+ birds by the end of 2008. This was in part also attributed to new food available which was through introduction of the surface-swimming *C. carpio,* despite the water level declining and increased water turbidity.

However, this again changed dramatically with the onset of rains, greatly distinguishing early 2010 and late 2010. There was a significant difference in lake ecology between the beginning and end of the year. At the very start of the year, the Nation of Kenya was reeling from a severe drought; the lake had shrunk to the lowest it had been in 60 years, (WRMA, 2011). Large swathes of muddied areas made human access difficult, with hippopotamus dying in huge numbers and the dry land created being invaded by thousands of cattle. It was in one such mud patches that our boat got stuck in one late evening, which brought significant apprehension to those of us on board that night.

At the same time, newspapers and television documentaries carried numerous stories about the 'dying lake' that would soon be a putrefying bog! However, contrary to the predictions, it subsequently rose over 2 vertical metres in just 3 months! The extensive mats of flowering water hyacinth re-appeared by the closure of 2010, and papyrus re-geminated around the lake and native plant beds (including water lily) re-appeared in 2011 (Harper *et al, 2011).* The rapid changes gave a peak review of the natural hydrological instability this lake which has great ecological resilience. However, this should not be taken for granted as the trends reveal, delay of the oncoming rains by a year would have resulted in very radical shifts in the ecosystem. There still remained a very great possibility that the lake would have been absolutely sucked dry resulting in death to the fishery and birdlife. Most birds, especially the piscivorous birds would have had to migrate to other habitats.

Lake Naivasha has two or three alien species that are dominant, at each of the three key levels of the food web (namely: producers; consumers and top predator) In this regard Lake Naivasha is a classic example of an alien ecosystem in the world. Childress *et al*., (2002), Only at demonstrated that its only at very top of the food web where native piscivores – such as aquatic birds *Phalocorax* spp. (cormorant) *H. vocifer are found.* Further to this Harper *et al*., (2002), also noted the presence of the Purple Heron *Ardea purpurea,* Goliath Heron *Ardea goliath*, and Ibises *Bostrychia hagedash* and *Threshkiornis aethiopicus*.

Lake Naivasha has three abundant fish species that supports 45 species of the fish-eating birds (Harper *et al*., 1990). Among these fish eating birds is the Great Cormorant. According to Harper *et al.* (2002), 90% of the Cormorants diet especially during breeding periods consists of fish. They are often foraging up to 100 meters away from the shore. This was the area under study as waters recede and levels rise during the next rain season. From this hypothesis, increased turbidity which reduces fish production will have adverse effects on the Great Cormorant

Yet another hypothesis sought to explain bird numbers based on the Louisiana Crayfish, *Procamburus clarkii.* A high population of P. clarkii led to the elimination of the floating-leaved and submerged aquatic plants. Another relationship that was found to be significant by Hickley & Harper (2002) was the inverse correlation between the large- mouthed black bass, *Micropterus salmoides* and crayfish. According to the same study, crayfish occupies a significant proportion in the black bass diet. Crayfish is also fed upon by *M. salmoides* (Hickley & Harper, 2002) and which is also consequently fed upon by cormorants. According to Childress *et al,* (2002) the fish Eagles sit at the top of the food chain. Harper *et al.,* (2002) also observed that wading birds such as ibises fed on crayfish. However, in seasons where P. clarkii numbers were very low, the above prediction was not validated. This meant that there were other factors that affected these birds and their prey.

Past studies on avian breeding season timing and its control factors near the equator have shown consistent patterns. For the vast majority of birds, breeding is an annual event that is timed to coincide with periods of food abundance and nest-site abundance. The aspect of food abundance is considered as the most important in predicting breeding timing. Birds have an endogenous cycle that brings each bird into breeding condition in phase with the period of abundance in the area where it normally breeds. The other factor is the environment which enables the bird to synchronize its breeding timing more precisely with the actual period of abundance each year (Phillips *et al., 1985*). There are particular markers that signal a season of breeding for the birds.

H. vocifer preys mainly on fish and small aquatic birds (Harper *et al*. 2002). It is the top predator of Lake Naivasha's aquatic web eating fish that are both herbivorous and carnivorous, as well as birds that are either herbivorous or piscivorous (Brown & Hopcraft, 1973). Birds of prey have been used in studies for decades as indicators of the state of the environmental health (Watson, 1991). African Fish-Eagle populations have been significantly fluctuating since the 1980's from 160 birds (Lincer *et al*., 1981) to about 119 individuals in 2010 (S. Kapila unpublished data 2009-2011). This has been marked at a time of increased economic activity, necessitating water abstraction to support the thriving floriculture industry.

Plate 2-3: Oserian Pump House Lake Naivasha

(**Researcher 2009**)

Plate 2-3 is of a pump house on the lake shoreline, and 2-4 excavations aided by tractor, the noise and suction power interfere with serene ecosystem needed by birds.

Plate 2-4: Motorised canal excavation works at the shoreline

(**Researcher 2009**)

Changes related to water quality, and canalization either mimic or disrupt bird breeding seasons and nesting patterns. For instance, during this the research, interruptions were rampant around the lake as heavy machinery serviced canals, people dug, dredged and pumped water, especially owing to water levels having receded over time in the lake. Near the equator the seasonal wet and dry periods are the ones that regulate the plant and insect life in these regions. Some piscivores synchronize their breeding seasons with primary production of phytoplankton and zooplankton, and hence the fish spawning cycles (Payne 1986). As these then are directly affected by water quality, inevitably changes in the water quality affect the birdlife breeding and distribution (Siddiqui 1977).

Low breeding success of the African Fish-Eagle and its population instability has been linked to food scarcity (Harper *et al.* 2011) especially during drought periods. As demonstrated by De Lorenzo *et al.* (2001) Lake Naivasha has a particularly complex web of interactions especially considering all the dynamics of introduced species. The predominant food of the African Fish-Eagle is fish, more specifically Common Carp *Cyprinus Carpio,* which is a recently introduced species in the lake. As Common Carp feed on 30% phytoplankton, aquatic-insects and detritus while submerged macrophytes make up 40% of its diet (Njiru *et al.* 2008) the integrity of the aquatic ecosystem is pivotal. As previously indicated, the alternative dietary source of the African fish Eagle are aquatic birds, mostly the *F. cristata*), which also in turn rely on the submerged macrophytes and aquatic insects for their food.

There has been a significant reduction in submerged macrophytes in the lake as a result of algal blooms (Harper *et al*. 2011). Macrophytes are also the major food source for the Louisiana crayfish and in the past these have been shown to be responsible for collapse of benthic plant communities within a short time span (Hickkley & Harper, 2002; Harper *et al.*, 2011). As a consequence of limited food options effected by the changing trophic levels, African Fish-Eagle productivity and populations decline below the carrying capacities. (Frank *et al*. 2007)

Studies by Adam *et al.* (2002) have shown that water hyacinth increases surface water loss through evapotranspiration. Growth and development of water hyacinth is affected by water quality. During periods of heavy rainfall the water hyacinth blooms it therefore cover huge tracts of the water surface (Harper *et al.* 2011). They also go on to demonstrate that some bird species such as the African Darter (*Ahinga rufa*) Great Crested Grebe (*Podiceps cristatus*), Great Egret (*Casmerodius albus*), the African Skimmer (*Rychops flavirostris*), Yellow bille Duck (*Anas undulate*), Baillon's Crake (*Porzaa pusilla*), White-backed Duck (*Thalassornis leuconotos*), Saddle-billed Stork (*Ephippiorhychus senegalensis*), and *F. cristata*) are seen with far less frequency with passage of time.

2.4 Lake Canalization and Environmental Impacts

It is imperative that effort is made towards proper conservation and sustainability of aquatic resources. History abounds with cases of environmental tragedies that have been committed over the years. One such monumental case is the Aral Sea demise, which is arguably one of the greatest environmental crimes ever to have been committed; it is a depressing example of water arrogance running amok. Located at the heart of Central Asia, the Aral Sea is within the boundaries of Uzbekistan and Kazakhstan. In just a few decades, from the 1960's, the Aral that hosted a thriving ecosystem chock-full of birds, fish, and other fauna seemed to have deteriorated beyond redemption (Anin, 2006).

Canalisation of this great lake, which was the brainchild of Josef Stalin initially had great impact on agriculture, making the region the breadbasket of the region. However, as water levels fell other critical problems began emerging. The food chains in the lake were disrupted as increased chemical pollution became rampant. Furthermore, with water levels being low, re-suspension of sunken pollutants only exacerbated the toxicity levels of the lake. From being one of the largest fresh water inland lakes of the world with a surface of 66,000 km^2 and volume of more than 1,000km^3 it split into two small lakes owing to the anthropogenic demands for agricultural land use. (Micklin, 1988)

Fig 2-2 captures systematic reduction of the Aral as a result of canalization of her water for commercial agriculture. Rehabilitation of the Northern part of the lake began in the year 2010, however it is almost impossible to restore the lake, with the Eastern Lake having dried up by 2014.

Until the early 1960's the Aral Sea was still the fourth largest fresh water lake on the planet. Straddling the nations of Kazakhstan and Uzbekistan this water body succumbed to pressure owing to the persistent canalisation that led to the largest man made ecological catastrophe close to the Chenobyl (NASA, Schlager 2,000) owing to intense canalisation water flow into the lake was significantly held back and the salinity greatly increased. Owing to agricultural land use the lake shrunk to less than a quarter of its original size. The continual deterioration of the Aral Sea also resulted in the change of climate in the region. This resulted in severe loss in biodiversity especially to birdlife, with the previously thriving fishery crashing. By the year 2007 the Aral Sea had shrunk to 10% of its original size leading to heavy decimation of fish and birdlife, especially piscivorous birds (Anin, 2006). Whereas water scarcity continues to be a problem both in the developing and developed world, environmentally sound principles need to be used to ensure sustainability of the resources for posterity.

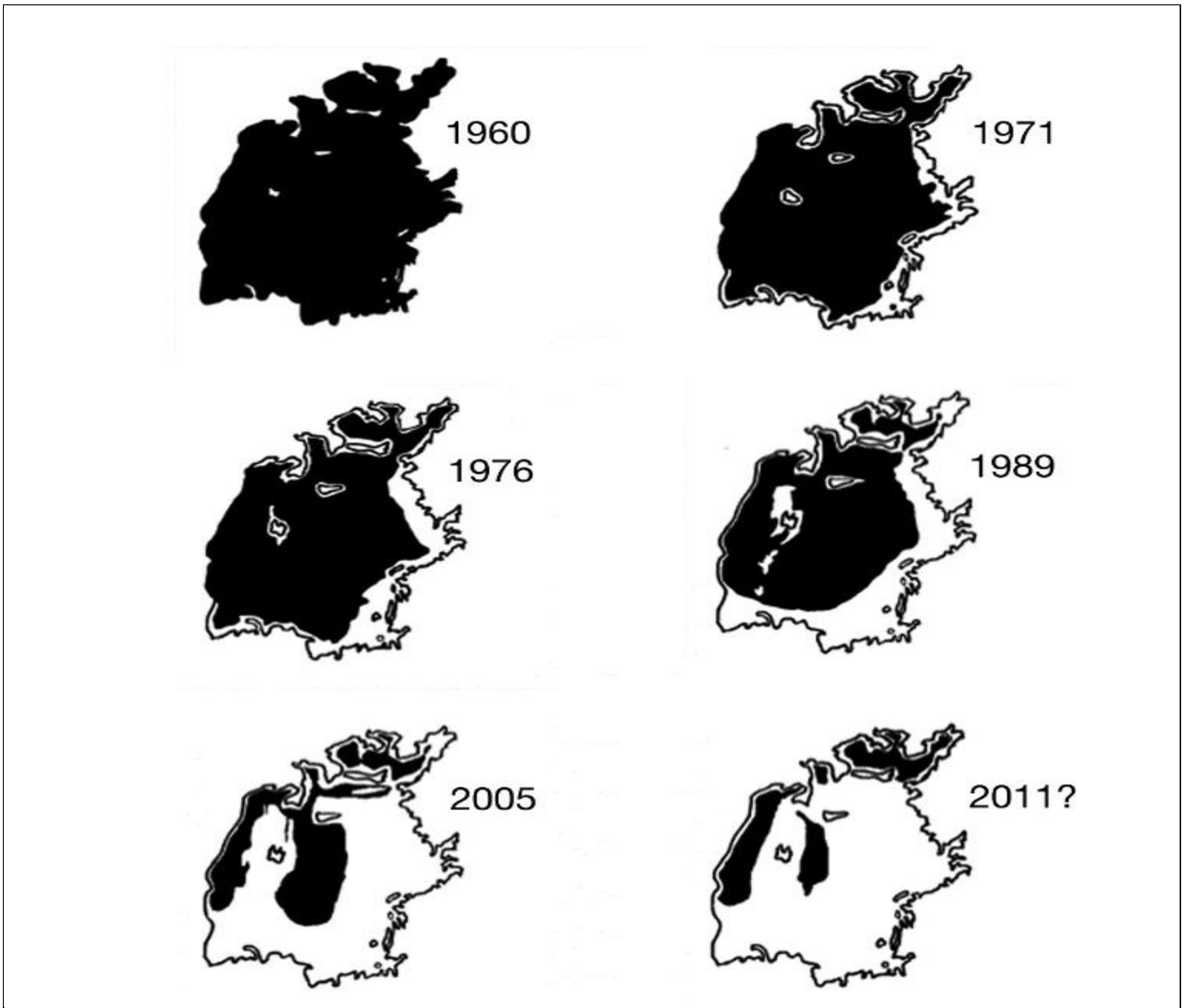

Figure 2-2: The Changing Profile of the Aral Area **(Anin, 2006)**

In his study report, Bogue (2007) states that the large canals around Lake Superior were major influencer of the water quality. The canals were built to serve economic development but had significant environmental consequences. They not only led to the decline of the water quality, but also collapse of the White fishery, affecting the wildlife and birdlife community.

In 1985, the Great Lakes Water Quality Board and the International Joint Commission identified canalisation as one of the area causing serious environmental degradation. It was observed that over time, lake shore canals begun to fill up. The primary causes for this were, natural vegetative encroachment, dust and soil wash off, wind and water erosion, decomposing leaf litter, and illegal dumping. All of these ultimately negatively impinged on the water quality of the lake.

Water backflows into the lake introduced more polluted water into the lake. Routine monitoring of existing canals was found to be most important. In order to restore the canals to their initial statement dredging was undertaken. However, dredging affected the water quality significantly through re-suspension of sediments and other materials that had settled at the canal bottom. The canals accumulate, sediments, nutrients and pathogens (Moe 2004). This study was also spurred by what was happening in the Apopka, a lake of 125 Km^2 that had been significantly affected by commercial interests and agricultural use. An estimated 676 piscivorous birds died in 1998 owing to birds consuming contaminated fish resulting from canalization and agriculture pesticides (Bogue 2007). The process of restoring the lake was a lengthy one.

2.5 Summary and Research Gaps

There is need to bridge the gap and conclusively indicate the key factors that have actually influenced the significant decline of bird numbers and species within the Lake Naivasha. Studies should be done that expressly reveal the impact of heavy canalization and water abstraction from within the lake systems. When commercial interests are in focus only convincing research can turn the tide and avert ecosystem degradation.

A study by Briceno & Serna (2013) of 20 canals around the shore of Lake Apopka and the Florida Keys showed that there was an elevated nutrient concentration in waters close to the shore next to the canal mouth. Water exchange at the canal got limited with time as sediments weeds and nutrient detritus get trapped. The dissolved oxygen (DO) in the deeper uncirculated water greatly decreased. Wastes and nutrients from agricultural land and the roads also got washed up to shore canals. The runoff, the study revealed, contained chemicals leached in soils and other organic elements. This was especially true after heavy rains and included heightened turbidity and light attenuation while the DO was lowered. Their objective for water quality monitoring was to measure the trends of these parameters so as to objectively compare diverse restoration methodologies used in the demonstration canals. The data would provide for unbiased, statistically rigorous statements that could inform management actions and policy development processes for improved water quality in the sanctuary.

In earlier studies Harper *et al.* (2002) demonstrated that the reason for the decline in birds was to be linked to food shortages. For although the water birds do occupy different niches, piscivorous birds are impacted by similar factors as they are part of the same food chain. Harper *et al*., (2002) observed that for the Great Cormorant, foraging was almost exclusively communal, 95.8% - when transparency was <40cm, however, when transparency was >40cm solitary foraging increased to 37.4%. Thus water transparency affected the foraging habits of these birds.

Since according to Goldson (1993) abundance of fish affected the Great Commorant both in numbers and their foraging activities by the water edge, there was need to explore the true impacts of lake shore canalisation. After discussions on the uncertainties and inaccuracies, he estimated a water abstraction figure for the 1990s which was at least six times the safe yield in the early 1980s. Presently, the Naivasha catchment waters are treated as common property as is the case in many parts of the developing world. These are usually exploited every person in need according to their capacity to draw from the resource.

The complexities are added in that there are no measurements of ‘how much’, for a sustainable/safe yield is yet to be determined. Unfortunately this means there is and no policy on how to match what is used with what is sustainable. Increasing human population causes a great strain on agricultural production and urban sewage systems which already have inadequate capacity. This places great uncertainty to the use of the lake subjecting it to the 'Tragedy of the Commons' (Hardin, 1968). Ashton (2002) puts it quite succinctly, that the lake has a bleak long term future, unless of course, drastic measures are put in place to redeem it.

2.6 Theoretical and Conceptual Framework

The ecosystem resilience theory refers to an ability of an ecosystem to bounce or spring back after a system experiences disturbances, without changing into a different system. (Holling, 1973). Further to this, according to Ludwig *et al*. (2001) ecosystem resilience is expressed in two forms: recovery and resistance. The study examined the hypothesis that abstraction through canalization causes a significant difference in the physical-chemical properties of the water of Lake Naivasha and that it does inevitably affect bird life. Environmental parameters influence the occurrence, abundance and survival of different species in a given habitat. The lake has revealed tendencies of stretching to its limit and accommodating adverse conditions. Degraded vegetation, fish and other organisms have seemingly reverted back after restoration of previous conditions. This has been especially true when water levels are restored during high inundation. However, this also reveals that changing one ecosystem attribute can significantly affect the entire ecosystem.

Within ecosystems, each environmental attribute such as water quality or biodiversity is connected to all other environmental variables such as canalization and water abstraction. Any serious transformation of one attribute will inevitably seriously affect the overall ecosystem balance (Odum, 1959), He posited this while discussing the integrated ecosystem theory. The theory postulates that, "all ecosystems are open systems embedded in an environment from which they receive energy, matter input and discharge energy, matter output" (Odum, 1959). This is a prerequisite to ecological processes and is vital as it follows the principles of thermodynamics.

Secondly, the theory espouses the principle that ecosystems have multiple levels of organisation and that they work hierarchically. These are normally based on differences in locality and spatial distance in between the components that are interacting. The distance in between the components is vital as it takes time for processes, events and signals to be disseminated. Higher dependency and close interaction will mean changes are less subtle in their manifestation. The third proposition of the theory incorporates the role of the temperature element, which gives viability to carbon based life, thermodynamically. Appropriate temperatures are crucial in order to build biochemically important compounds or decompose organic matter (Jorgensen, 2007).

It is therefore, not feasible to consider particular aspects of an ecosystem in isolation as each affects the others. In this regard, the theory correctly concludes that mass inclusive of biomass and energy are conserved. This is an important principle in ecological modeling. The theoretical minimum for any ecosystem is two populations, with one fixing energy and another that decomposes and cycles waste. In reality though, all viable ecosystems are very complex networks of several interacting populations. According to Patter et al. (1990) there are no ecological entities that exist in isolation, the ecosystem is more than the sum of the components. The number of interacting components is usually very high, this complexity therefore makes it impossible to assess all properties of working ecological networks which is characteristic for all ecosystems.

The theory further indicates that all ecosystem processes are irreversible, which is an expression of the second law of thermodynamics. All living organisms require energy inputs to enable maintenance of life processes. Therefore, as biological processes utilize the captured energy, or input, they move further from thermodynamic equilibrium and maintain a state of low-entropy and high energy relative to their surroundings and to the thermodynamic equilibrium (Jorgensen, 2007). This is necessary as it indicates that the ecosystem can and does grow. Svirezhev, (1992) demonstrated that the eco-energy of an ecosystem corresponds to the energy needed to breakdown the system.

Once the initial energy has been captured across a boundary, ecosystem growth and development is possible. This takes place through an increase of the physical structure (biomass) and a concomitant increase of the network (more cycling) which essentially entails increasing the information embodied in that system. The growth indicates that the system has moved on, away from thermodynamic equilibrium. When an ecosystem receives solar radiation it attempts to maximize eco-exergy storage or power to the extent that if more than one possibility is offered, in the long term it is the one moving the system furthest from thermodynamic equilibrium that is selected. Fath *et al.* (2004) demonstrated that in order to maximize eco-exergy storage the ascendency and power must be maximized, (Odum, 1983) in this it becomes evident how this works in cases of nutrient cycling. The eco-exergy of a water body increases when the most abundant nutrient relative to its use is cycling faster, this becomes clear when considering eutrophication models (Jorgensen, 2007).

It is apparent that Lake Naivasha has recovered after fairly adverse seasons in recent years. The effects of habitat degradation therefore, have ecological and economic consequences in terms of biodiversity loss, especially distribution of birdlife, decline in fishery and the collapse of the tourism industry. The lakes ecosystem has time and time again managed to re-organize itself after the changes that have occurred. The study seeks to find a pattern that is revealed by the bird distribution within the heavily canalized areas that give direction to recovery pathway of the lakes ecosystem after this anthropogenic disturbance.

Resilience can be defined as the modes in which a complex adaptive system is re-organises itself (as opposed to the lack of organization of by being compelled to change by external factors) it is also the degree by which a system builds and increases its capacity to learn and adapt (Carpenter *et al.,* 2001). Walker *et al*., (2004) posits that in this wise, it is the capacity of a system to absorb disturbance and reorganize while undergoing change so as to maintain its own functions, its structure, identity, and communication with the environment. Ecosystems experience disturbances (natural and anthropogenic) with differing magnitude and frequency. These disturbances include fires, flooding, diseases, overgrazing, climate change, deforestation, poaching, pollution etc. Such disturbances may gradually erode the resilience of ecosystems eventually driving them into different states. When resilience is eroded, the ecosystem becomes more vulnerable to change and gradual external perturbations can make it to shift to other states (Folke *et al.,* 2004).

Lake Naivasha is currently facing multiple threats. Forshay (2001) demonstrated that disturbance and disruption of the shoreline integrity affects the invertebrate prey availability which in turn affects the number of birds foraging for food. He found a very strong correlative relationship between amphipod density and foraging birds. Canalization disrupts natural recuperative tendencies for the environment and needs to be checked. However, it provides good grounds for foraging for piscivorous birds. This is temporary as prolonged access to breeding fish in the shallow water inevitably lowers fish stocks with long term dire consequences. The status of the fishery inevitably affects birdlife especially the piscivorous birds.

The conceptual framework, Fig 2-4, shows the various relationships in the Lake Naivasha ecosystem. Wetland birds require habitat cover, food and nesting material protection from shoreline vegetation and the aquatic plants. Canalisation disrupts this by clearing vegetation and affects fish habitats (food for piscivorous birds) by decreased water quality caused by turbidity and eutrophication. Since all the species are reliant on the ecosystem integrity, the integrated ecosystem ensures all the recovery of vegetation has a domino effect on recovery of the entire ecosystem.

Conceptual Framework

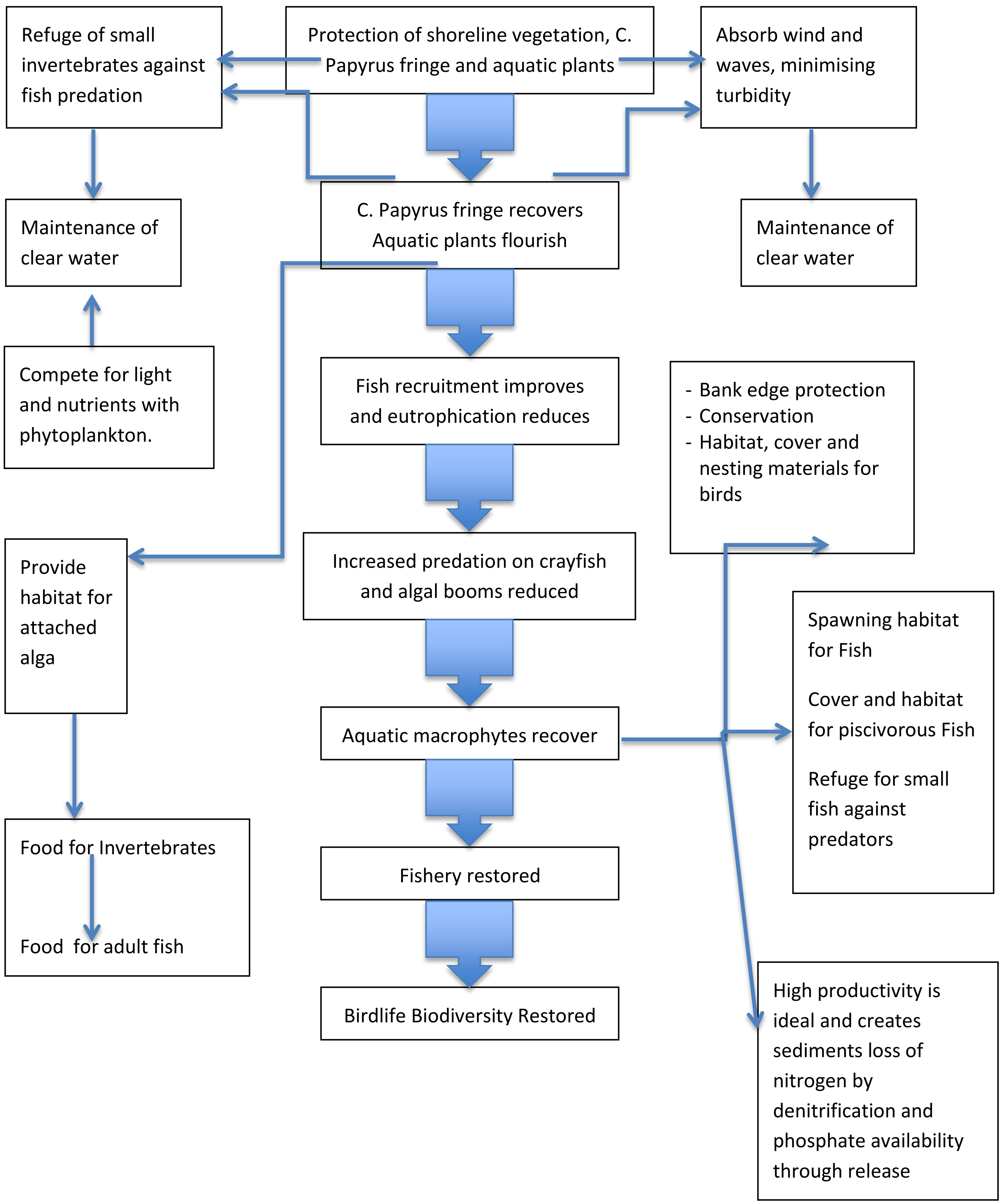

Figure 2-3: Conceptual framework **(Modified after Moss et al. 1996; Hickley et al. 2004)**

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Reconnaissance Survey

An initial reconnaissance survey of the study area was done, essentially taking note of how far water had receded and assess what was required. The exploration field trip was also to acquaint the researcher with the data collectors, research assistants, government officers and other field personnel who would assist in the research. Several logistical issues and constraints were also assessed and noted on the initial survey. Access points to the lake were mapped out and so was the suitability of the sampling areas. Transport used while on the lake was a fiberglass boat with a 25HP engine, belonging to the State Department of Fisheries. All the sampling was done from within the lake on board the boat. A very reliable coxswain was available during all the field trips to help in navigation.

A desk review was done of data collected on the lake on the water quality and rainfall statistics from WARMA, WWF and the Fisheries Deparment.

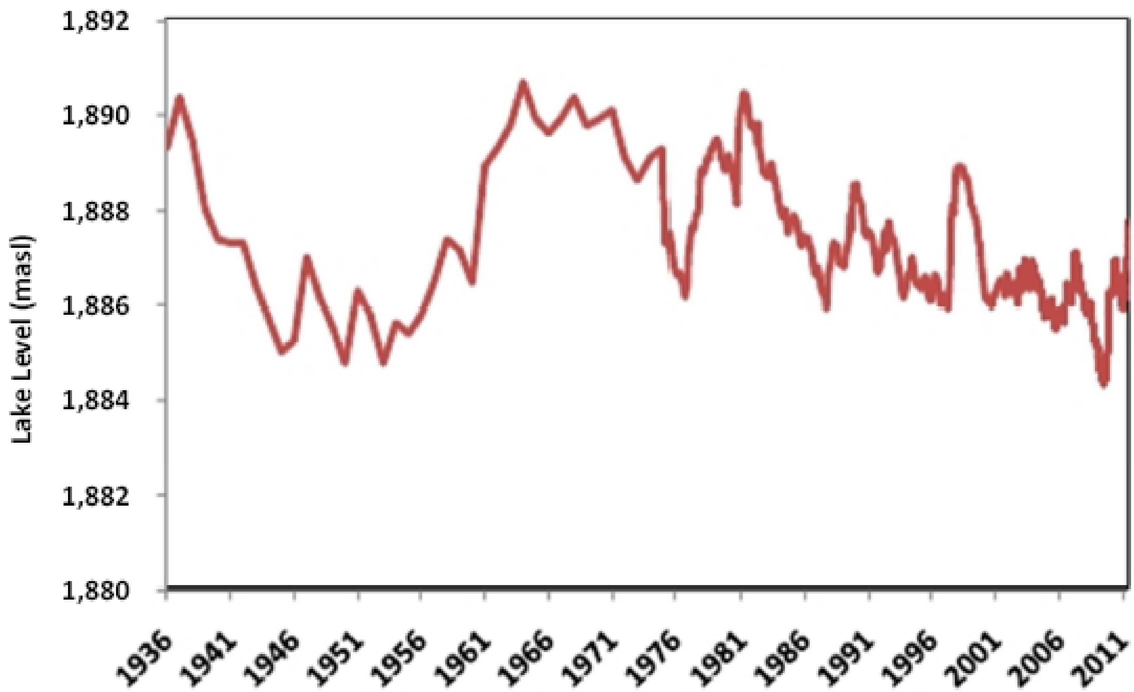

Chart 3-1: Lake water level dynamics in Lake Naivasha (1936-2011)

(Source: WRMA 2010)

3.2 Description of Study Area

The Lake Naivasha is a freshwater ecosystem situated in the Naivasha Sub County, approximately 100km Northwest of Nairobi. The lake's inflow system is associated with three rivers, namely the Gilgil, the Malewa and the Karati, with Malewa the largest with an annual flow of 153 million cubic metres, the Gilgil 24 million cubic metres and the Karati which intermittently flows in the rainy season (Ase *et al*., 1986; Harper *et al*. 1995). The lake basin provides drinking water for approximately 300,000 people (50,000 in 1977) within urban centers such as Nakuru and Naivasha towns. Lake Naivasha contributes significantly to poverty reduction and food security. It is a source of dietary proteins from fish and provides revenue through fish harvest, and tourism through sport fishing, aesthetics, and bird watching.

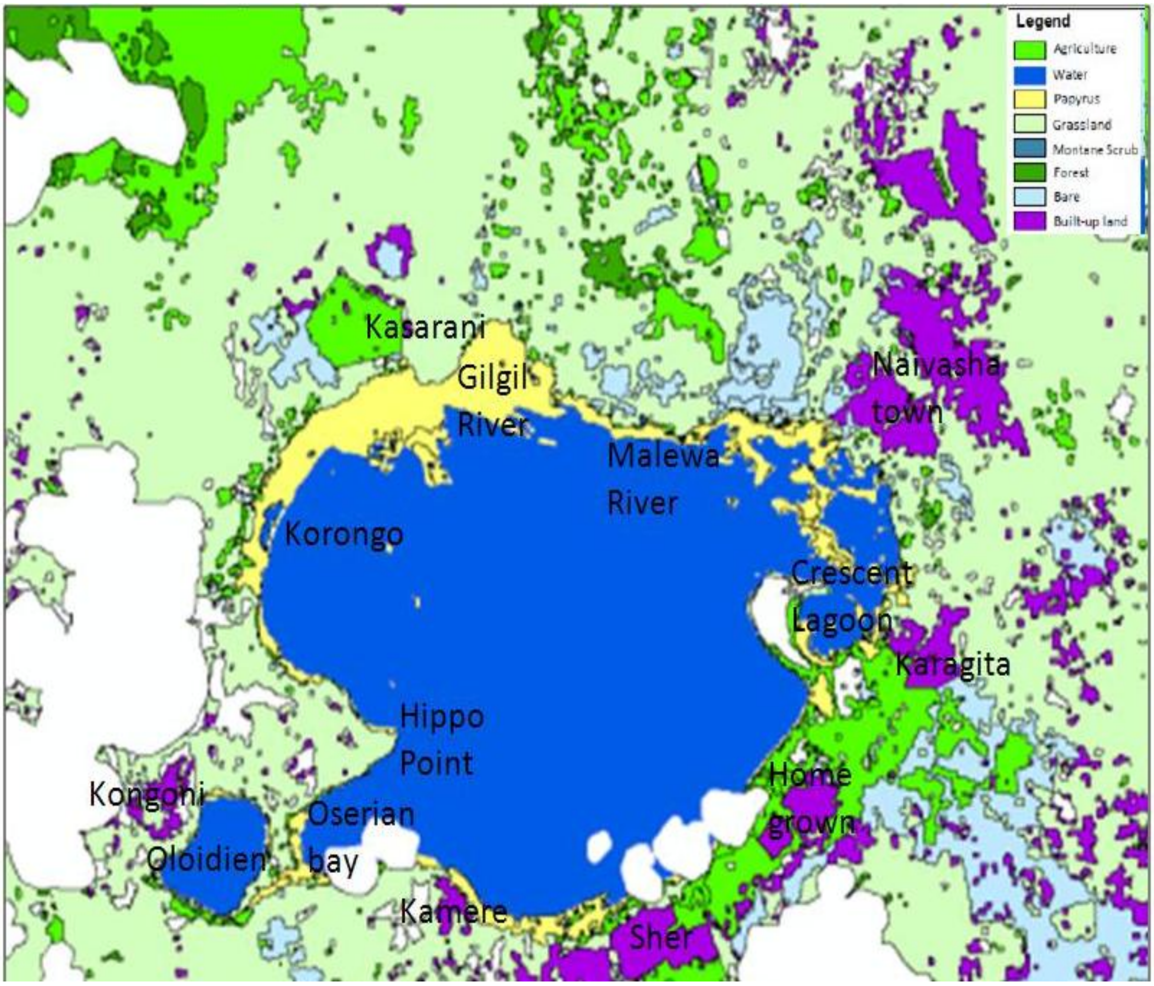

Figure 3-1: Location of the study Area

(Fisheries Department, 2012)

Lake Naivasha is located 100 km Northwest of Nairobi. The lake has four basins, as a consequence of its volcanic history (Figure 3-1). The almost circular main basin has the deepest point in the south, with steadily decreasing depth moving to the north and the delta of the major inflow. One flooded volcanic crater in the northeast, part of the main lake except during extreme low levels (in 1945 and 2010), is its deepest point (12 m depth when isolated).

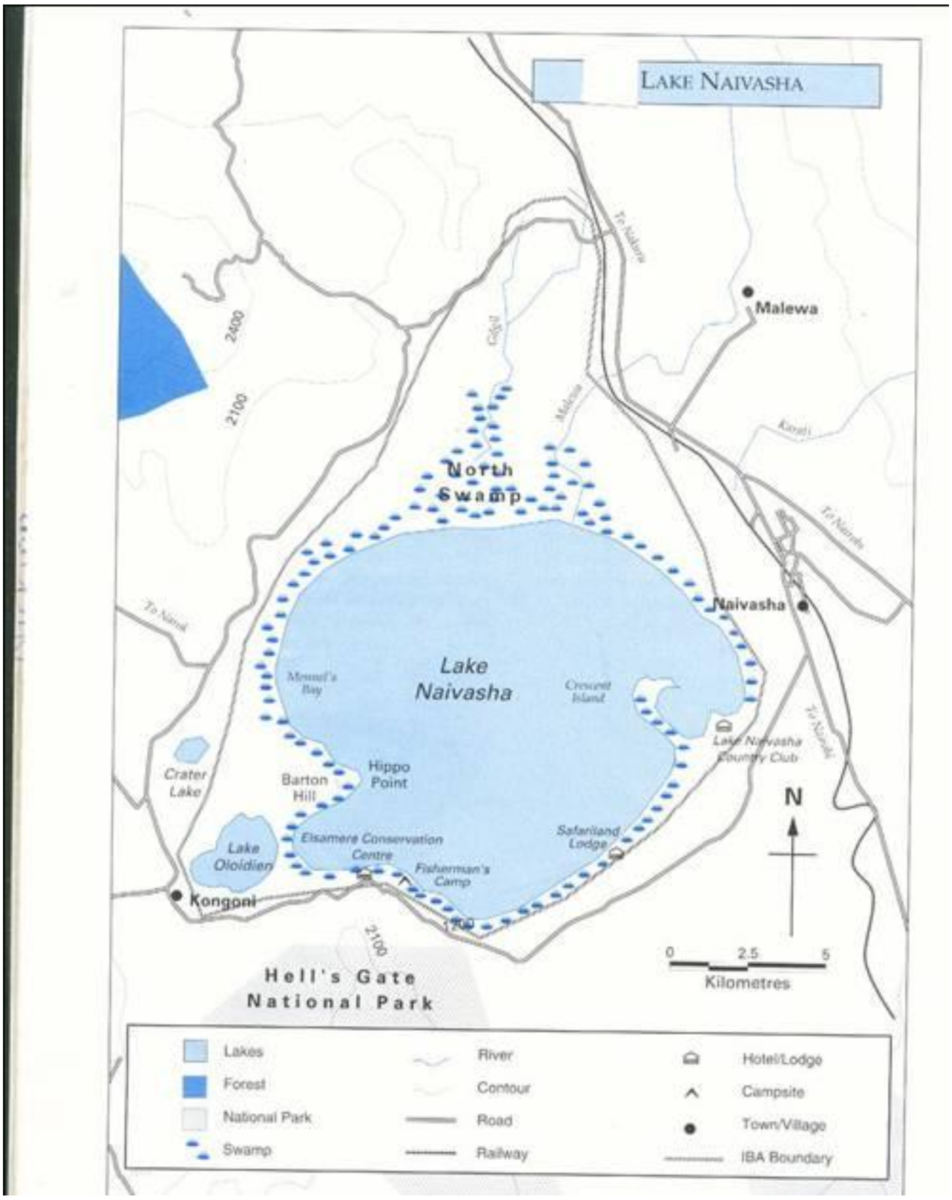

Figure 3-2: Lake Naivasha and immediate environs

Mwaura (2009)

Administratively, Naivasha is one of Nakuru County's 16 divisions and has a population of about 158,679 people according to the 2009 Census of Kenya. The County of Nakuru is currently led by Governor, Kinuthia Mbugua. Naivasha is 76 km from Nairobi, 63 km from Nakuru and 516 km from Mombasa and is within the Kenya rift valley.

Kenya, is a republic in the East African region, and has a boundary to the north with Sudan and Ethiopia, on the eastern shares a border with Somalia and the Indian Ocean, with Tanzania to the south, while bordering Lake Victoria and Uganda to the west. Kenya has a total area of 582,646 sq. km (224,961 sq. miles) with Nairobi as the country's capital city. The equator passes bisects the country. Figure 3-2 closely shows the study area, the focus area was the immediate shoreline around the lake.

Lake Naivasha is of importance to the national economy as a natural asset, particularly in the context of tourism. It is the only fresh water lake in a vastly semi-arid region. In addition, its water is fresh enough to support fish populations and provide support to the local economy by enabling a fishing industry. The water surface of the lake covers an area of about 130 km2 with the average depth of 4m.

3.2.1. Climate

The ambient air temperatures are moderate with means from 15.9 to 18.5°C monthly and seasonal variations in water temperature ranging from 19.5 to 23°C. closer to the surface and from 19.2 to 21.5°C. closer to the bottom. There is a combination of warm temperature, low relative humidity and low rainfall which make January and February the months with highest evaporation. The rainfall is bimodal and is distributed between two rainy seasons. The period between April and May is a rainy season, with the long rains coming then, while the short rains commence during October-November window. The average rainfall and evaporation are 610 mm/yr and 1800-1900 mm/yr respectively. This is consistent from annually with minimal seasonal variations. (Ase, *et al*. 1986).

3.2.2. Hydrology

The lake receives drainage water mainly from two perennial rivers Malewa and Gilgil that account for 90% of the river inflows to the lake. Their drainage areas are 1730 and 420 km^2 respectively. River Karati also contributes considerable amount of water. Several ephemeral streams flow into the lake in the southern part. Their contributions are insignificant. It is a fresh water lake surrounded by the alkaline lakes of Elementeita, Nakuru, Magadi, and Bogoria. It is in a closed drainage basin and has no visible outlet.

Consumption of water, irrigation and natural losses, often eliminate flow in the Gilgil the water reaches the lake. Both rivers enter from the northern part of the lake after passing the North Swamp for several kilometres. Floating mats of Cyperus papyrus occupy a major portion of the northern swamp. Additional recharge is provided by several ephemeral rivers, with a total catchment size of 1000 km^2, such as Nyamamithi and Marmanet as well as substantial underground seepage from the previously almost permanently waterlogged, meadow and bog environments in the Kinangop plateau which have nowadays been heavily desiccated by the widespread introduction of eucalyptus trees.

3.2.3 Agriculture and Population

Intensive agricultural practices occur in the riparian zone of the southeastern part of the lake. Kenya is a leading exporter of cut flowers with the Naivasha area supplying upto 75% of the market. Intensive greenhouse commercial floriculture and horticulture farms are to be found located around the lake each with water canal access to pump water from the lake. Even though the horticulture and floriculture sector employs thousands of Kenyans and contributes significantly to the GDP, it poses a major threat due to pesticide and fertilizer use, removal of fringing swamps, and over-abstraction of water. (LNBIMP, 2012).

The population of the lake basin was estimated at 650,000 people of with almost 160,000 living around the Lake itself, as per the 2009 census. The population surrounding the lake area depends on it for drinking water, fishery, recreation and irrigation water, because of that the demand on the resource is increasing dramatically with the associated consequences of pollution over the exploited resource. Within the period of 1989 and 1999 (during the booming and exponential growth decade for the horticulture industry), the basin’s population of the grew by 64%. However, this growth has since slowed down to approximately 13%, (WWF, 2011)

The direction of wind is mainly from the southeast or northeast depending on the season. In contrast to the calm conditions or slight winds in the morning over the lake, the typical wind speed is 11-15 km/h in the afternoon. It causes mixing of the lake water down the complete water column, and cause well-oxygenated water from top to bottom (LNROA, 1993). This situation helps to increase the concentration of dissolved oxygen of the lake water and improve the lake water quality

3.2.4. Water Balance

The hydrological equilibrium for water within the drainage basin is kept in balance by the water sources and losses. With the principal sources that bring in water being the rivers, precipitation and in-bound seepage. Conversely, the water is lost through seeping out and evaporation. However, the water abstraction levels have been contributing significant losses to the water.

The Lake Naivasha water balance has been predominantly controlled by river discharge, rainfall and evaporation. In comparison to river discharges and rainfall, the seepages play an insignificant part in the main lake water balance equilibrium and how the lake levels flunctuate. The rate of water seeping in seems to be consistently related to the amount of rainfall on the catchment. As the lake has no visible surface outflow, this has led to researchers postulating that the lake has a subsurface outflow, as it remains a fresh water lake. (Gaudet and Melack, 1981)

3.2.5 Lake Levels

The water levels for the last 70 years have fluctuated between 1884-1891 masl in response to net inflow. According to Litterick *et al.* (1979), he reported that the daily recordings revealed repeated fluctuations leading to an 8 m decline between 1931 and 1952 followed by a 5 m increase during within the following 10 years. However, the level of Lake Naivasha has consistently shown a long-term downward trend over the greater part of the last century and only responded dramatically during the abnormally heavy and widespread rains of September-December 1961. Since then, Beresford *et al*., (1981) noted it was yet to recede to its pre-1961 levels. However was however surpassed by the 2009-10 levels which attained levels lower than 1961. Chart 3-1 and 3-3 give the water levels of the lake from 1900, WRMA has maintained consistent recordings of the levels.

3.2.8 Biodiversity and Wildlife

The Lake Naivasha basin is well endowed with biodiversity and is one of the important biodiversity hotspots in Kenya with several hundred species of plants and animals. The basin has quite a rich and diverse mammalian fauna. The key indicator bird species include the African Fish eagle and the red-knobbed coot. However, rare and endangered species are now hardly ever seen, at the lake e.g., great crested grebe, maccoa duck (endangered), African darter, great egret, saddle-billed stork, white-backed duck, Baillon’s crake and African skimmer (all vulnerable).

According to Adams *et al.*, (2002) the overall bird species richness of lake Naivasha had been maintained, though there were significant ecosystem changes, some of these were created by the floating mats of alien plants which supported numerous aquatic invertebrates (Harper, 1992). However, a report by IUCN ‘near threatened’, (2011) indicated that only 200 bird species were still recorded from the lake, with others being less frequent, e.g. maccoa duck, great crested grebe, African darter, great egret, saddle-billed stork, white-backed duck, Baillon’s crake and African skimmer. The people surrounding the lake depend on the lake for their sustenance which includes drinking water supply. The core human activities within the region include wildlife and livestock ranching, agriculture, tourism, pastoralism and fishing. _

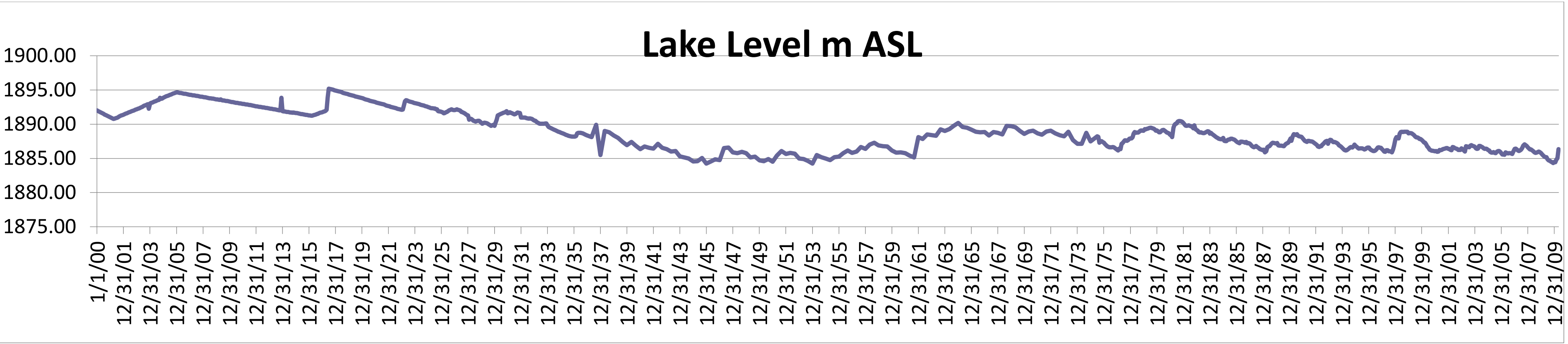

Chart 3-2: Lake Levels in Lake Naivasha: 1900-2009

(Source:WRMA 2010)

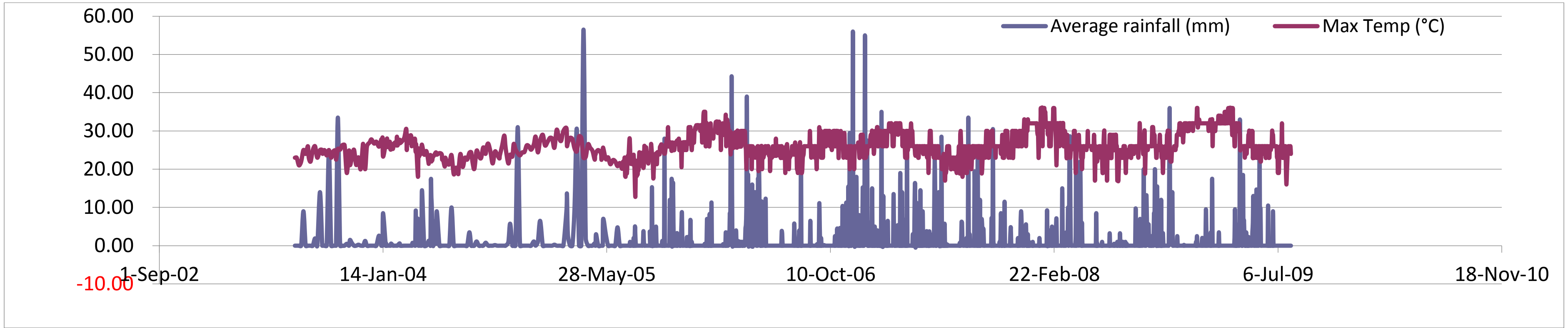

Chart 3-3: Average Rainfall in (mm) and Temperature (ºC) over five years.

(Source: WRMA 2010)

3.3 Sampling Strategy

According to Kothari (2004), descriptive research entails conducting surveys and fact-finding, with the major purpose of the description being to understand the state of affairs as it exists at present. According to Mugenda and Mugenda (2003), this requires the collection of quantifiable information from the sample. In this study the entire shore line was surveyed and sampling done at each and every canal seen. The water analysis was done in situ using a multi-parameter measuring meter whose probe was inserted into the water and the indicated figures recorded.

3.4 Lakeshore Canalization Mapping

The points chosen for collection of data were the canal points of Lake Naivasha. The entire perimeter area of the shoreline of the lake was targeted. All the points were accessed from the boat within the water and all visible canals were sampled. Identification of the canals and naming by was done with assistance of two resident Fisheries assistants who were very conversant with the lake as they were involved in routine patrols of the lake for about 20 years on the routine discharge of their duties. Marking of the canal points was done by a hand held Garmin 64 GPS (Global Positioning System) portable device. GPS units are used to determine the geographic coordinates of landscape features. The coordinates were recorded as Eastings and Northings to be later plotted on a satellite map of the area in order to ascertain the actual positions on a map. At every canal, the width of the canal was recorded and the water quality and bird counts taken. The use of binoculars was most useful in noting the birds present within the shoreline while still a long way off thus avoiding disturbing the counting process (Plate 3-1).

Plate 3-1 – Canalization survey
Researcher (2009)

3.5 Water Quality Assessment

The water quality assessment involved the analysis testing on site, for water transparency, water pH, TDS, electrical conductivity, dissolved oxygen turbidity and oxygen redox potential. Water Transparency was determined using a white secchi disk. The secchi disk was attached to a nylon rope with some weight at its tip. The weight facilitated vertical movement of the disc and minimized tapering of the rope. It was gradually lowered in the water column until a point it becomes invisible to the eye. The corresponding point on the rope just at the water surface is marked and measurements taken using a measuring tape. The secchi disc was then raised until the point where it is visible again. Lake water transparency water turbidity measurements (in centimeters) were taken with a Secchi disc. Salinity measurements were taken using a hand held combined meter which measured salinity and other parameters such as TDS, conductivity, pH, dissolved oxygen, turbidity and oxygen redox potential.

The parameters were measured on site using a portable multi-parameter water analyzer model Hanna HI 9828 (Plate 3-2).

Plate 3-2: On site water quality measurement

Researcher (2009)

The water quality parameters were taken, pH: - Determines reactivity of the water, frequently it is used in determining the chemical and biological property of water. pH ranges of 6.5 - 8.5 are best adapted for great environmental and aesthetic results. From past studies on the Naivasha, water samples had a range of 6.75 – 8.33. Temperature: –Temperature determines the speed of reactions because of its effect on chemicals. This also would indicate whether this was consistent with previously recorded figures. Total Dissolved Solid or Conductivity: Is associated with freshwater systems and consists of inorganic salts, small amounts of organic matter, and dissolved material in the water mass. Dissolved Oxygen (DO): Determination of DO concentration is an important measure for oxygen is involved in, or influences, most of the chemical and biological process within water bodies. DO is required for the respiration of aerobic microorganisms as well as all other aerobic life forms. The typical range of average DO is 15 mg/l at 0^0C to 8 mg/l at 25^0C. DO concentrations below 5 mg/l adversely affect the functioning and survival of biological communities while below 2 mg/l does lead to the death of most fish. Turbidity: High turbidity can be caused by runoff or sediment re-suspensions. It is also indicates the presence of microorganisms in the water. It is used to measure the light-transmitting property of water, and is effective in determining colloidal or residual suspended matter.

3.6 Bird Life Assessment

During the surveys, bird counts and quantification of bird species was done by physically counting the birds available on the shoreline within the canal area, while still a long way by use of binoculars. The engine of the boat was switched off to avoid disruptions and bird numbers counted by three persons on board. The numbers of bird species were also identified and counted. Both swimming and foraging birds on the shoreline were counted. However, birds overflying the area were not included, unless they landed and remained within the area in focus.

Plate 3-3: Birdlife assessment

Researcher (2009)

A physical count of the bird species around the canal and the actual number of birds sited, whether swimming or foraging within the canal area was noted and reconfirmed (Plate 3-3). The number of birds and species was recorded and averaged in cases where the three persons noted disparities. Identification of the various species was done by identifying the common name and later adding the scientific name.

3.7 Data Analysis

Experimental data was analyzed using both simple descriptive statistics and where appropriate parametric or non-parametric statistical procedures. The researcher used the IBM Statistical Package for Social Sciences (SPSS 21) analysis. Correlation and regression multivariate statistics were also run to make necessary extrapolations and projections. Correlation analysis was done to assess the strength of association between the variables being analysed. The regression analysis was to quantify by how much the same impacted the environment. The Chi square test was used to check if there was any statistical significant difference in qualitative variables while Analysis of Variance (ANOVA) was used to test mean difference. Correlation of the bird life data, the canalization density and water quality was done to determine the effect of the canalization on the lake.

After the analysis, data was presented in the form of tables, charts, data summary tables with descriptive analysis explaining what was deduced. Interpretation of results was done in comparison to scientific theories and past findings and discussed, compared with existing literature on similar or related works. The projects objectives provided the guiding principles for the presentations and deliberations.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results of the study, which sought to establish the state of canalisation of the lake, the areas with the highest canal density and their impact on water quality and birdlife distribution. The overall objective of the study was to assess how shoreline canalization affects water quality and birdlife in Lake Naivasha. The specific objectives were as follows:

1. To assess the intensity of canalization on the shore line of Lake Naivasha and the pattern of canal distribution around the Lake
2. To determine whether the canalized areas exhibited unique patterns in lake water quality
3. To determine if canalization within the lakeshore has significant impact on the distribution of wetland birdlife.

4.2 Lake Canalisation

Plotting of the canal points Geographical Positioning System (GPS) readings on the Lake Naivasha satellite map using Arc-View GIS software showed a pattern of distribution into three distinguishable zones as shown in Figure 4-1. The pattern revealed that most of the farms are also concentrated on these three parts of the lake. Both the distance between the canals in each transect and the total transect distance were computed. This was important in assessing the density of the canalization per zone.

Figure 4-1 shows the actual distribution of all the canals within the lake. It reveals the actual shoreline area around the lake with canals, these being the areas where sampling was done. The research findings were categorised into three distinct areas that have canals, to ease in data analysis these are named as the Eastern, Northern and Southern zones. From the results, it was apparent that most of the canals lie on the southern side of the lake. Majority of the canals were directly drawn to irrigate the flower farms and bore the name of the farm or horticultural enterprise. From the map, it is evident that if the canals on the Northern Zone side were to be disaggregated further, there would be one canal to the north and four to the west.

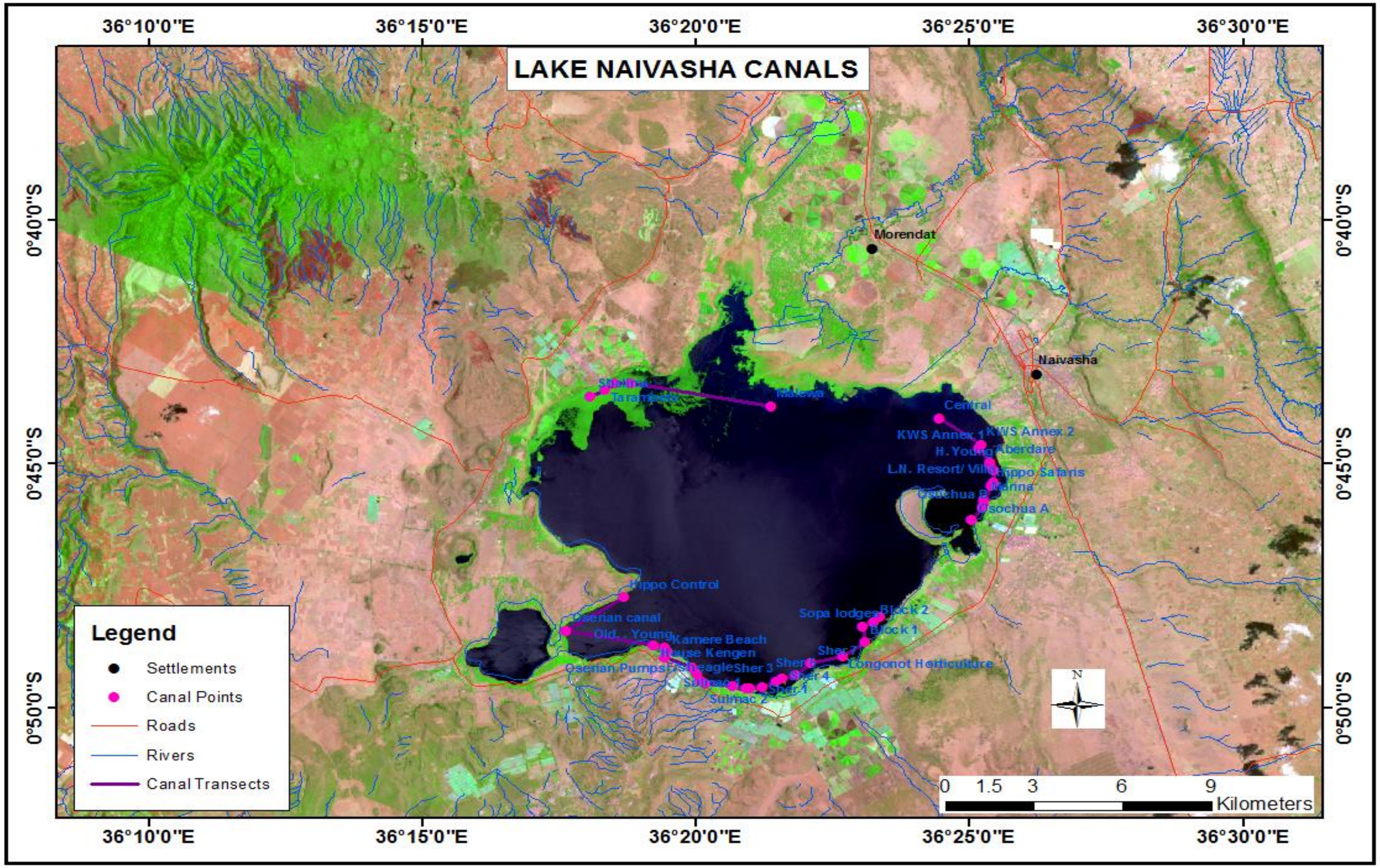

Figure 4-1: GIS map plotted to show canal points in 3 canalised zones (Researcher, 2015)

The transect distances for the 3 zones where canals were located was computed using the Arc View software and the length given in meters, this is as shown in Table 4-1. The canals transect line shows the total distance occupied by canals within the specific zone. This made it easier to calculate the density of canals within a specified zone. Further to this, the table also gives the calculated cumulative canal width for each of the three zones and the percentage this represents of the total transect distance in the specified zone.

Zone	Overall Transect Distance	Number of Canals	Cumulative Canal Width	% Canalised lakeshore area per zone
Eastern Zone	4992.6 Meters	12	153 Meters	3.1
Northern Zone	6342.9 Meters	5	36 Meters	0.6
Southern Zone	15138.1 Meters	24	319 Meters	2.1

Table 4-1: Transect Zone Distance and Number of Canals (Researcher, 2015)

The few canals on the south-west or north-west part of the lake have been included in either the Southern or Northern sector as this allowed a better aggregation and density pattern, as shown in the GIS maps in Figure 4-1, 4-2, 4-3 and 4-4. The true west of the lake did not have a recorded canal. Chart 4-1 summarises the number of canals in the respective zones and Table 4-2, Table 4-3 and Table 4-4 give the names and the widths of the canals in meters. The cumulative width of the canals for every zone as indicated in table 4-1 are aggregated to give a grasp of how wide the canals actually are when viewed wholly.

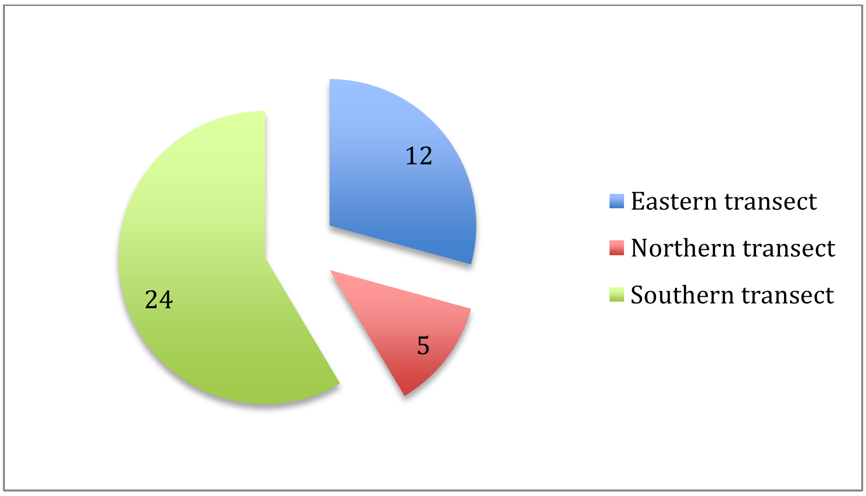

Chart 4-1: Number of canals in the 3 zones (Researcher 2015)

During the field sampling exercise, all the widths of the canals were taken. In terms of individual widths the widest canals found within the zones were as follows: The eastern zone had three 20 meters canals which were the widest on that zone; on the northern zone the widest canal was 10 meters, whereas, the southern zone had two canals of 30 meters each. The water levels were fairly low by late 2009 and the water within the canal areas had a deep green appearance as can be seen on the foreground of Plate 4-1 and 4-2.

Plate 4-1 – Oserian canal (Researcher)

Plate 4-2 – KenGen canal (Researcher)

Name of Canal	Osochua A	Osuchua B	Mbegu Farm	Marina	Hippo Safaris	Lake Naivasha Resort	Floating restaurant	H. Young	Aberdare	KWS Annex 1	KWS Annex 2	Central
Canal width (m)	5	3	8	10	14	15	20	20	8	15	15	20

Table 4-2: Eastern Zone Canal Width Size

Name of Canal	Malewa	Loldia 1	Loldia 2	Tarambete	Shalima
Canal Width (m)	8	5	5	10	8

Table 4-3: Northern Zone Canal Width Size

Name of Canal	Hippo Contro l	Oserian canal	Oserian Pumps	House Kengen	Old. . Young	Kamere Beach	Plantation / Power	Gold Smith	Gold Smith 2	Fish eagle	Fishermens Camp	Kwa Muhia
Canal Width (m)	8	15	25	8	6	8	20	15	15	15	30	4
Sulmac 1	Sulmac 2	Sher 1	Sher 3	Sher 4	Sher 5	Sher 6	Sher 7	Longonot Horticulture	Sopa Lodges	Block 1	Block 2	Sanctuary Farm
18	30	10	8	8	8	10	7	12	8	8	5	18

Table 4-4: Southern Zone Canal Width Size

4.2.1 Canalization on the Eastern part of the Lake

The Eastern part of the lake had a total of 12 canals points at which water was drawn out of the lake. Figure 4-2 shows the specific canals on the eastern part of the lake. It will be noted that the canals appear deep in the lake and not on the shore line. However, this is mainly because, at the time of data collection, the lake waters had receded significantly to the lowest levels they had been in about 60 years (WRMA, 2011). A number of the canals are also in very close proximity, for example, Marina, Mbegu and Osochua B. The Map also captures the positions of the farms, especially to the right side of the cresent island.

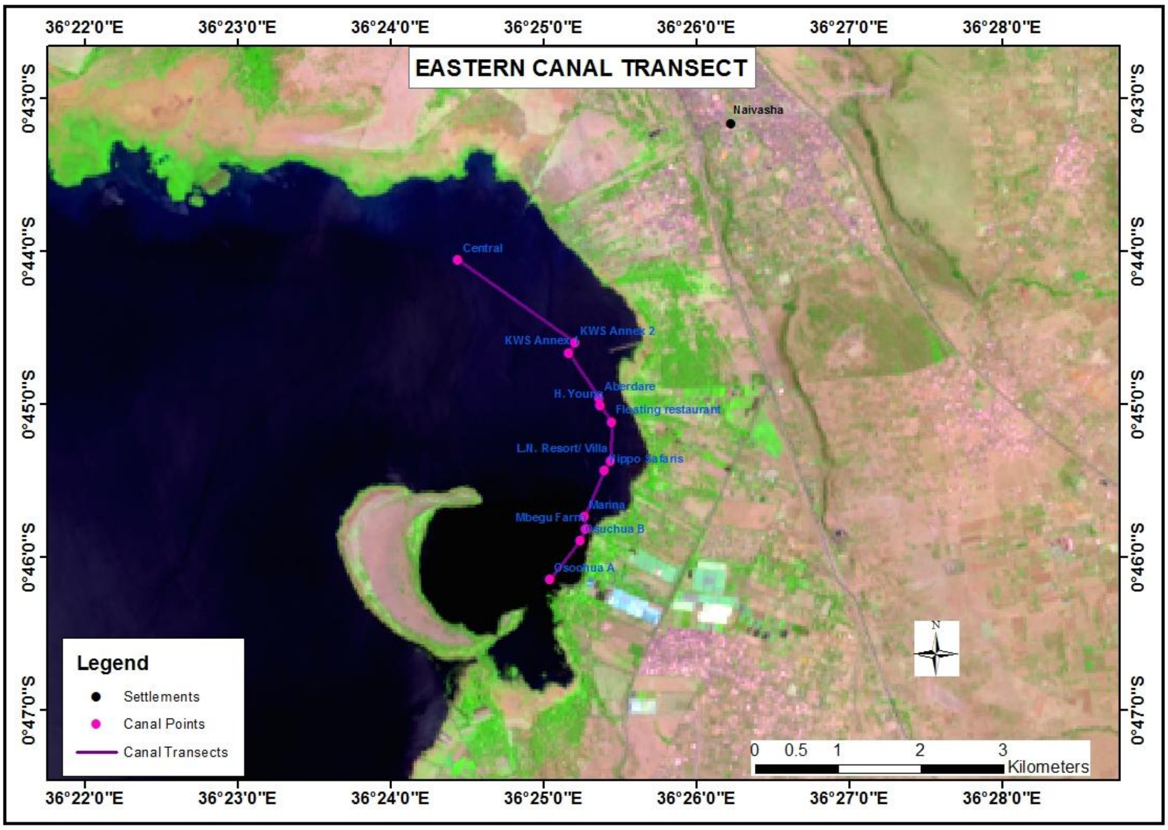

Figure 4-2: GIS Map of the Eastern Canals Transect sector (Researcher, 2015)

The 12 canals sampled on the Eastern part of the lake were found within a total distance of 4992 meters and represented the highest average density per meter for the lake. The inter-canal distances are shown in Table 4-2. The inter-canal distance was calculated so as to show the proximity of the canals to one another and their density within each the zone. Table 4-5 shows the inter canal distances in the eastern zone.

Transect Section	Canal shoreline distance (m)
Osochua A - Osuchua B	593.3
KWS Annex 2 - Central	1740.3
KWS Annex 1 - KWS Annex 2	144.4
Aberdare - KWS Annex 1	667.6
H. Young - Aberdare	92.9
Floating Restaurant - H. Young	234.80
Lake Naivasha Resort/Villa - Floating Restaurant	467.4
Hippo Safaris - Lake Naivasha Resort/Villa	139.5
Marina - Hippo Safaris	606.5
Mbegu Farm - Marina	152.2
Osuchua B - Mbegu Farm	153.8

Table 4-5: Eastern Transect, Distance and Number of Canals

4.2.2 Canalization on the Northern part of the Lake

Figure 4-3 shows the canals sampling points on the northern part of the lake. Essentially, there was only one canal perfectly located on the north, the other four were towards the north-west. Most of the farms on the northern part of the lake drew water directly from river Malewa. The north maintained a more pristine shoreline as there was little anthropological disruption in the area. Not only did the northern side have the fewest number of canals, the canals were also relatively narrower compared to the counterparts in the other zones. The density of canals over the calculated transect distance was also the lowest.

Table 4-6 show the actual inter-canal distances. It is the shortest canal transect with the fewest canals, with the distance between the Malewa Canal and Loldia 1 being more than three times the other distances put together.

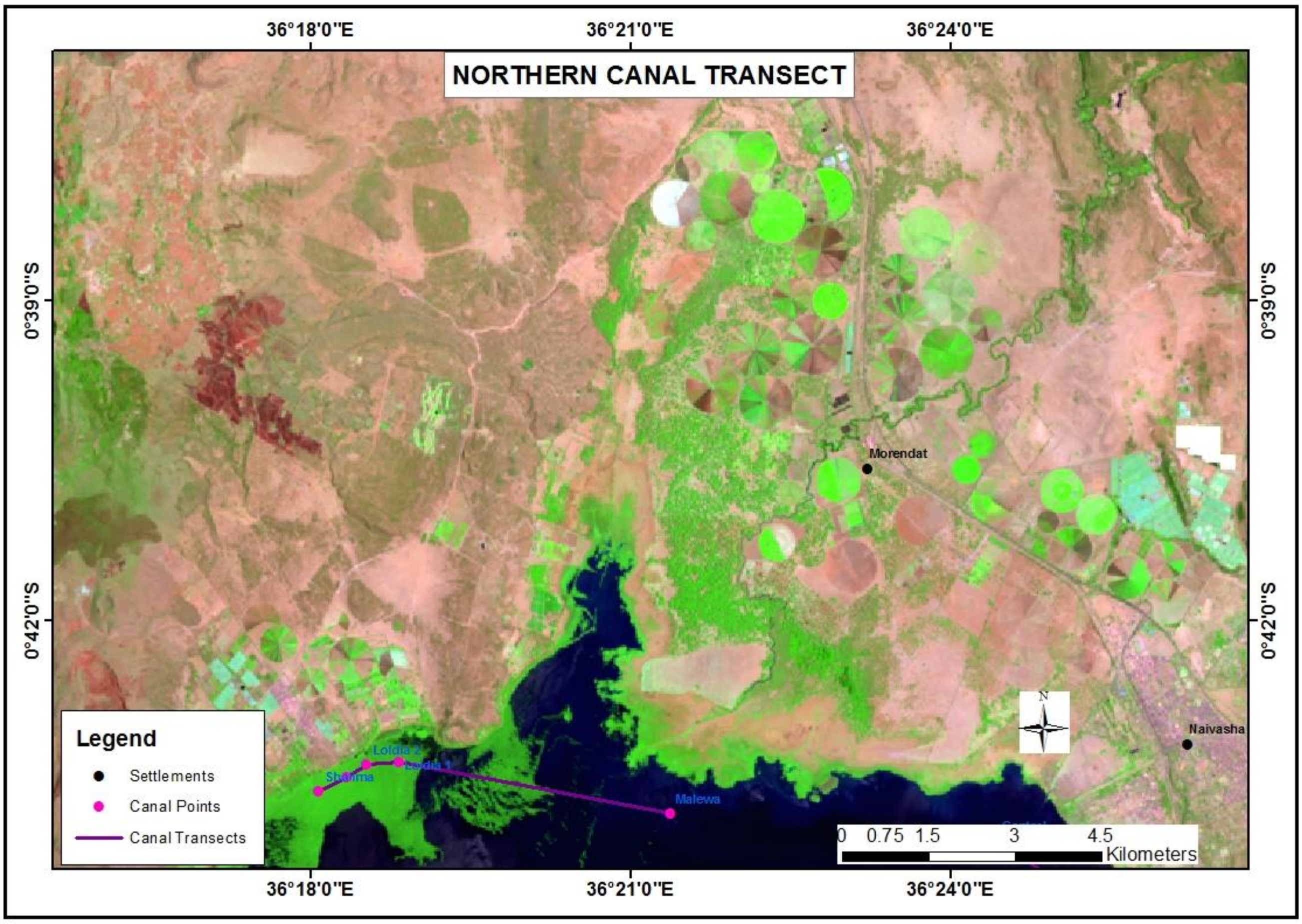

Figure 4-3: GIS Map of the Northern Canals Transect sector (Researcher, 2015)

Transect Section	Canal Shoreline Distance (m)
Loldia 1 - Malewa	4811.80
Shalima - Tarambete	550.03
Tarambete - Loldia 2	416.52
Loldia 2 - Loldia 1	564.53

Table 4-6: Northern Transect, Distance and Number of Canals

Source: Researcher (2015)

4.2.3 Canalization on the Southern part of the Lake

The southern part of the lake had the highest number of canals recorded and sampled. Figure 4-4 shows the entire southern transect zone. It is also apparent from the map that the southern area has a large number of farms. Table 4-7 gives the details of the inter-canal distances. In terms of canal density though it had the most number of canals, the eastern zone had a higher density of canals be meter owing to the close proximity of canals within the eastern zone.

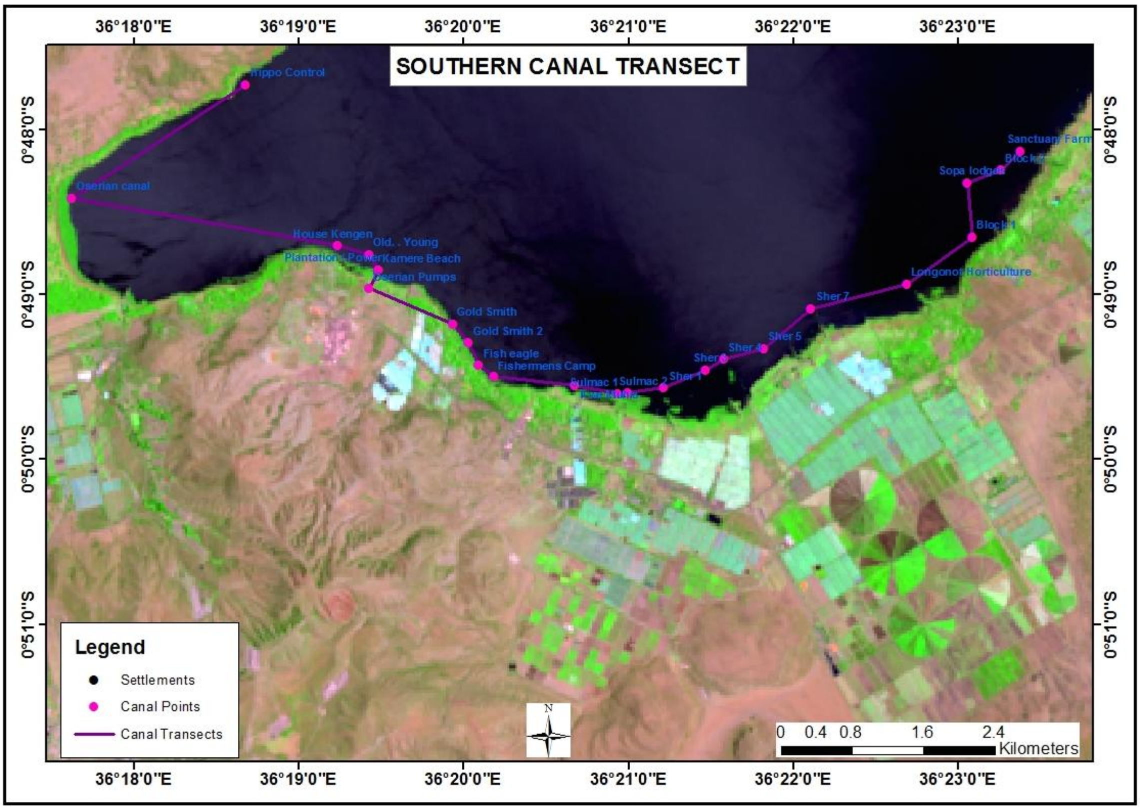

Figure 4-4: GIS Map of the Southern Canals Transect (Researcher, 2015)

Transect Section	Canal Shoreline Distance (m)
Oserian Canal - House Kengen	3040.96
Block 2 - Sanctuary Farm	302.43
Sopa Lodges - Block 2	401.47
Block 1 - Sopa Lodges	610.87
Longonot Horticulture - Block 1	897.58
Sher 7 - Longonot Horticulture	1116.02
Sher 5 - Sher 7	695.39
Sher 4 - Sher 5	464.31
Sher 3 - Sher 4	241.14
Sher 1 - Sher 3	508.93
Sulmac 2 - Sher 1	411.37
Sulmac 1 - Sulmac 2	115.70
Kwa Muhia - Sulmac 1	490.60

Fishermens Camp - Kwa Muhia	919.96
Fish Eagle - Fishermens Camp	206.36
Gold Smith 2 - Fish Eagle	278.16
Gold Smith - Gold Smith 2	271.66
Oserian Pumps - Gold Smith	1028.13
Kamere Beach - Oserian Pumps	234.04
Old Young - Plantation Power	203.76
House Kengen - Old Young	362.68
Hippo Control - Oserian Canal	2332.04
Plantation Power - Kamere Beach	4.57

Table 4-7: Eastern Transect, Distance and Number of Canals

(Researcher, 2015)

It is clear that the Southern Zone had the largest number of canals which was 24, and most of these were more than twice the average width of 12.25 meters, two southern canals had a width of 30 meters. The northern zone had canals averaging 7.2 meters, this was the least number of canals in the three zones and they measured between 6-10 meters The Eastern Zone canals had an average width of 12 meters, with the a canal range of between 3-20 meters.

4.3 Water Quality Assessment

The data collected on water quality from the canals was aggregated into the various zones. Water quality is a measure of the condition or its chemical state relative to the requirements of the biotic environment and human requirement. The water quality of a given aquatic system is what maintains the ecological processes that support biodiversity. It therefore, follows that; declining water quality will affect the stability of the biotic integrity by hindering ecosystem services and functioning of the aquatic ecosystems. The historical values for conductivity, pH, secchi disc depths were as given in Table 2-1 presented in the literature review section. The water quality parameters that were measured from the water surface at the canal points were given for the three zones.

4.3.1 Eastern Zone

Table 4-8 is a summary of the data from the eastern part of the lake. It is notable that Osochua A canal secchi disc readings exhibited the highest water transparency around the lake. However, this is consistent with literature that shows that the crescent lake area, especially during very low water, gets severed from the rest of the lake. This is also a very deep part of the lake and in the area significantly minimizes the effect of sediment re-suspension by wind or water waves, Hubble and Harper (2000).

Name of Place	pH	TDS	Secchi Disc	Conductivity	Temperature
Osochua A	8.47	208	72	416	23.2
Osuchua B	8.16	199	22	399	22.9
Mbegu Farm	8.16	199	16	397	23.4
Marina	8.07	193	13	587	23
Hippo Safaris	8.29	188	17	377	23
L.N. Resort/ Villa	7.83	188	18	376	23.5
Floating restaurant	8.16	190	18	385	23.3
H. Young	8.25	187	18	375	23.1
Aberdare	8.26	187	15	374	22.8
KWS Annex 1	7.92	98.3	16	197.4	23.8
KWS Annex 2	8.07	189	14	379	23
Central	8	183	16	366	23.2
Zone Mean	**8.14**	**184.11**	**21.25**	**385.70**	**23.18**

Table 4-8: Water quality in the Eastern Zone

The last row of Table 4-8 presents the mean frequencies of the data in summarized form. The Eastern side had the highest TDS score average with 184.1mgl- compared to the Southern Zone with 166mgl- and the Northern 160.2mgl-.

4.3.2 Northern Zone

Table 4-9 provides water quality data from northern canals. This zone exhibited the lowest mean frequencies for all the water quality variables in the lake. The mean temperature for all the zones remained constant. The notably high turbidity at the River Malewa area had the effect of giving very low secchi disc readings which is attributed to sediment discharges from the river into the lake.

Name of Place	pH	TDS	Secchi Disc	Conductivity	Temperature
Malewa	7.84	112	10	224	23.2
Loldia 1	8	161	14	324	23.2
Loldia 2	8.22	167	42	334	23
Tarambete	8.19	195	20	390	23.1
Shalima	8.03	164	54	329	23.1
Zone Mean	**8.1**	**160**	**28**	**242**	**23.1**

Table 4-9: Water quality in the Northern Zone

Secchi disc transparency averages were the highest on the Northern side, as compared to other zones as shown by table 4-9. The Malewa entry point into the lake on account of suspended solids entering the lake from the river, was the major difference. The effect of eutrophication was minimal with much lesser productivity and the appearance of the water was brownish red within the entire zone.

4.3.3 Southern Zone

Table 4-10 shows the water quality measurements on the southern side. The mean frequencies on the last row provide valuable data which was used in graphical presentation in Chart 4-2. The chart provides a snap shot average of the water quality status of the three zones.

Name of Place	pH	TDS	Secchi Disc	Conductivity	Temperature
Hippo Control	8.12	185	30	372	23.6
Oserian canal	8.05	168	18	336	23.6
Oserian Pumps	8.01	164	41	329	23.2
House Kengen	8.2	175	16	350	23.2
Old. . Young	8.02	169	17	338	23.2
Kamere Beach	8.14	168	21	335	23.2
Plantation / Power	8.28	162	16	324	22.9
Gold Smith	8.45	163	24	327	23.2
Gold Smith 2	8.09	164	26	328	22.8
Fish eagle	8.38	163	27	326	23
Fishermens Camp	8.24	164	21	329	23.4
Kwa Muhia	8.09	166	28	333	22.7
Sulmac 1	8.33	163	28	326	22.9
Sulmac 2	8.27	163	26	327	23
Sher 1	8.3	164	25	327	23.7
Sher 3	8.13	164	26	327	22.9
Sher 4	8.02	164	26	330	22.9
Sher 5	8.32	165	20	331	22.9
Sher 6	8.29	168	22	337	23.1
Sher 7	8.28	166	23	333	23.1
Longonot Horticulture	8.23	167	22	336	23.1
Sopa lodges	8.06	163	20	327	23.1
Block 1	8.22	166	18	329	23.1
Block 2	8.1	167	21	334	23.1
Sanctuary Farm	8.1	165	20	329	22.7
Zone Mean	**8.2**	**166.2**	**23.8**	**265.1**	**23.1**

Table 4-10: Water quality in the Southern Zone

4.3.4 Water Quality Summary for the Three Zones

A correlation analysis was done to get the relationship between canal density (Independent variable) and pH (dependent variable) showed the canal size and density was positively correlated with the pH. Further correlation carried out showed that increase in canal width had a significant effect on the turbidity. Chart 4-2 shows the water quality graphical summary within the three zones. In order to have the figures presentable within the same chart, the TDS and conductivity were divided by a factor of ten (10) across the three zones, while the percentage canal density was multiplied by ten.

Overall, Chart 4-2 gives an indication that canalization does affect the water quality in the lake. The results are consistent on pH, Turbidity and Conductivity. As canal density increases so does the pH, Turbidity and Conductivity. Results of the eastern and southern side further indicates that canal density exerts further influence especially on conductivity and turbidity. The eastern side which had the highest canal density per meter of transect shoreline elicited the highest parameter shift that we can attribute to canalisation.

Canal	**Temp.**	**pH**	**DO Mg/ml & %**	**TDS**	**Total Bird Count**	**No of Bird Species**
Eastern	21.8	9.1	73.7	172.5	41	6
Northern	23.2	8.7	89.9	186.0	344	5
Southern	20.4	8.8	83.7	173.9	48	4

Table 4-11: Mean Parameters taken during Low water levels

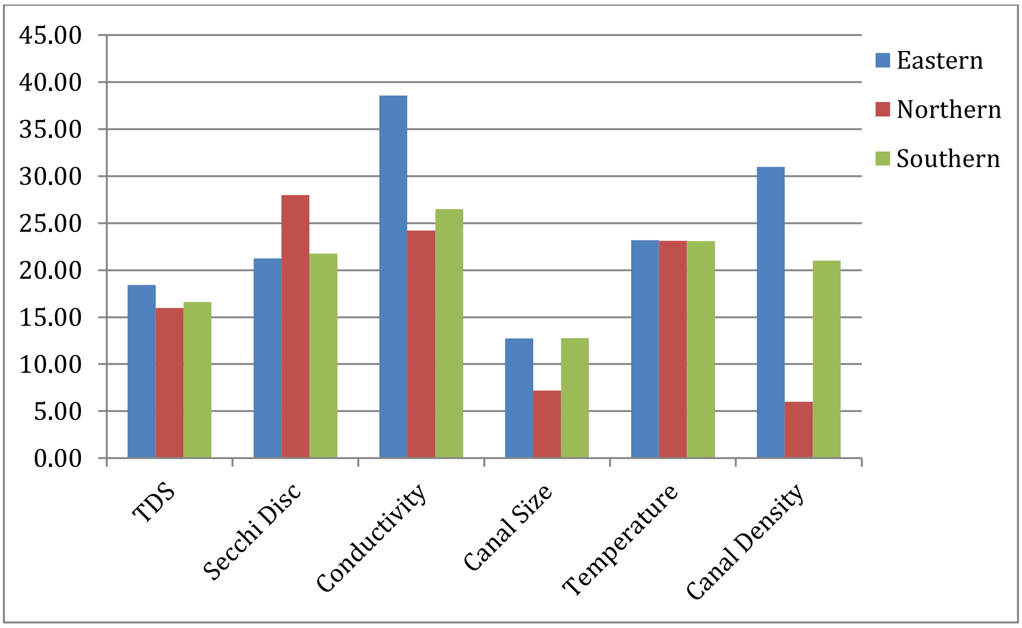

Chart 4-2: Water Quality Across the Three Zones

4.4 Birdlife

The Northern Zone elicited the highest bird count with a total of 1,375 birds counted and an average of five (5) species per canal over a transect distance of 4,992.6 meters. This presented a very high bird density for the Northern Canal Zone; it had the lowest number of canals. The Eastern Zone recorded a total bird count of 245, with an average bird species count of 5 per canal also. The Eastern Zone measured at 6,342.9 meters. The Southern Zone yielded a total bird count of 1,051 in a length of 15,138.1 meters with an average species count of 4. From the map, it is apparent that if the canals on the Northern side were to be disaggregated further, there would be one canal to the north and four to the west. The north would have 512 birds, and the west 863 birds for the four canals.

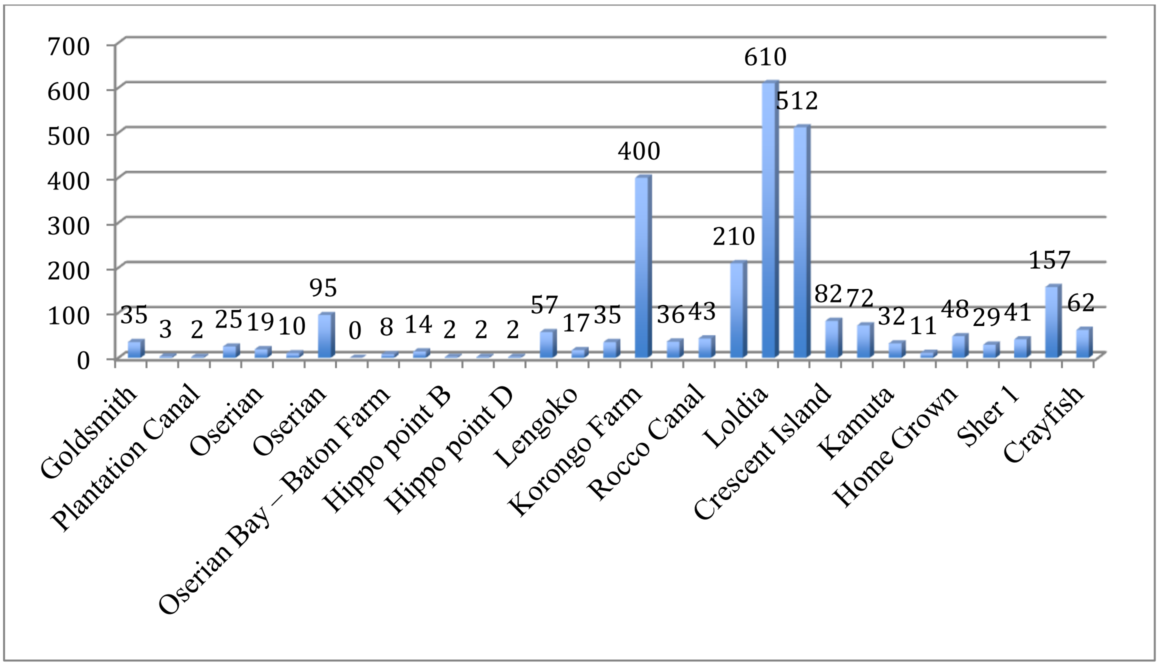

Chart 4-3: Total Bird Count in the Canals (Researcher, 2015)

Chart 4-3 is a graphic presentation of the actual bird count at the canal points around the lake. The number of bird species around the lake during the exercise did not vary significantly, it was the actual bird numbers that did. The numbers of birds in the northern zone far outnumbered both the eastern and southern zone combined. The disruption caused by the canals may have had a major impact in the bird distribution. Birds require a more tranquil environment in order to feed and reproduce optimally. In addition to the attendant disruptions, the effect on living organisms of such parameters such as turbidity and pH cannot be gainsaid. Further research should be undertaken in order to clarify the actual impact of canalization on birdlife.

The Northern Zone elicited the highest bird count. Chart 4-4 shows the actual number of birds counted for every canal zone. Chart 4-5 and chart 4-6 further gives the total number of birds for each of the zones and the average number of birds per canal in the zones. The Eastern zone had the least number of birds counted at the canals and also the lowest number of birds per canal. The bird numbers are inversely related to the canalization density.

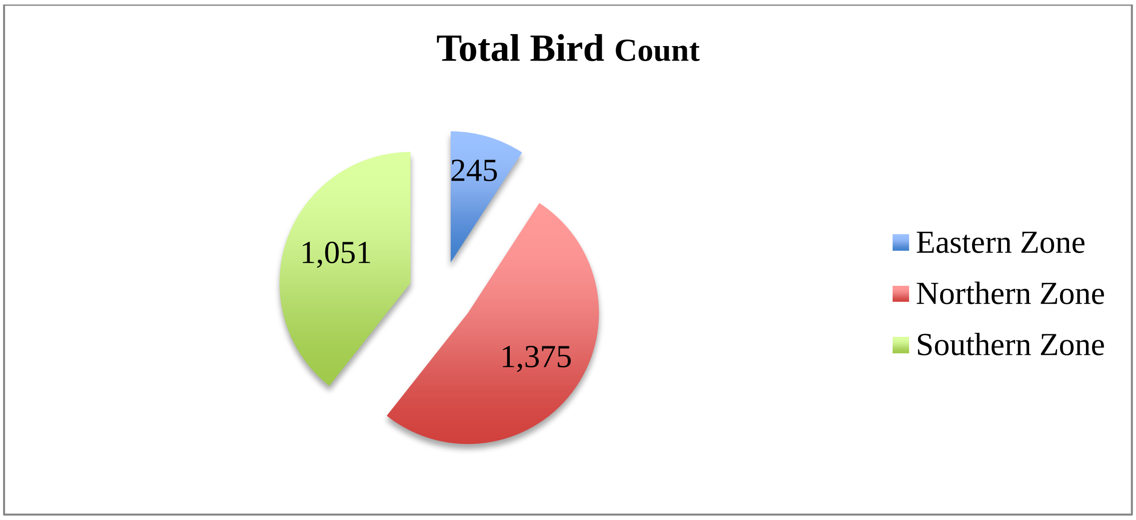

Chart 4-4: Total Bird Count per Sector for the 3 Zones (Researcher, 2015)

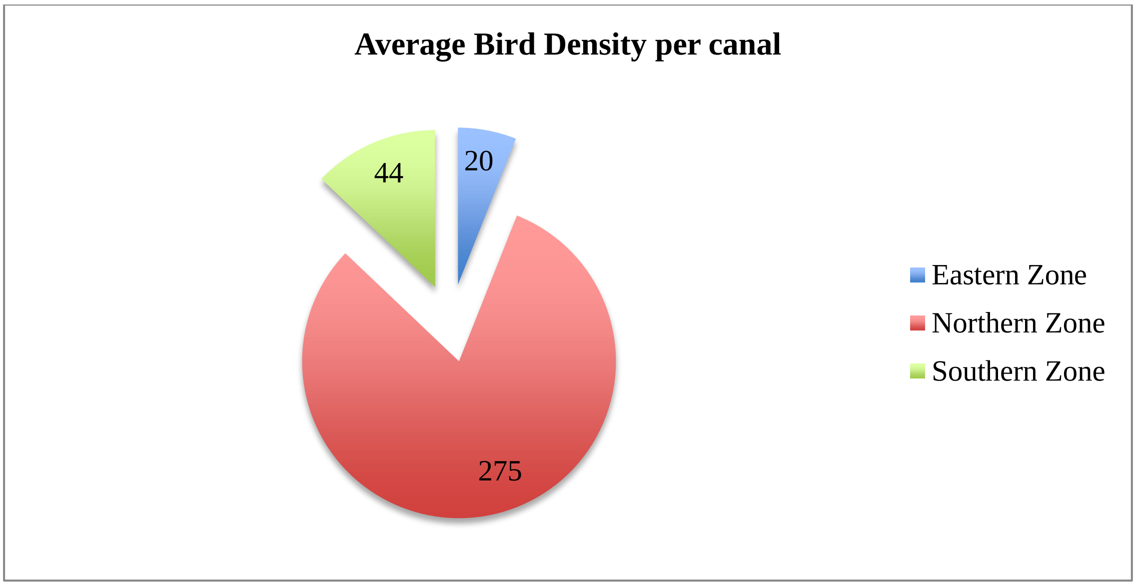

Chart 4-5: Average Bird Numbers per Canal in the 3 Zones (Researcher, 2015)

Chart 4-6 captures the number of species around the lake. Although the number of species varied from canal to canal the lowest count, zero was on the southern zone and can be attributed to the noise and other disruptions at the Kengen pumping abstraction station on the lake. The average bird species density for each zone was 5; zonally there was no marked distinction in the average bird species distribution. However, the actual numbers of bird was notably high in the northern canals.

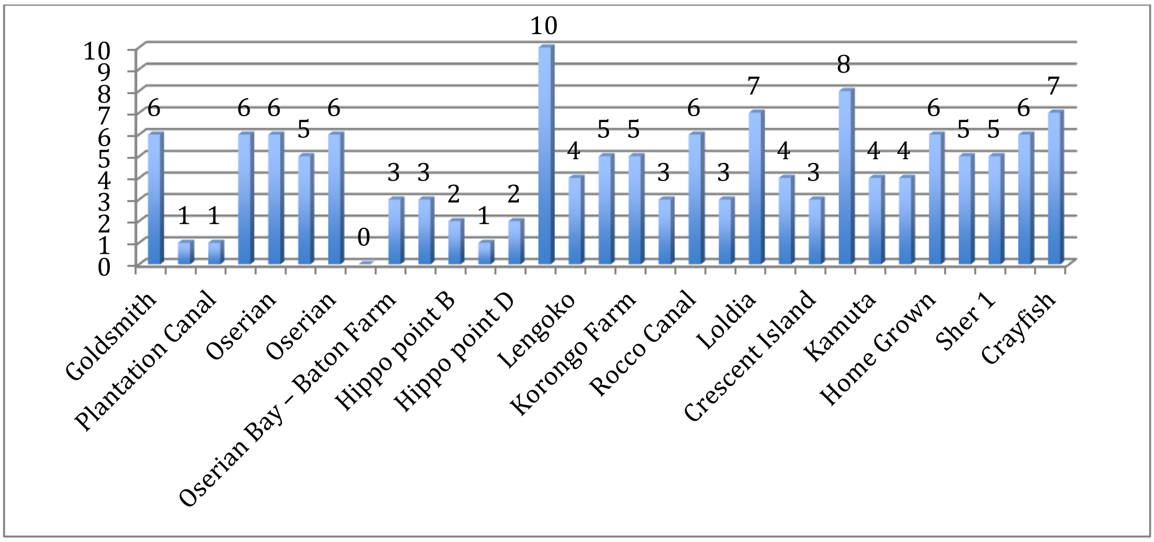

Chart 4-6: No. of Bird Species (researcher, 2015)

4.4.1 Lakeshore Canalization and Birdlife

A correlation analysis was done between canal size and bird distribution. The results revealed that there was a negative correlation between canal size and total bird count. The Pearson correlation coefficient for the variables was $r=-0.679$. Statistically it gives an indication that as the canal size increases in width, the total number of birds decreases. Table 4-11, Table 4-12 and 4-13 gives the actual data collected around the lake at the time of taking the bird counts. The larger the size of the canal the more the habitat quality tended to be degraded. This was also conspicuous in cases where several canals were in close proximity to others.

A - Southern Zone

Time	Canal	Temp	pH	DO Mg/ml & %	TDS	Total Bird Count	No of Bird Species
11:22	Florima	19.29	8.96	8.3 92%	148	35	6
11:44	Goldsmith	19.44	8.97	8.6 92%	154	5	2
11.49	Plantation Canal -2	19.61	8.93	7.8 84	152	3	1
11:56	Plantation Canal	19.84	8.67	8.1 87	173	2	1
12:07	H. Young Canal	19.63	8.8	8.2 92	163	25	6
12:24	Oserian	19.8	8.92	9.2 100	175	19	6
12:46	Oserian 4	19.16	8.98	7 79	169	10	5
13:14	Oserian Kengen	19.52	8.95	7.6 83	176	95	6
13.3	Oserian Bay – Baton Farm	20.33	8.79	6.9 77	177	8	3
13.42	Hippo point A	21.28	8.99	7.9 88	175	14	3
13.46	Hippo point B	21.87	8.68	7.3 82	180	2	2
13.56	Hippo point C	20.65	8.55	5.2 59	177	2	1
14.03	Hippo point D	21.68	8.63	7 82	177	2	2
14.1	Dr. Sylventein	20.18	8.69	6.1 70	178	57	10
14.3	Lengoko	20.52	8.84	7 79	177	17	4
14.36	Rima Island	21.11	8.89	7.9 90	177	35	5
14.44	Korongo Farm	21.42	8.84	7.6 85	180	400	5
14.54	Korongo	21.64	8.98	8.4	174	36	3

	2			94			
17.49	Block – Longonot	20.56	8.83	7.6 81	180	29	5
17.59	Sher 1	20.37	8.92	8.2 88	186	41	5
18.09	Sher 2	21.26	8.97	7.9 88	188	157	6
18.16	Crayfish	20.62	8.84	7.7 84	190	62	7

Table 4-11: Water quality and Birdlife in the Southern Zone

B - Northern Zone

Time	Canal	Temp.	pH	DO Mg/ml & %	TDS	Total Bird Count	No of Bird Species
15.03	Rocco Canal	22.79	8.87	7.1 80	171	43	6
15.22	Tarambete	24.28	8.67	7.9 93	196	210	3
15.38	Loldia	23.37	8.25	6.5 76	192	610	7
15.52	River Malewa Mouth	22.26	9.02	7.2 82	185	512	4

Table 4-12: Water quality and Birdlife in the Nothern Zone

C - Eastern Zone

Time	Canal	Temp.	pH	DO Mg/ml & %	TDS	Total Bird Count	No of Bird Species
17.1	Sanctuary	22.6	9	7.4 86	173	72	8
17.21	Kamuta	21.83	9.2	8.3 90	162	32	4
17.3	Kijabe	21.65	9.09	7.8	176	11	4

	Ltd			87			
17.39	Home Grown	21.21	9.07	8.2 89	179	48	6

Table 4-13: Water quality and Birdlife in the Eastern Zone

4.4.2 Water quality and Bird Count

Further correlation and regression analysis was done to investigate what relationship pH and transparency elicited on the bird count. This was undertaken with pH as the constant/ independent variable, against the total bird count. The results indicated there was a high degree of correlation, *sig=0.001*, between the two variables while the secchi disc indicated a relationship to the effect that decrease in transparency corresponded to lower bird counts. This indicates that as canal size increased, the water transparency decreased as denoted by the secchi disc depth, overall this had an effect on the birdlife. Though the current increase in pH may not have directly affected birdlife if the pH went beyond 9.2, previous studies done have shown that aquatic plants that sustain fish and other aquatic organisms would be adversely affected, this in turn would have the same domino effect on avian species as postulated by Odum (1959).

4.5 Discussion

This research sought to establish the state of canalisation of the Lake Naivasha, the impact this has on the water quality and their impact on the birdlife distribution. From the results and analysis of the data, it is apparent that canalization of the lake has had a significant impact on the water quality and birdlife distribution around the lake. Past studies have shown that canals impact on the water quality of water bodies and its aquatic life in various ways.

Bogue (2007) noted that the large canals around Lake Superior significantly affected the water quality. In his study, he noted that though the canals were built with a noble purpose to enhance the economic development of the region, the environmental consequences were adverse. Not only did the canals lead to a decline of the water quality, but also collapsed the White fishery, while at the same time decimating the wildlife community and birdlife. The Great Lakes Water Quality Board identified canalization as a major threat to the ecosystem integrity that lead to serious environmental degradation.

An earlier study by Harper *et al.* (2002) had shown that aquatic bird numbers decline was primarily linked to food shortages brought about by lowered water quality. He had further observed that for the Great Cormorant, which is abundant in Lake Naivasha, foraging was almost exclusively communal, and this was recorded at a high of 95.8% when transparency was greater than 40cm as measured by a secchi disc, however, when transparency decreased to 40cm solitary foraging increased to 37.4%. For these birds, transparency affected their communal foraging habits and hence their numbers at a given place. Although aquatic birds occupy different niches, piscivorous birds are especially impacted by similar factors, as they are part of the same food chain. Birds rely on their vision in order to see their prey and increased turbidity, and decreased transparency affects their feeding and therefore their overall numbers.

This in part explains why the numbers of species across the zones are close to uniform yet with significant differences in actual bird counts within the various canals in the 3 zones. The research findings indicated three distinct areas that have canals that could be aggregated into a pattern and analysed. Most canals around the lake were on the southern part of the lake. This is noted to be consistent with the literature and may in part explain the massive fish kills in the southern part of the lake that caused uproar and was correctly adjudged to have been as a result of de-oxygenation and not direct industrial pollution as initially postulated. There were over 1,000 fish kills ascribed to asphyxiation in February 2010 (Morara, 2010). Though some people initially disputed the results attributing the fish kills to a lack of oxygen, this study corroborates the results.

However, it is clear that this does not exculpate and vindicate the flower farm as initially envisaged. On the contrary, it spells out a demand for rapid action to remedy the current situation. The lake is unable to sustain the heavy water abstraction levels demanded by the horticultural farms. Low water levels compound the effects of canalization on the water quality. The coming of rains in the year 2010 that raised water levels significantly by four meters may have bargained for more time, but complacency towards the prevailing trends will lead to the collapse of the ecosystem integrity. Arguably, the emergence of uncontrolled horticultural farms from the late

1980's led to major urbanisation problems with the resultant informal settlements and increased water abstractions for irrigation; this exerted agricultural and pollution pressures on the lake.

Theoretically we can only deduce by extrapolation what the environmental effect of three large waterways or rivers flowing out of Lake Naivasha would have on its environment. Table 4-1 gave cumulative width if the canals were aggregated in every zone. The researchers estimation is the ecological transformation on any environment that has three wide rivers of 153 meters, 36 meters and 319 meters respectively would be undoubtedly significant. Tana River for instance, Kenya's largest lake has an average width of 60 meters and the river gets to 100 meters at its widest point. (Butynski, 1994). Since all these canals are man-made and are tended, dredged and cleared throughout the year to ensure they meet the supply they were created for, the possible changes they actually have on the ecosystem are enormous and need even deeper investigation.

The direct drawing of water from the lake using wide canals increases the interaction of the lake with the external environment leading to higher levels of eutrophication. And, whereas this may lead to increased fish productivity, the excess nutrients lead to proliferation of algal blooms which in turn decrease transparency which limits the foraging activities of aquatic organisms and birds which depend on vision to identify their prey. The decrease in water levels leads to an increase in turbidity. The lake's levels were highest in the 1890's and lowest in the 1940's. It is only in the 2009/2010 window that levels had sunk to the levels of 60 years ago (Betch and Harper, 2002) Increased human consumption of the water of the lake is a huge contributor to what led to the very low levels.

Aquatic vegetation plays a vital role in stabilizing the benthic layers and also dissipating the wave energy of the winds. However, the process of digging and dredging canals ensures these aquatic plants are removed as they impede flow of water through canals. The absence of these plants gives the wind and waves a field day in re-suspension of sediments and particulate matter. These total suspended solids (TSS) contribute to the turbidity levels and play a significant role in transport of toxic pollutants and nutrients. Furthermore, the increased presence of TSS does lead to clogging of fish gills, it affects spawning and fish reproduction which in turn affects food for the piscivorous birds.

The water transparency, expressed by the Secchi depth assists in predicting the ecological quality of shallow lakes and water bodies. The main causes of turbidity in the Lake Naivasha includes excess sediment input from eroded catchment soils, eutrophication, the increase in algal biomass and a re-suspension from the benthic layers of sediments, as a result of water movement and the burrowing of fish such as the *Cyprinus carpio.* Considering the large surface area created by inshore low water level canals, it seems inevitable that the effects of these are highly amplified.

The integrated ecosystem energy flow theory as posited by Odum (1959) indicated that in ecosystems, each attribute such as water quality or biodiversity is connected to all other environmental variables such as canalization and water abstraction. The theory indicated that transformation of one attribute inevitably and seriously affected the entire ecosystem balance. According to this school of thought, all ecosystems are open systems embedded in an environment from which they receive energy, matter input and discharge energy, matter output.

From the results of the study, it is apparent that the western part of the lake had minimal farm activities. The Northern part of the lake which also had the fewest number of canals, had farms but which did not mainly draw water from the lake itself. These drew the water from the river Malewa. High turbidity levels noted on the northern zone are mainly attributed to the inflow of river Malewa. The discharge from this river contains significant organic matter and inorganic sediments of fine particles. Turbidity at the Malewa area was notably higher, and this may be ascribed to the influence of the discharge emanating from the catchment run-off. For purposes of this research, we cannot preclude the effluents discharges from municipal wastewater plant and farming activities in the riparian zone.

Turbid lakes have less diversity in terms of animals and plants when compared to clear lake enviroments. This clearly underscores the fact that the diversity of water plants is significantly determined by the water quality. In essence, good water quality tends to maintain the ecological processes that support biodiversity. Odum (1959) postulated as part of the ecosystem theory that the energy balance within the system is retained. That explains why we notice that a change in the water quality parameters significantly affects organisms and their food chains. Water in Lake Naivasha as a resource is most important and proper policies should be implemented to ensure sustainability of resources.

Lake Naivasha has been transformed from a fairly clear lake to become quite turbid in a couple of decades. Whereas effluent discharges can be partly responsible, the researcher postulates that wind driven currents play a significant role in the rising turbidity especially in lower water conditions. The vast surface area created by the canals which are relatively shallow does give indication that there is a significant shift in the hydrodynamics of the lake. These changes inevitably impinge on the long term water quality of the lake and other ecosystem services the lake provides. From observation of secchi depth at the canal points, and physical examination of the water revealed greener colouration of the canal water. This is attributable to high phytoplankton growth and by extension the chlorophyll effect on the water.

Water abstraction from the lake can have positive consequences in the lake by reducing pollutant concentrations within the lake body. However, at the time of the study, it was evident that with severe volume reductions, water abstraction was significantly detrimental. By affecting the volume and hence the depth due to large areas of receding water, high turbidity had the overall effect of ensuring higher sediment re-suspension.

There was notably high secchi disc depths noted at the Crescent Lake. As indicated earlier, this study was carried out in late 2009, during a season of very low water levels in the lake. This was therefore consistent with other studies done that corroborate the results. Hubble and Harper (2000), demonstrated that the differences in the Crescent Lake physio-chemical characteristics in comparison to the main lake are because of limited connection between the two. This prevents suspended materials from reaching Crescent Lake owing to the low water levels. During the study the levels were so low as to produce an actual separation of the crescent lake to the main lake. Further to this, the deep depths may also have enhanced settlement of suspended material with limited re-suspension at the crescent lake leading to this noted low turbidity.

All these water quality factors combined played a role in affecting avian distribution across the lake. Though the water quality, and especially the turbidity of the lake seems to have significant impact as also shown by other previous studies, the anthropological disruptions would also need to be studied further. Besides human presence with the dredging and cutting machinery in use from time to time, the noise produced by generators and other artificial interruptions to birdlife and the aquatic environment do seem to have an impact that may not have been adequately researched upon.

CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of Findings

This research sought to establish the state of canalisation of the lake, the areas with the highest canal density and their impact on the birdlife. From the results and analysis of the data, it is apparent that canalization of Lake Naivasha has had a significant impact on the water quality and birdlife distribution around the lake. The research findings indicated three distinct areas that have canals patterns unique to its part of the lake. By studying data from these zones, it revealed changing levels of interaction within the ecosystem. The Southern side with the highest number of canals showed lowered water quality and less bird life interactions compared to the Northern side that had the lowest canal density and highest number of bird counts. The patterns of canal distribution were notably distinct and so is the effect on the overall water quality and birdlife distribution in three the zones studied.

5.2 The effects of Canalisation

The data from the study and its analysis showed that canalization of the lake does have significant impact on Lake Naivasha's ecosystem. By comparing results of three zones with differing canal densities, the results are consistent that canalization affects water quality which inevitably affects other aquatic life and birdlife distribution. As earlier discussed this tended to be consistent with other literature and does in part explain the fish deaths of early 2010 as a result of de-oxygenation. High productivity in the southern zone lead to algal blooms and aerobic decomposition of re-suspended detritus that deprived fish of sufficient dissolved oxygen. Though the effects of canalization are notable, this study does not distinguish the weight of the various variables on the lakes environment. Canalization also has its attendant anthropological distruptions to the tranquil and pristine environment required by birds, its effect has also been alluded to but its actual impact may need a more elaborate and targeted study.

5.3 Water quality

Canalization of the lake shoreline produced an observable water quality trend. The water temperature, which was measured at every point, did not provide specific patterns for this research. However, temperature is a very important parameter for it effects chemical reactions, aquatic life, and therefore suitability of the water for beneficial uses.

5.2.1 pH and Alkalinity

Measuring pH helps determine the biological property of water. The sample range for the pH of the water was 7.83 – 8.47 for the first sampling done in 2007 and from 8.26 – 9.2 for the second trip in 2009 during very low water levels. The soils of Lake Naivasha are alkaline with high levels of calcium carbonates. It is apparent that with low water levels the lake seems to resemble the earlier patterns of Oloiden. From correlation analysis, very high pH inversely correlates to bird numbers as is the case with the Eastern Zone which also recorded the highest pH readings. This is also most likely owing to other changes affecting other organisms in the lake, which provide fish with food. There is need to carry out an independent study on pH and aquatic life in Lake Naivasha to elucidate on this.

5.2.2 Turbidity

Turbidity, measures the light-transmitting property of water, and affects productivity of fish and other aquatic organisms that require light. High turbidity creates a challenge for piscivorous birds which either forage or fish for food. The more turbid the water the more microbes present, this tends to lower the water quality significantly.

5.2.3 Total Dissolved Solids (TDS) and Conductivity

Generally associated with freshwater systems Total Dissolved Solids (TDS) consists of in- organic salts, small amounts of organic matter, and dissolved material. The results did not indicate significant patterns relating to conductivity. Data from previous researchers and WRMA, as quoted in table 2-1 do not show significant variation that can be latched on for a credible scientific conclusion.

5.2.4 Dissolved Oxygen (DO)

The oxygen saturation levels in the water was consistent from highs of 9.2mg/l at 100% saturation early morning levels to the lowest at 5.2 mg/ at 59%. The saturation levels were influenced by the water temperature. The determination of DO concentration is a crucial part in water quality assessment. Oxygen is utilised in, or influences, virtually all chemical, biochemical and biological process within water bodies. DO is required for the respiration of therefore, with increased turbidity and microbes in the water, the fish species which sustain 45 species of piscivorous birds in Lake Naivasha have less oxygen available. This leads to stunted growth and lowered food availability.

5.3 Canalisation effects on Aquatic Birdlife

The canals on the north-western side of the lake had the highest bird count. In analysis of the study data, as canal width increases, the Pearson correlation coefficient for these two variables is *r=-0.679, it indicates* the total number of birds (second variable) decreases. Increase in canalization therefore inversely relates to bird numbers.

5.4 Conclusions

The study shows that the in shore canalization of the lake has had a significant impact in bird distribution and water quality of the lake. It is apparent that there are several aspects that favour bird distribution in the areas with least canalization. As the water recedes these factors are accentuated. We can conclude that had the heavy rains that caused the water levels to rise vertically by four meters not arrived when they did, disasters like the fish kills would have happened with increasing frequency.

With information of the rainfall patterns and water levels available it is prudent that measures be put in place to avoid the drying of the lake. The growth of agriculture, and more specifically horticulture and increase in population in Naivasha, have raised demands for higher quality water. Since the activities from the town also influence the Lake Naivasha, there should be consistent assessment and monitoring of the water quality.

Lake Naivasha has proven resilient in the heart of great odds against it. It is however, the humble view of this researcher that unless proper measures are put in place at the current rates of exploitation, the Lake is a disaster waiting to happen. As earlier postulated in this study, the ecosystem resilience theory posits that the environment will bounce back, however, if the threshold is exceeded it can lead to a total collapse. Recent trends in the ecosystem of the lake point to inevitable collapse if the current challenges are not addressed.

This study aimed at assessing the effects of canalization of the lake water quality, and the bird life distribution around the lake. From the results, though canalization does have an effect on the water quality of the lake, it is not possible, with the current analysis done to truly tell the scope of the effects of water quality on the bird life. Further, canalization and water abstraction should be more rigidly regulated, for if the current trends are left unchecked water levels will get so low with irreparable destruction to the ecosystem.

5.5 Recommendations

There is need to understand the impact of canalization and build an accurate water balance of Lake Naivasha. Equally, there is an important requirement to scientifically and logistically establish the relationship between water abstraction canals, their effect on the food web. But there are other factors beyond the jurisdiction of this study that have far reaching consequences for the water quality of the lake. Based on the findings in the study, some recommendations related to the water abstraction canals and water quality study in Naivasha are presented as follows:

a.) In order to ensure, sustainable utilization of Lake Naivasha, research and stakeholder integration must be factored into the decision making process. There is need for Government to adopt and implement the Lake Naivasha Basin Integrated Program. This would ensure implementation of decisions that are founded on scientific findings. As it stands currently, many of the scientific recommendations just wind up as scientific papers with little or no benefit to users of the resource as short term economic priorities ride roughshod over posterity.

b.) A bird census research survey should be made to arrive at the current actual numbers of birds and bird’s species within the Lake Naivasha. There is need for reliable authority and current data on this.

c.) Studies have demonstrated that current application amount of water for irrigation is twice the crop requirements. Enhanced technologies for example computerized drip irrigation as practiced in Israel can assist in reducing the amounts of the irrigation water utilized. This decrease irrigation water will reduce abstraction amounts and the lowering of lake levels while at the same time reducing pesticide leaching.

d.) A study should be done to put in place mechanisms for monitoring sewage effluents and discharge from the horticultural farms to ensure that all comply with known best practices. In order to give a comprehensive assessment for the lake water quality and effectively control pollution sources. Quantifying wastewater discharge and pollutant content from all industrial and agricultural sources will be pivotal.

e.) An assessment of the microbes present in Lake Naivasha and the current ratios in numbers in order to determine how these influence fish, birds and aquatic plants.

f.) Scientifically demonstrate the risks of cultivation next to the shoreline with regard to disruption of birdlife and water quality.

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APPENDIXES

Appedix I: Birds Cited at the Lake

General Name	Scientific Name
Whiskered Tern	*Chlidonias hybridus delalandi*
Grey Headed Gull	*Larus Cirrocephalus poicephalus*
African Spoonbill	*Platalea alba*
Glossy Ibis	*Plegadis f. falcinellus*
Goliath Heron	*Ardea goliath*
Purple Heron	*Ardea p. purpurea*
Striated Heron	*Butoridas striatus atricapillus*
Great Egret	*Cosmerodius albus melanorhychos*
Cattle Egret	*Bubulcus i. Ibis*
Great White Pelican	*Pelecanus onocrotalus*
Great Comorant	*Phelacrocorax carbo lucidus*
Long Tailed or Reed Cormorant	*Phalecrocorax a. africanus*
Egyptian goose	*Alopochen aegyptiacus*
Long toed Plover	*Vanellus c. crassirostris*
African Jacana	*Actohilornis africanus*
Lesser Jacana	*Microparra capensis*
Red-Knobbed Coot	*Fulica cristata*
African Fish Eagle	*Haliaeetus vocifer*
King Fisher	*Ceryle rudis*

Species Cited within the Lake

Appendix II: Field Recording Schedule

Eastern Zone Readings:

Point	Name of Place	pH	TDS	Secchi Disc	Conductivity	Canal Size	Temperature
1	Osochua A	8.47	208	72	416	5	23.2
2	Osuchua B	8.16	199	22	399	3	22.9
3	Mbegu Farm	8.16	199	16	397	8	23.4
4	Marina	8.07	193	13	587	10	23
5	Hippo Safaris	8.29	188	17	377	14	23
6	L.N. Resort/ Villa	7.83	188	18	376	15	23.5
7	Floating restaurant	8.16	190	18	385	20	23.3
8	H. Young	8.25	187	18	375	20	23.1
9	Aberdare	8.26	187	15	374	8	22.8
10	KWS Annex 1	7.92	98.3	16	197.4	15	23.8
12	KWS Annex 2	8.07	189	14	379	15	23
13	Central	8	183	16	366	20	23.2

Northern Zone:

Points	Name of Place	pH	TDS	Secchi Disc	Conductivity	Canal Size	Temperature
14	Malewa	7.84	112	10	224	8	23.2
15	Loldia 1	8	161	14	324	5	23.2
16	Loldia 2	8.22	167	42	334	5	23
17	Tarambete	8.19	195	20	390	10	23.1
18	Shalima	8.03	164	54	329	8	23.1

Southern Zone:

Points	Name of Place	pH	TDS	Secchi Disc	Conductivity	Canal Size	Temparture
19	Hippo Control	8.12	185	30	372	8	23.6
20	Oserian canal	8.05	168		336	15	23.6
21	Oserian Pumps	8.01	164	41	329	25	23.2
22	House Kengen	8.2	175	16	350	8	23.2
23	Old. . Young	8.02	169	17	338	6	23.2
24	Kamere Beach	8.14	168	21	335	8	23.2
25	Plantation / Power	8.28	162	16	324	20	22.9
26	Gold Smith	8.45	163	24	327	15	23.2
27	Gold Smith 2	8.09	164	26	328	15	22.8
28	Fish eagle	8.38	163	27	326	15	23
29	Fishermens Camp	8.24	164	21	329	30 (15 X 2)	23.4
31	Kwa Muhia	8.09	166	28	333	4	22.7
32	Sulmac 1	8.33	163	28	326	18	22.9
33	Sulmac 2	8.27	163	26	327	30 (15 X 2)	23
34	Sher 1	8.3	164	25	327	10	23.7
35	Sher 3	8.13	164	26	327	8	22.9
36	Sher 4	8.02	164	26	330	8	22.9
37	Sher 5	8.32	165	20	331	8	22.9
38	Sher 6	8.29	168	22	337	10	23.1
39	Sher 7	8.28	166	23	333	7	23.1
40	Longonot Horticulture	8.23	167	22	336	12	23.1
41	Sopa lodges	8.06	163	0	327	8	23.1
42	Block 1	8.22	166	18	329	8	23.1
43	Block 2	8.1	167	21	334	5	23.1
44	Sanctuary Farm	8.1	165	20	329	18	22.7

Southern Zone: Trip 2

Site No	Time	Canal	Temp.	pH	DO Mg/ml & %	ORP	EC Micro	TDS	Total Bird Count	No of Bird Species	Resistivity
1	11:22	Florima	19.29	8.96	8.3 92%	-30.7	281	148	35	6	0.0033
2	11:44	Goldsmith	19.44	8.97	8.6 92%	-55.0	306	154	5	2	0.0033
3	11.49	Plantation Canal -2	19.61	8.93	7.8 84	-58.5	302	152	3	1	0.0038
4	11:56	Plantation Canal	19.84	8.67	8.1 87	-24.7	346	173	2	1	0.0029
5	12:07	H. Young Canal	19.63	8.80	8.2 92	-25.5	324	163	25	6	0.0031
6	12:24	Oserian	19.80	8.92	9.2 100	-8.8	349	175	19	6	0.0029
7	12:46	Oserian 4	19.16	8.98	7.0 79	-28.8	336	169	10	5	0.0029
8	13:14	Oserian Kengen	19.52	8.95	7.6 83	-7.10	351	176	95	6	0.0028
9	13.30	Oserian Bay – Baton Farm	20.33	8.79	6.9 77	-5.2	352	177	8	3	0.0028
10	13.42	Hippo point A	21.28	8.99	7.9 88	-32.7	349	175	14	3	0.0028
11	13.46	Hippo point B	21.87	8.68	7.3 82	-25.9	360	180	2	2	0.0028
12	13.56	Hippo point C	20.65	8.55	5.2 59	-31.3	354	177	2	1	0.0028
13	14.03	Hippo point D	21.68	8.63	7.0 82	-13.8	353	177	2	2	0.0028
14	14.10	Dr. Sylventein	20.18	8.69	6.1	-29.3	354	178	57	10	0.0028

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15	14.30	Lengoko	20.52	8.84	7.0 79	-25.8	354	177	17	4	0.0028
16	14.36	Rima Island	21.11	8.89	7.9 90	-17.5	352	177	35	5	0.0028
17	14.44	Korongo Farm	21.42	8.84	7.6 85	-13.5	360	180	400	5	0.0028
18	14.54	Korongo 2	21.64	8.98	8.4 94	-34.2	347	174	36	3	0.0028
28	17.49	Block – Longonot	20.56	8.83	7.6 81	-5.0	360	180	29	5	0.0027
29	17.59	Sher 1	20.37	8.92	8.2 88	+4.3	370	186	41	5	0.0027
30	18.09	Sher 2	21.26	8.97	7.9 88	-13.7	376	188	157	6	0.0026
31	18.16	Crayfish	20.62	8.84	7.7 84	+3.5	380	190	62	7	0.0026

Northern Zone: Trip 2

19	15.03	Rocco Canal	22.79	8.87	7.180	-23.7	341	171	43	6	0.0028
20	15.22	Tarambete	24.28	8.67	7.993	-12.5	372	196	210	3	0.0027
21	15.38	Loldia	23.37	8.25	6.576	-38.6	383	192	610	7	0.0027
22	15.52	River Malewa Mouth	22.26	9.02	7.282	-28.5	371	185	512	4	0.0027

Eastern Zone: Trip 2

23	16.52	Crescent Island	24.61	8.76	5.667	-5.8	254	127	82	3	0.0040
24	17.10	Sanctuary	22.6	9.0	7.486	-13.5	344	173	72	8	0.0028
25	17.21	Kamuta	21.83	9.20	8.390	-28.2	318	162	32	4	0.0028
26	17.30	Kijabe Ltd	21.65	9.09	7.887	-5.9	352	176	11	4	0.0028
27	17.39	Home Grown	21.21	9.07	8.289	+3.0	357	179	48	6	0.0028