STATUS AND CAUSES OF DETERIORATION OF WETLANDS IN THE EASTERN RIFTVALLEY, CASE STUDY OF LAKE NAKURU - KENYA

BY

AVNI RAJESH DAVDRA

A Project Submitted in Partial Fulfillment of the Requirements for the Award of Degree of Master of Arts in Water Resources Management, in the Department of Geography and Environmental Studies, University of Nairobi

November 2020

DECLARATION

This project is my original work and has never been presented for examination or degree award in any other University.

Avni Davdra

C50/6028/2017

Date: 9/11/2020

This research project has been submitted with our approval as University supervisors

Signature: ______________________ Date: 9/11/2020

Dr. Shadrack M. Kithiia

Signature: ______________________ Date: 9/11/2020

Dr. John M. Nyangaga

DEDICATION

This project is dedicated to my parents Mr. Rajesh Davdra and Mrs. Ila Davdra who have supported me and motivated me throughout in every way possible.

ACRONYMS

AEWA	African Eurasian Water Bird Agreement
APHA	American Public Health Association
CBD	Convention on Biological Diversity
CMS	Convention on the Conservation of Migratory Species of Wild Animals
DDT	Dichlorodiphenyltrichloroethane
DO	Dissolved Oxygen
EIA	Environment Impact Assessment
EMCA	Environmental Coordination and Management Act
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
GNF	Global Nature Fund
GoK	Government of Kenya
GPS	Global Positioning System
IBA	International Bird Area
ILEC	International Lake Environment Committee
IUCN	International Union for Conservation of Nature
IWMI	International Water Management Institute
KFS	Kenya Forest Service
KMS	Kenya Meteorological Service
KNBS	Kenya National Bureau of Statistics
KWS	Kenya Wildlife Service
LNNP	Lake Nakuru National Park
MEA	Multilateral Environmental Agreement
MEMR	Ministry of Environment and Mineral Resources
Mg/L	Milligram per Liter
MoALF	Ministry of Agriculture, Livestock and Fisheries
NAWASSCO	Nakuru Water and Sanitation Services Company
NEMA	National Environment Management Authority
SDGs	Sustainable Development Goals

SPSS	Statistical Package for the Social Sciences
SWRM	Sustainable Water Resources Management
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific And Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WHC	World Heritage Convention
WHO	World Health Organization
WRMA	Water Resources Management Authority
WWF	World Wide Fund for Nature

ABSTRACT

Lake Nakuru is a shallow hyper-eutrophic, alkaline and saline endorheic lake located in Rift Valley's eastern arm. Despite its great importance, Lake Nakuru has undergone profound changes due to anthropogenic activities, mostly due to the amplification of industrial and agriculture activities, urban sprawl and rapid population growth in the last few decades. The study aimed to determine the threats facing the lake, to identify the factors leading to water pollution, to evaluate the status of the surface water quality, investigate the seasonal variations in the physio-chemical parameters of the surface water and to assess levels of toxic heavy metals in the surface water and sediments in the lake.

Quantitative and qualitative methods of data collections were used. These included questionnaires, insitu measurements, and laboratory analysis as well as field observations. The respondents comprised of 11 KWS staff members and 196 households from 3 sub-locations; Mwariki A, Mwariki B and Pwani. A total of 20 samples were collected in the wet and dry season to measure temperature, pH, DO, alkalinity, TDS, TSS, nutrients (Nitrate, Phosphate, Ammonia) and heavy metals (Cu, Zn, Pb, and Cr) of the surface water and 4 sediment samples were collected to assess heavy metal concentration. The data were processed to descriptive statistics using SPSS and Excel in order to measure distribution trends, dispersions, disparities and associations and inferential statistics, specifically a two tailed t-test was used to assess the significant difference in the lake water parameters in the dry and wet season.

Sewage and industrial pollution were amongst the top contributors of water pollution. Physio-chemical properties of the surface water varied in the dry and wet season. Temperature, pH, TDS, TSS and nutrient values were above the permissible limits for aquatic ecosystems. Temperature, TDS, Phosphate, Nitrate and Ammonia concentration were higher in the dry season where as alkalinity, DO and TSS concentrations were greater in the wet season. Concentration of Pb and Cr were higher in the surface water than the recommended limit. From the findings, the highest level of pollution was in the storm drain, lake center, mouth of River Nderit and Lamdiac. Presence of all four metals were detected in the sediments, with the highest concentration at the storm drain. Seasonal variations showed there was a significant difference ($p < 0.05$) in temperature, DO, TSS, Phosphate and Ammonia levels between both the seasons.

The study concludes that the main issues threatening Lake Nakuru are the disruptions to its water quality arising from human activities in the catchment area. Strict implementation of policies related to the protection of Lake Nakuru is required. Legal action should therefore be taken in respect of all of those sectors that discharge toxic chemicals into the feeding rivers and the lake. Public awareness of pollution issues and their implications in the lake is necessary. This can be done through environmental education, as it is critical to enhance, spread knowledge and enable communities to protect the integrity and complexity of nature and ensure that the use of valuable resources is fair and environmentally sustainable.

ACKNOWLEDGEMENTS

My greatest appreciation starts with the Omnipotent God who gave me the power and strength to complete this work. This research wouldn't have completed without His blessings.

I am extremely grateful to my supervisors Dr. Kithiia and Dr. Nyangaga for their suggestions, advice, constructive feedback and encouragement from the beginning till the completion of the study. Their overall patience, particularly in allowing me to work with my own pace on the project as well as their insightful criticism were invaluable contributions without which my project would not have reached this far. I would also like to thank Dr Shah for her assistance.

I want to also thank the University of Nairobi, Department of Geography and Environmental Studies for all the knowledge and skills I have gained throughout. My sincere thanks goes to all my respondents from Mwariki A, Mwariki B, Pwani and Lake Nakuru National Park. I also extend my appreciation to my research assistants Vincent and Anita from Lake Nakuru National Park who helped me with data collection. I would also like to acknowledge Nakuru Water and Sanitation Services Company (NAWASSCO) for their kind assistance during field sampling and laboratory work.

Finally, last but not the least I owe my deepest gratitude to my family, my extended family and friends for their boundless support and encouragement for bringing me this far. I can't thank you ALL enough!

TABLE OF CONTENTS

CHAPTER FOUR

RESEARCH METHODOLOGY

CHAPTER FIVE

RESULTS AND DISCUSSION

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE: INTRODUCTION

1.1 GENERAL INTRODUCTION

While water is known to be a prestigious resource, the risks to it are unlimited and increasing with human advancement in technology and population increase. Water is a habitat, quenches thirst, absorbs excess carbon dioxide of the globe, is a source of transport and the list is unlimited. Today this very precious commodity is facing catastrophes. Rivers, streams and lakes are drying out, being polluted and their waters over-abstracted. Lake Nakuru in Kenya's Rift Valley is a global pride due to its flamingos. Yet this lake, which is a protected area, is under siege from the upsurge in the economic and social development cycle. Increased population and development has resulted in changes in land use, high sewage and solid waste generation, inefficient use of resources, all of which have had a significant effect on the natural environment and water quality. This study aimed at assessing the status and the causes of water quality deterioration of Lake Nakuru.

1.2 BACKGROUND OF THE STUDY

From space, the Earth is distinct by the green vegetation and blue waters, with the most being reflected in blue. This illustrates that the Earth is primarily composed of water covering almost 71% of the surface. But the question remains – what is the water's value? Much of this blue compartment is stored in wetlands. Wetlands are sites of exceptional importance which include lakes, rivers, tidal flats, deltas, mangroves, coral reefs, swamps, marshes, fens, peat lands and rice paddies (Ramsar Convention Secretariat, 2016).

According to the Ramsar Convention (1971), "wetlands are areas of natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water the depth of which at low tide does not exceed six meters". These wetlands were the first terrestrial systems to gain international attention in February 1971 through the Convention on Wetlands of International Importance opened for signature in Ramsar, Iran.

The wetlands of Kenya are a vital part of the natural capital of the nation. They are categorized into riverine, marine, estuarine, lacustrine, palustrine and man-made wetlands which cover roughly 14,000 km^2 of the country's land cover (Macharia *et. al.,* 2010). Many of these wetlands are recognized as significant areas of conservation such as National Reserves, National Parks, Important Bird Areas (IBA) and World Heritage Sites.

Wetlands support animals and plants integrating the characteristics of terrestrial and aquatic environments especially water, vegetation, soil and nutrients (Ngodhe *et. al.,* 2016). They are highly valued and prioritized by the United Nations (UN) under the Sustainable Development Goals (SDGs). Wetlands are of value to the world's population as over a billion people around the world make their living directly from them (International Water Management Institute [IWMI], 2014). They consist of abundant biodiversity including natural environments for a range of plants and animals, some of which are of high significance comprising endangered, migratory and endemic species like the waterfowl. They deliver several benefits such as water purification and storage, nutrient cycling, storm protection and soil erosion control, flood mitigation, storm and shoreline protection (United Nations Environment Programme [UNEP], 2004).

The Ramsar Convention is one of the first International Multilateral Environmental Agreements (MEA) based on sustainable use and conservation of natural resources. Kenya became a member of the Convention on 5th October 1990. Currently the country has six Ramsar sites which are Lake Nakuru (1990), Lake Naivasha (1995), Lake Bogoria (2001), Lake Baringo (2002), Lake Elementaita (2005), and Tana River Delta (2012) (Government of Kenya [GoK], 2015). The Kenya Wildlife Service (KWS) is appointed as the country's focal national institution and their mandate is to protect the wetlands and to oversee the successful implementation of the Ramsar Convention's objectives. This is done through the implementation of several policies and frameworks.

Lakes are found on terrestrial landscapes and appear like 'blue diamond mosaics' from space (UNEP, 2006). The lakes are part of the larger wetlands. Despite the numerous benefits they provide, wetlands continue to face severe threats particularly due to increased population. This situation is exacerbated as mostly all the townships, establishments, industries, urban centers and institutions within the lakes' catchment areas have poor waste treatment facilities leading to discharge of partly treated or untreated wastes in the water (Oketch, 2006). According to the Ramsar (2015) report, the greatest challenges in implementing wetland conservation in Kenya are: increased agriculture, urbanization, deforestation, pollution, invasive species, eutrophication, overgrazing and overexploitation of resources. Varying rainfall patterns and increasing temperatures have also exacerbated the threats.

The focus of this study is on Lake Nakuru which is a closed basin lake in the eastern arm of Rift Valley. This site is also unique as it has been several times described as the lake with a million flamingos as well as the world's greatest ornithological spectacle (Raini, 2009). Regardless of being such an important site, Lake Nakuru continues to face several challenges. Population around its catchment area has rapidly increased, leading to urbanization, industrialization, deforestation, waste production and water pollution. All the factors have led to a drop in the quality of the water.

In a study by Ndetei and Muhandiki (2004), the findings indicated that the presence of heavy metals in surface water was a significant contributor to the mortality of flamingos. Toxic heavy metals were present in high concentrations such as Cadmium (0.11 mg/L), Chromium (0.03 mg/L), Copper (0.12 mg/L), Iron (3.39 mg/L), Mercury (10.17 mg/L), Manganese (85 mg/L), Nickel (0.08 mg/L), Zinc (0.4 mg/L) and Lead (0.08 mg/L).

Similarly, in a study by Jackson and Kulecho (2008) on the review of environmental impacts of land use changes in Nakuru estimated approximately 178 small-to-medium scale industries that have been known to dump a range of products such as batteries, detergents, paints, and plastics among others. The findings revealed a three times spike in toxic heavy metals (Cadmium, Zinc, Lead, Arsenic and Copper) compared to previous studies. The water level of Lake Nakuru fell dramatically due to an unprecedented drought in 2009 which led to a major evapo-concentration, with an rise in total salinity from around 20% to 63%. Parameters such as Carbon, Sodium, Calcium, Potassium and Arsenic also rapidly increased with dropping water levels (Jirsa *et. al*., 2012).

1.3 STATEMENT OF THE RESEARCH PROBLEM

Ecological systems have altered more significantly and concretely in the past five decades than in any other era of the earth's history. Anthropogenic practices have resulted in an ecological imbalance, influencing the hydrological system, leading to increased water quality and quantity deterioration. These ecosystems continue to be polluted and over-exploited amid international awareness of the importance of wetlands. This leads to increased resource pressure, resulting in a decline in the productivity of wetlands.

Lake Nakuru is a site of international importance as it possesses unique and endangered wetland species especially the Greater Flamingos (*Phoenicoptus ruber roseus*) and the Lesser Flamingos (*Phoeniconaias minor*) (Thampy, 2002). Besides the flamingos, there are more than 51 waterfowl species and water birds occupying the lake and an additional 450 terrestrial bird species that inhabit the buffer zone (Daniels and Bassett, 2002). Large economic pressures, uncoordinated management systems, uni-sectoral expansion, absence of transparent and effective legislative institutions via optimal policies and legal frameworks have caused enormous environmental problems to arise in this wetland.

There has been an increase in population growth over the last three decades in Nakuru town (Kenya National Bureau of Statistics [KNBS], 2015). This has led to a basin that was once sparsely populated and thickly forested to a site that is now heavily settled, rapidly urbanized, industrialized and widely cultivated. Small businesses such as gas stations, restaurants, breweries, open garages, photo studios generate solid and liquid wastes, most of which are dumped into the rivers. The major industries in town are paint, food processing, chemical battery and textile. So many of these industries often do not have or just do not have adequate treatment facilities to lessen the pollutant load on the general public sewage system. Its effluents comprise of heavy metals, dioxins and many other toxic chemicals that cannot be effectively removed by sewage treatment operations. These eventually enter the lake, gradually altering the water quality (Mwanzia *et al.,* 2013).

Due to the fact that Lake Nakuru is a closed hydrological basin, input if toxic waste tends to accumulate in the water, and once it is polluted, it is a great challenge to recover the quality of the lake water. Despite laws and regulations, pollution still continues to be a large problem in Lake Nakuru and if this still continues, the wetland risks being deregistered as a United Nations Education, Science and Cultural Organization (UNESCO) World Heritage Site. This study is therefore to investigate causes of pollution in the study area, and its conforming hydrological challenges in terms of water quality. It also highlights threats occurring due to human activities such and how they affect the water quality of Lake Nakuru.

1.4 RESEARCH QUESTIONS

The study was guided by the following research questions:

i. What are the major natural and anthropogenic threats facing the lake?
ii. What are the main sources of water pollution and the factors that contribute to the deterioration of water quality?
iii. What is the status of water quality in terms of physio-chemical parameters in Lake Nakuru?
iv. What is the seasonal variation in the physio-chemical parameters of Lake Nakuru?
v. What are the levels of toxic heavy metals in the surface water and sediments of Lake Nakuru?

1.5 RESEARCH OBJECTIVES

1.5.1 Main objective

The overall objective of this study was to assess the status of the water quality of Lake Nakuru.

1.5.2 Specific Objectives

The specific objectives include:

1. To determine the natural and anthropogenic threats facing the lake.
2. To identify the major sources of water pollution and the factors contributing to water quality deterioration.
3. To evaluate the status of water quality in terms of physio-chemical parameters in Lake Nakuru.
4. To investigate the seasonal variations in the physio-chemical parameters of Lake Nakuru.
5. To assess the levels of toxic heavy metals (Pb, Zn, Cu, and Cr) in the surface water and sediments of Lake Nakuru.

1.6 RESEARCH HYPOTHESIS

The study hypothesis is as indicated below:

1. H_0: There is no significant difference in seasonal variation in the lake water parameters

   H_1: There is a significant difference in seasonal variation in the lake water parameters

1.7 JUSTIFICATION OF THE STUDY

Globally wetland deterioration has been a hot topic, especially between the 20^{th} and 21^{st} centuries, with a massive loss of around 65-71% of the wetlands (Davidson, 2014). Lakes indirectly or directly contribute to human well-being through numerous provisioning, regulatory, supporting and cultural services. At present, Kenyan lakes are being degraded at a disturbing rate through unsustainable anthropogenic activities such as agriculture, encroachment, mining, dredging among many others which has led to changes in the lake morphology, biogeochemistry of nutrients, hydrology, ecosystem metabolism, storage of carbon, growth of invasive alien species, loss of native and endangered species, disease emergence and catastrophes such as droughts, floods and reduced community coping approaches (Carpenter *et. al.*, 2011).

The alkaline conditions in Lake Nakuru provide a great environment which supports a unique ecosystem. In 1960, the lake was titled as a bird sanctuary, in 1968 a National Park, in 1987 a rhino sanctuary, in 1990 Kenya's first Ramsar site, in 1999 an IBA, an outstanding National Park in 2005 and a UNESCO designated World Heritage Site in 201l (Vareschi, 1982; Raini, 2009; Birdlife International, 2019). Lake Nakuru is under the management and supervision of KWS with suitable staff members and stakeholders' forum under the umbrella of Lake Nakuru Catchment Conservation and Development Forum.

Lake Nakuru was chosen as a study site due to its physical location in relation to anthropogenic activities hence extremely prone to threats and challenges particularly water pollution. Water quality is a crucial aspect that must be monitored in the management of lakes. Therefore, for decision making, credible information on the state of the catchment and its water resources must be identified. The study tried to supplement emerging issues related to the threats in the study area based on past and current trends in the basin. It sort to establish any relationships between the human activities and water pollution in the lake. The results of this study will be valuable to a range of stakeholders including KWS, land and water environmental managers, policy experts as well as local consultants involved in the management of Lake Nakuru. It will also help in monitoring programs in the future.

1.8 SCOPE AND LIMITATIONS OF THE STUDY

1.8.1 Scope of the study

Lake Nakuru is located in Lake Nakuru National Park (LNNP), a fully fenced park with a 74 km chain link. The study area was limited to the LNNP as well as three surrounding sub-locations; Mwariki A, Mwariki B and Pwani. The study focused on the extent of pollution in the lake through determining the physiochemical properties of the water at different points of the lake. It covered two groups of respondents; households and KWS staff members. The study also determined the anthropogenic activities that have led to the deterioration of the lake regardless of the laws and policies that exist.

1.8.2 Limitations of the study

The time allotted for field work didn't cover all four different seasons. The sampling was therefore conducted in the wet and dry seasons. The boat at LNNP was not always available at all sampling points therefore weathers (gumboots that reach the abdomen level) were used by the researcher to enter the water for collection of water samples.

1.9 DEFINITION OF OPERATIONAL TERMS AND CONCEPTS

Anthropogenic activities – These are activities in which humans/members are involved in for their survival. These include development projects, agricultural activities, deforestation amongst many others.

Biodiversity – The diversity between living organisms from all influences, including but not limited to, land, marine and other aquatic structures and biological networks of which they are part of.

Catchment – A region where water flowing on or across the land surface runs into a specific river or stream and eventually passes through a single outlet.

Ecosystem – Group of interacting organisms that depend on one another and the environment for nutrients and shelter (Kooi *et. al.,* 2008).

Environmental degradation – An act or process to lower the state, value or condition of the environment. In this situation, it applies to the ecological deterioration of Lake Nakuru.

Sewage – Includes human body faeces or other waste material which streams through underground pipes or other corridors to a treatment plant or anywhere else such as septic tanks.

CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides a comprehensive, in-depth literature associated to the topic of study. It begins by looking at the concept of lakes and their importance in the functioning of a healthy ecosystem. The benefits and threats are also reviewed. The study review goes on to look at the challenges faced by these wetlands at a global, regional and local scale. This chapter also discussed the existing policies and regulations on wetland management and conservation. It then concludes by establishing a theoretical and conceptual framework.

2.2 LAKES

Lakes can be defined as bodies of salty or fresh water of significant size, entirely surrounded by natural body, land or pool of water (GoK, 2017). Lakes are typically shaped when natural depressions on the earth surface are filled with water with time. These lakes can array from tiny ponds to aquatic bodies extending hundreds of kilometers comprising huge amounts of water (UNEP, 2006). Roughly 70% of the lakes are found in the tropical region with eight million lakes of more than one hectare. Kenyan lakes consist of two dominant types, freshwater and alkaline (soda) lakes.

Lake surface temperatures can indirectly or directly affect the biological, physical and chemical functions in a lake such as water column stability, the temperature of the photosynthetic zone, fish species range shifts, primary productivity and species interactions (Sharma *et. al,*. 2015) Climatic factors such as temperature, solar radiation and geomorphometric aspects such as depth and area of the lake influence surface water temperatures in the lakes (Oswald and Rouse, 2004).

2.3 IMPORTANCE, SIGNIFICANCE AND VALUE OF LAKES

Lakes are among the large productive environments in the world. At the broadest point, lakes provide people with a variety of uses or principles that change over time, from initial values for survival to later values of nature and community. They provide biological biodiversity as well as water and primary production on which countless species of plants and animals rely for survival (Ramsar Convention Secretariat, 2004). These lakes provide immense benefits which include fishing, recreation, water, regulation of water quality and quantity and a cradle to biodiversity

(UNEP, 2004). Some of the lakes also contribute to biopharmaceuticals. Lakes are also implicated under the SDGs which are very important in contributing towards food security (SDG 2), health and wellbeing (SDG 3), security of energy (SDG 7), sustainable cities (SDG 11), in control use and production (SDG 12), climate change (SDG 13), life below water (SDG 14) and terrestrial biodiversity (SDG 15). Healthy lakes not only provide a number of environmental benefits but they influence livelihoods and they strengthen the economy as implied by the SDGs (Hoverman and Johnson, 2012).

Lakes transition areas between coastal and marine habitats where the water table is situated on or near the surface or where the land is surrounded by shallow water. Proper lake functioning can ease the effects of droughts and floods by storage of huge amounts of water and discharging it during shortages. The local drainage lets the water remain in one area for a duration that can maximize infiltration, improving recharge of the aquifers and groundwater. Surplus water in lakes and aquifers is usually discharged into rivers, springs and other water bodies. Lakes act like a sponge, and resist flood waves. The plant life is the key as they reduce the velocity of the wave, retain some portion during peak storm or overflow and slowly release towards the lower gradient (Macharia *et. al.*, 2010).

They provide provisioning services such as water for irrigation, industries, domestic use, and dilution of pollutants, transportation, hydroelectric power and recreation (Carpenter and Cottingham, 1997). Globally, freshwater lakes provide a vital source of food and livelihood for billions of people (Hecky and Bugenyi, 2017). Lakes in Africa support approximately 17% of inland fisheries with exports worth about US$3,000 million out of which Uganda is one of the major freshwater fish producers worldwide (UNEP, 2006; Hammerle *et. al.*, 2010).

Such water bodies offer great opportunities for leisure, hospitality and cottage or housing (Dokulil, 2013). Nature-based tourism is one of the top emerging industries based on the lakes (Hadwen, 2007). The Great Salt Lake in the USA for example has an economic value of $1.32 billion per annum (Wurtsbaugh *et. al.*, 2017). In Kenya, LNNP received approximately 245,500 people in 2011 which included 149,500 international tourists and 95,500 national visitors (Ramsar Convention Secretariat, 2012). This trend continued in 2013 also. However, in 2018 the number of visitors reduced by 20%, that is the visitors were only 200,000 according to the Senior Warden of KWS, Catherine Wambani (Chebet, 2019). This was because of the reduction in the number of flamingos as water levels keep increasing and thus affecting the food for the flamingos.

2.4 THREATS TO THE LAKES

Regardless of their significant importance, lakes undergo profound changes in their normal state and circumstances owing to anthropogenic practices, mainly attributable to the amplification of industry and agriculture, urban sprawl and rapid population growth over the last few decades, with all the others concerned. The proximate causes of these issues may emerge from both the active use of lake resources as well as from anthropogenic activities taking place within and outside the basins that have little or nothing to do with the direct use of lake resources (Wurtsbaugh *et. al.*, 2017).

Water pollution is one of the greatest threats of this century. It can be defined as any chemical, biological and physical alteration in water quality which unfavorably impacts on living organisms and makes water unsuitable for consumption and other beneficial uses (UNEP/World Health Organization [WHO], 1988). It can also be defined as the presence of excessive amounts of hazardous substances generally induced by humans. Nevertheless, water is said to be contaminated as unguided and anomalies from several anthropogenic practices also impaired some of the water quality criteria, making water unsafe for planned usage (Gupta, 2016).

Water pollution can be categorized by point and non-point sources (Holas and Hrncir, 2002). A point source can be defined as a single distinguishable confined source of water pollution such as pipes from industries while a non-point source is a diffused source which may be difficult to track back to a specific location due to physical and manmade processes (World Bank, 2006). The types of non-point sources are agrochemicals, soil erosion from overgrazed lands, degraded catchments and infrastructural developments such as road networks and unmanaged storm water from urban centers. The main sources of water pollution in lakes are domestic wastewater, radioactive waste, sewage, agricultural and industrial pollution and solid waste dumping (Ngodhe *et. al.*, 2016).

The agricultural sector is not only the largest consumer of water resources, using approximately 70% of the earth's surface water supply, but it's also a significant source of water pollution. To produce high-quality crops for human and animal consumption, modern agriculture depends on irrigation, chemical fertilizers, herbicides and pesticides. Nitrogen-based fertilizers are dispersed on the ground to enhance crop yield. The extra fertilizers and pesticides flow into streams and lakes during heavy rains. High Nitrate and Phosphate concentrations from these chemicals can contribute to harmful algal blooms that can affect both aquatic and human health. When found in water bodies and used for consumption, chemicals such as Nitrates can cause Oxygen starvation in the brain, and can cause cancer and heart problems (Smith *et. al.,* 1999).

Industrialization is a major driving force of growth and urbanization in any nation. Even though the positives of industrialization are countless, it has been recognized as a significant threat to the planet as it emits multiple toxic chemicals, pollutants, microbes and solid wastes of many kinds into our environment. Industrial waste of ever-increasing chemical complexity is far more complicated than domestic waste. Approximately 300 million tons of chemical and synthetic substances used in manufacturing and consumer products enter surface waters every year (Schwarzenbach, 2006). Specifically heavy metals like Iron, Lead, Zinc, Cadmium, Chromium and Copper produce highly poisonous sludge that even when embedded and condensed, they are impossible to dispose of. The accumulation of these in lakes causes accelerated growth of macrophytes, increase in algae production and water quality deterioration. In addition, many countries continue to use Dichlorodiphenyltrichloroethane (DDT) to control malaria around the lakes (Dudgeon *et. al.,* 2005). Metals released may affect the human body for example Lead that damages the nervous system, Chromium that affects the skin and Cadmium that causes failure of the kidney.

Sewage and wastewater entering water systems from ground drainage, septic systems, wastewater treatment plants and outflows from storm drain has also become a major source of pollution (Fayomi *et. al.,* 2019). Chemical and microbiological behavior inevitably degrades organic matter in wastewater or manure and food waste in water bodies. These processes of degradation use Dissolved Oxygen (DO) in water, causing stress to many aquatic life such as species of fish that necessitate Oxygen to breathe. Low levels of DO also result in chemical reactions resulting in the release or emergence of many other toxic chemicals such as Hydrogen Sulfide and Ammonia in sediments and in lower waters. Untreated or partially treated human sewage can cause tuberculosis, cryptosporidium, salmonella, dysentery and many other infectious diseases if consumed. Regardless of the type or origin of the pollutant reaching the lake or the feeding rivers, the ultimate environmental consequences may be the same whether the destruction is induced by soil erosion which destroys the ecosystem of the aquatic organism or the development of a chemical which interferes with the water quality and reproductive cycle of the organisms (Oguttu *et. al.,* 2008; Oliviera, 2012; Gupta, 2016).

Deposition of sediments, mostly attributed to soil erosion and surface runoff, has a high potential to have a negative effect on lake water quality. Sedimentation effects involve high turbidity that lowers the distance from the photic zone and increases the sediment outcome which could shield invertebrates and primary producers from the vegetation of the lake (Mahaney *et. al.,* 2005). Therefore, increased sediments potentially alter aquatic food webs and also the basic ecosystem functions associated with improving water quality, water holding capacity, cycling of nutrients, and pollutant altering and isolating processes. In fact, sediments usually contain high levels of pesticides and fertilizers contributing to eutrophication and inevitably water pollution (Ministry of Environment and Mineral Resources [MEMR], 2012).

In the last 30 years, tourism growth in and around the lake has had a strong impact on the degradation and loss of wetlands. Tourism activities consist of building infrastructure that explicitly disrupts plants and animals and, in turn, typically raises all kinds of urbanization-related impacts, such as water extraction, pollution and wastewater (Dokulil, 2013). Even deceptively harmless activities such as rafting and boating can pose a danger to fragile lake environments. Additionally actions such as overgrazing, aquaculture, hunting and fishing contribute to degradation of ecosystems (International Lake Environment Committee [ILEC], 2005).

In addition to human activities, lakes are also vulnerable to climate change. Minor changes in precipitation and groundwater levels have dramatic consequences such as drying of feeding rivers and streams, size reduction or upland modification. Temperatures changes may decrease the profusion and distribution of fish in lakes by dropping water quality, introduction of new predators and pathogens, fish mortality, longer dry seasons and changes in the prey richness for fish. So far, the major drivers of change in aquaculture and fisheries are the floods and droughts that result from variations in temperature and rainfall (Larsen *et al.,* 2011).

2.5 THREATS FACING LAKES GLOBALLY, REGIONALLY AND LOCALLY

2.5.1 Global scenario

Lakes contain only 0.0078% of the earth's water, of which salt lakes account for 44% of the volume and 23% of the total surface area of the earth's lakes (Messager *et. al.*, 2016). According to a new study, 117 million lakes were discovered, not counting the glaciers on Antarctica and Greenland. Lakes form a small fraction of the surface of the Earth, but they are areas for extreme biogeochemical operation. The abundance of lakes in some countries is rapidly changing and alterations in the relative richness of large and small lakes can reflect important features of regional geomorphic and hydrological processes (Verpoorter *et. al.,* 2014).

The Great Salt Lake in the United States is the world's eighth largest lake, an IBA named with over 35 million birds (Peterson, 2008). It is afflicted by countless challenges, including misdirected water management schemes, climate change and historic droughts. Diversions have taken about 40% of the inflows, causing the level of the lake to fall by 11 feet. As a result of increased agriculture, mineral production, municipal and industrial use, the lake has also shrunk by 50%. Mining companies have deposited tons of waste including heavy metals such as Copper and Arsenic, significantly altering the water quality by rising Nitrogen and Phosphorus levels, over fertilizing the water and causing algal blooms. Together with these risks, there are no strict regulations on water quality for discharges (Wurtsbaugh *et. al.,* 2017).

Texcoco Lake in Mexico is also an IBA because it supports about 100,000 birds and is located on the migratory waterfowl's central flyway. Pollution, desiccation, hunting and urbanization (over 18 million in 1300 square kilometers) are just some of the major factors that caused the lake to degrade severely (Valenzuela-Encinas *et. al.*, 2009). It also receives municipal waste and although most artificial ponds are lined with treated water, some places still have untreated and polluted water with uncertain effects on the wellbeing of species that live in them. Habitat modifications and depletion have culminated in a major loss in biological diversity generally and especially for birds with about 20 species of birds facing extinction (Alcocer and Hammer, 2008).

Lake Winnipeg in Canada is the 10th biggest freshwater lake in the world and covers an area of 24,500 km^2. A report by the Lake Winnipeg Stewardship Board of Manitoba Conservation reported that nearly 8,000 tons of phosphorus and 96,500 tons of Nitrogen are dumped into the lake every year as a result of human activities and is deemed to be the most eutrophic of the world's largest reservoirs (Schindler *et. al.*, 2012). The greatest algal bloom ever recorded in this lake had a size of up to 25,000 km^2 and was identified in 2013 by the Global Nature Fund (GNF) as the most endangered lake in the world (Kraus, 2018). Similarly, a case from Philippines' Lake Sampaloc indicates that the risks posed by lakes due to human activities include the proliferation of floating fish cages and contamination from unauthorized lake residents living on the shorelines. The excessive number of fish cages has resulted in the cages being overfed and crowded, resulting in increased eutrophication and worsening the lake state. This was evident by the massive fish kills and the rapid growth of green algae due to increased pollution (Brillo, 2015).

In India, the release of waste gases and particulate matter into the air by numerous factories, the release of industrial waste and sewage into lakes has added new dimensions to the facets of water quality. Due to human activity, the Wular Lake in Kashmir has faced various threats. Chemicals including fertilizers, dishwashing oils, soaps and cleaning solutions continue to pollute the lake seriously (Hassan *et. al.,* 2015). It also receives high quantities of silt and untreated sewage from the Jhelum River. The habitat is now strongly eutrophic, rendering the resistant weeds a great environment, but at the same time an Oxygen poor system. The fish population has declined rapidly, thus affecting the region's livelihoods (Shah *et. al.,* 2014).

Considering that 70% of Australia is arid, it is not shocking that more than 80% of wetlands are soda lakes occupying more than 100,000 km^2. Salinization is by far the most pernicious factor in the deterioration of lakes, especially in Western Australia, whereby 30% of the landscape is expected to be impacted. In this state, mining also impinges on many salt lakes, primarily through saline groundwater dewatering. Typically, pit lake waters are contaminated with heavy metals and metalloids which rarely approach natural water body chemistry. Lake Eyre in Central Australia is a victim of such threats. Additionally, within its catchment, agricultural practices have highly affected the runoff pattern, quality and quantity of the lake and hence its ecology (Williams, 2002).

Water pollution has been a significant problem in China with rapid economic growth. Discharges such as agricultural fertilizers, chemical sewage and household wastewater, combined with limited capacity for wastewater treatment, are major drivers of water pollution. Approximately two-thirds of the total waste released into the lakes and sea is from factories, out of which only 20% is treated

(Zhao *et. al.*, 2013). The Taihu Lake Basin is among the most advanced areas in China. The region has recently been at the forefront of China's industrialization process, yet at the same time it is a key ecologically sensitive area. River flows are the primary source of contaminants in the lake watershed, causing serious environmental and sanitary problems. Intensive farming and rapid urbanization in recent decades have increased the nutrient inputs leading to severe eutrophication (Ding *et. al.*, 2019). Also after years of extensive treatment, the lake water quality is fragile and out of balance.

2.5.2 Regional scenario – African context

In Africa, there are about 677 lakes, 88 of which are classified as the major lakes. Among the most heavily abused lakes on all continents are African lakes (UNEP, 2010). While these lakes are a food outlet for most African people, they are also a significant source of natural hazards, tropical diseases, and epidemics. These ecosystems are undergoing major changes due to the combination of anthropogenic activities and climate change, with potentially severe impacts on community lives and aquatic biodiversity. Untreated discharge of industrial waste to lakes in most African countries is a major and persistent health issue. Frequent droughts are also a key threat to, and cause of, water scarcity (UNEP, 2006).

As a result of severe droughts, Lake Tonga in Algeria is currently under great pressure due to reduced water levels. It has also been added to the Montreux Record because of a decrease in water supply to the lake and the spread of invasive alien species. The Montreux Record is an index of wetland sites on the List of Wetlands of International Importance where changes in ecological character have taken place, are occurring, or are likely to occur due to technological expansions, pollution or other human induced activities. Lake Tonga is also an IBA as it hosts some of the most endangered bird species such as the Marbled Teal and the White-headed Duck (UNEP, 2006). The situation is aggravated by human-induced threats including eel fishing, smuggling, wastewater management and irrigation. Trace metals such as Arsenic, Iron and Cadmium are found in high concentrations in lake water, which have a serious impact on the aquatic ecosystem (Bourhane-Eddine *et. al.*, 2013).

Lake Victoria in East Africa is one of the largest freshwater lakes in the world with a combined catchment area of approximately 250,000 km^2 shared by Kenya (6%), Uganda (51%) and Tanzania

(43%) (Mutuku *et. al.,* 2014). The lake serves over 30 million people in these three nations, but the health of the lake has been heavily impacted by the emission of waste from various activities around the states. The four main causes of water pollution of Lake Victoria waters are storm water runoff, agricultural runoff, untreated municipal sewage, animal and industrial waste (Oguttu *et. al.,* 2008). These factors have highly contributed to the degradation of tributary rivers as well as the water quality for aquatic inhabitation and domestic use. Hyacinth invasions of the lake shores have been described to worsen the water quality in terms of color, temperature and pH which has highly increased treatment costs. In many areas of the basin, water erosion is also widespread, with nearly 45% of the land prone to such erosion. Amplified lake siltation and increased flooding hazard in estuaries are the direct effects of soil erosion and additional degradation forces in the lake (Scheren *et. al.,* 2000).

Nyarumbu and Magadza (2016) recently conducted a study to assess the physio-chemical changes of Lake Chivero in Zimbabwe. Due to increased organic pollution, the results showed very low levels of DO. Because of domestic sewage, industrial effluents and agricultural runoff, the lake was highly eutrophic. In addition, high pH and conductivity values showed signs of soil leaching in organic rich elements due to storm water runoff and increased nutrient loads from waste water treatment, fertilizer salts, and burst sewer pipes.

Africa's second largest wetland, Lake Chad continues to shrink raising many concerns. The lake is shared by four countries; Cameroon, Chad, Niger and Nigeria offering a lifeline to almost 40 million people. Due to overuse of water, prolonged drought and the effects of climate change, the volume of the lake has shrunk by 90 percent over the past decades. The lake's total area has dropped from 26,000 km^2 in 1963 to less than 1,500 km^2 at the moment (UNEP, 2018). The results of the reduction not only destroyed livelihoods, but also resulted in the loss of essential biodiversity. The Food and Agriculture Organization (FAO) has called this situation an "ecological catastrophe," predicting that the lake could disappear this century.

2.5.3 Local scenario – The case of Kenyan Lakes

Kenya is blessed with an array of lakes; freshwater and saline water where some of them possess important ecological roles hence have been designated as IBAs, World Heritage Sites and Ramsar Sites. Kenya has 13,600 km^2 of inland lakes and 640 km of coastline lakes (UNEP, 2009). Despite being such vital ecosystems, most of these lacustrine environments are continuously facing degradation both by natural circumstances and human induced activities. Increased population is a major driver of the multifarious pressures exerted on the Kenyan lakes.

Located in the north of the Rift Valley, Lake Baringo is one of the largest freshwater lakes in Kenya that supports over 500 species of birds including over 50 migratory species and seven indigenous fish species. During the last decades the catchment has undergone drastic changes. The upper catchment converted from thick forests into large commercial ranches and plantations, whereas the lower catchment is cut off attributable to overgrazing and livestock production. The natural forest cover of the drainage basin has been reduced by almost 50% from 829 km^2 in 1976 to 417 km^2 in 2001 (GoK, 2007). The situation has been worsened by increased industrialization and urbanization causing severe erosion, high silt loads in runoff, mass wasting, agro-chemical pollution, deforestation, land degradation and fragmentation as well as encroachment into sensitive aquatic habitats. The water quality has deteriorated over time as a result of increased pH, turbidity, heavy metals contamination and nutrients such as Nitrates and Phosphates (Ochuka *et. al.*, 2019).

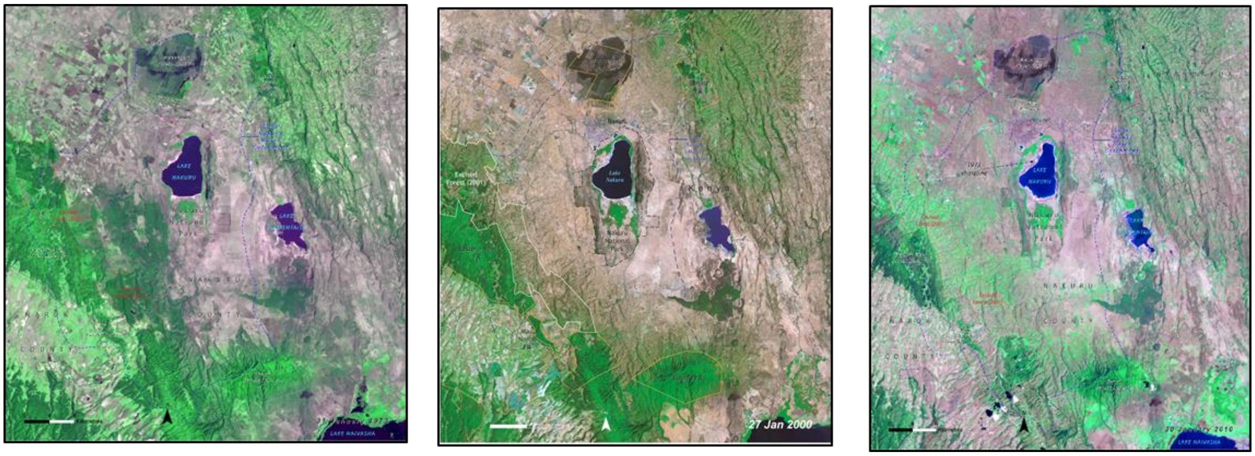
The feeding rivers of Lake Baringo, which are Molo, Endao, Wesegese, Perkerra, Chemeron and Or-Arabel are extremely turbulent during the rainy seasons between April and August. During this period they carry along masses of silts, sediment and uprooted trees which are all deposited in the lake. Each rainy season approximately 400 tons of sediments are deposited in the lake, altering the consistency of Lake Baringo water both physically and chemically. Additionally, the installation of dams on the rivers and the diversion of water have posed major threats to the lake (Ouma and Mwamburi, 2014).

Lake Naivasha, a nationally and internationally significant freshwater lake located in the Kenyan Rift Valley is under constant anthropogenic pressures. Rapid population growth of about 250,000 people living along the lake has resulted in increased energy demand and deforestation of the catchment to provide firewood and construction timber. Deforestation has led to more soil erosion and transport of nutrients due to increased runoff. High levels of metals such as Lead, Cadmium and Copper have been observed in the lake because of pesticides, fertilizers and effluents produced by the Naivasha floricultural (Kamau *et. al.*, 2008). The lake was also surrounded by heavy *Cyperus papyrus* that regulated entry of sediments, nutrients and operated as a natural purifier of water. However, they were reduced from 1200 hectares to 200 hectares due to human settlement compromising their effectiveness as a shield that allows nutrients to enter the lake that contribute to eutrophication. The nutrient levels have gradually increased; at present, the Nitrogen of the lake is 4 mg/L compared to 0.04 mg/L in the 1970's designating Lake Naivasha as a eutrophic lake (Njiru *et. al.*, 2017).

The lone freshwater lake in central Kenya, Lake Olbolossat is situated 7,600 feet above sea level, and below the magnificent Aberdare Mountains. It is Kenya's 61^{st} IBA and is a habitat to many hippopotamus families and is a crucial point for migrating birds. Degradation of the wetland went unnoticed up until when the habitats were deemed unproductive and led to poor health But in the last few years, the significant qualities, standards, ecology of the lake and possible benefits which can be sustainably obtained from the lake ecosystem are under danger because of human threats such as strip mining, road building, overgrazing, pollution and unauthorized settlement on lakeside land have significantly decreased the body of water (Zacharia, 2013). A report shows that the area under water had decreased from 2127 hectares to 674 hectares from 1989 to 2010, a reduction of 68% during this timeframe. Increased population of humans has triggered land fragmentation, animal dispersal and loss of habitat, deterioration and extinction of species. Lake Ol Bolossat was gazetted as a protective wetland area in 2018 with the expectation that negative impacts would shift to a positive direction (National Environment Management Authority [NEMA], 2018).

The Kenyan Lake System covers three interlinked shallow salty lakes of the Great Rift Valley namely Bogoria, Elementaita and Nakuru. They are a home to 13 globally endangered bird species and some of the world's largest bird species, particularly 75% of the globally endangered population of Lesser Flamingos. These three lakes form a vital stopover site for migratory birds flying from other sites in Asia, Europe and South Africa. They are also part of a global network of IBAs and wetlands of global significance. Currently, the major threats faced by the three lakes are the result of developments around them affecting the inflow of water in the lakes (International Union for Conservation of Nature [IUCN], 2014). Fluctuations in land use over the last few decades have affected both the quantity and quality of inflowing waters. The catchment areas of all three lakes are quite small, nevertheless exposed to rapid deforestation, increased agriculture and overgrazing (Macharia *et. al.*, 2010).

Figure 2-1 shows the changes in vegetation cover of Lake Nakuru watershed. Large areas of woodlands and forest have been lost to agriculture and human settlements in the catchment areas of Lake Nakuru in the past decades affecting water supply to the lake and enhancing soil erosion.



January 1973 **January 2000** **January 2010**

Figure 2-1: Changes in vegetation cover around Lake Nakuru catchment

Source: UNEP (2010)

Water pollution is also a major issue in the three lakes, most of which originate from growing agricultural and industrial activities. A study conducted by Yang *et. al.,* (2017) on heavy metal pollution indicated high levels of metals such as Copper, Nickel, Cadmium, and Mercury in Lake Bogoria whereas Lake Elementaita showed great concentrations of Mercury and Arsenic. Cause detection using Principal Component Analysis revealed that mostly human activities played an increasingly essential role in these lakes' heavy metal pollution.

Lake Nakuru receives treated sewage water as well as untreated sewage from houses unconnected to the sewer system. The largest single source of pollution in Lake Nakuru is as a result from urban runoff from the first major rains of two wet seasons consisting of oil and toxic chemicals from motor vehicles; sediments from new construction sites; viruses and bacteria from leaking septic tanks. Minor facilities such as garages and textile-dying plants dump their wastes into pits that eventually drain into ground water. Toxic algal blooms have been observed in the lake as a result of increased runoff which has caused the deaths of flamingos (Kotut and Krienitz, 2010).

According to the World Bank (2006) report, nearly 9000 m^3 of sewage is produced every day in Nakuru, out of which 40% ends up in the rivers and lake by runoff and storm water. From the most current statistics, it was noted that 4500 m^3 of sewage enters the waste water treatment plant everyday however 2000 m^3 of waste is discharged into the lake (Nakuru Water and Sanitation Services Company [NAWASSCO], 2015). Sewage effluents entering the lake include bacteria and pathogens causing an outburst of diseases. Excess nutrients from the sewage have resulted in eutrophication of the lake, as well as reduction of the DO concentrations (Kulecho and Muhandiko, 2005).

2.6 PHYSIO-CHEMICAL PARAMETERS INFLUENCING LAKE WATER QUALITY

2.6.1 Temperature

Water temperatures are physical properties that show how cold or hot water is. Temperature regimes in bodies of water are very complex and difficult to interpret. It is one of the simplest properties yet many other water parameters depend on temperature for accuracy. Surfaces of water bodies undergo variations in temperature along with climatic oscillations. The temperatures are influenced by latitude, air circulation, cloud cover, different seasons, flow depth temperature and altitude (Sharma *et. al.,* 2005). In addition to natural climatic variations, surface water temperatures are highly influenced by human induced activities. Thermal emissions, deforestation, erosion and runoff have influenced water temperature (Råman Vinnå *et. al.,* 2017).

Temperatures also influence photosynthesis production and metabolic rates, compound toxicity, conductivity, salinity and water density. Species are sensitive to high temperatures in bodies of water as their metabolism rate is temperature dependent. In warm waters, the respiration rate increases, resulting in an increased decomposition of organic matter Oxygen consumption (Umerfaruq, 2015). In warmer waters there is less solubility of Oxygen which restricts the supply of Oxygen. As the solubility of DO decreases with increasing water temperature, the supply of DO for aquatic life is limited by high water temperature. Additionally, water temperature controls increasing levels of biochemical reaction affecting water quality.

2.6.2 pH

The pH of water is the measurement of how acidic or alkaline the water is. In water, molecules dissociate into Hydrogen and Hydroxide ions. Point source contamination is a frequent cause, and depending on the chemical components will increase or decrease pH. Such chemicals may come from agricultural or industrial runoff and discharge of wastewater. When other compounds (pollutants) come into the water, they react with the ions of Hydrogen and Hydroxide, creating a difference in ion count (Brosset, 1979). As more Hydrogen ions react, the water becomes more alkaline, and the water becomes more acidic when more Hydroxide ions react. Low or high pH numbers can indicate a sign of pollution in environmental surveillance and sampling. The pH is expressed on a scale of 1 and 14, with 1 being very acid, 7 being neutral and 14 being very alkaline. The pH value in saline lakes usually varies from 9 to 12 (Khmelenina *et. al.*, 2010).

2.6.3 Dissolved Oxygen

It is the presence of Oxygen gas in water, measured in mg/L. DO levels differ depending on water temperature, altitude, depth, time of day, season as well as rate of flow. Where the water temperatures and altitudes are high, the level of DO is low. DO reaches its highest level during the day and decreases at night because photosynthesis stops while oxidation and respiration continue till evening (Prasad *et. al.*, 2014). The concentrations of DO can also drastically change with the depth of a lake. The production of Oxygen occurs in the top fraction of a lake, where sunlight powers the photosynthesis engines. Usage of Oxygen is highest near a lake's floor, where organic material builds up and decomposes. Large-scale industrial development, intense fertilizer use and human waste disposal can rapidly pollute water leading to Oxygen starvation. If DO levels drop under 5.0 mg/L in water, stress is imposed on aquatic life. The lesser the concentration, the bigger the stress. Oxygen levels remaining below 1-2 mg/L for a couple of hours can lead to large fish kills (Boudaghpour, 2011).

2.6.4 Total Dissolved Solids

Total Dissolved Solids (TDS) integrate the amount of all ion particles which are less than two microns. They also include all the dissociated ions and electrolytes that cover salinity concentrations as well as dissolved organic matter (Bowman and Sachs, 2008). TDS concentrations commonly found in lakes and streams range between 50 to 250 mg/L. TDS majorly constitutes the ions; Sulphates (SO3-), Carbonates (CO3-), and cations; Potassium (K+), Magnesium (Mg2+) Sodium (Na+) and Calcium (Ca2+). Various factors affect the concentration of TDS in a body of water. Fertilizers may add an amount of ions to a water body. Increases in TDS can often be the product of runoff from winter salted fields. Organic matter from sewage treatment plants can contribute to increased Nitrate or Phosphate ion levels (Bhateria and Jain, 2016). Many types of aquatic species are impacted if TDS levels are high, particularly due to dissolved ions. High TDS levels can also reduce the overall clarity, limit photosynthesis, and mix with toxic chemicals and heavy metals, and upsurge water temperature.

2.6.5 Total Suspended Solids

Total suspended solids (TSS) are particulates in the water column which are bigger than two microns. TSS may include a diverse range of natural and synthetic materials, like silt, bacteria and microbes, rotting plants, algae, animal waste, effluents, and sewage. These solids can clog gills of fish, either kill them or decrease their rate of growth. They minimize the penetration of light, too. This reduces algae's ability to produce food and Oxygen (Prestigiacomo *et. al.*, 2007). The photosynthesis rate slows down as the amount of light passing through the water is decreased. Reduced photosynthesis levels allow the plants to release less DO into the water. If light from underlying plants is totally blocked, the plants will stop producing Oxygen and end up dying. Bacteria will use more Oxygen out of the water as the plants are disintegrated. Low DO levels can cause killing of fish. High TSS may also increase the temperature of the surface water, because the suspended particulates absorb heat from the sun. High TSS in a body of water can sometimes mean greater concentrations of nutrients, chemicals, and heavy metals. Such contaminants can attach to soil particles on the ground and transfer with storm water or surface runoff into water bodies (Rossi *et. al.*, 2006).

2.6.6 Alkalinity

Alkalinity is a water body's buffering potential. It measures the water bodies' capacity to neutralize acids and bases, thus maintaining a relatively stable pH. Water that would be a suitable buffer includes compounds, such as Carbonates, Bicarbonates and Hydroxides, which interact with water ions, hence increasing the water's pH (Hecky and Kilham, 1973). It usually originates from soils and rocks, salts, a few plant activities and certain industrial effluents. For aquatic life, alkalinity is critical as it supports or buffers from abrupt pH changes. Natural water alkalinity levels can range from less than 5 mg/L to quite a few hundred mg/L. Low-alkalinity water bodies are more vulnerable to acid rain acidification, and are usually less productive.

2.6.7 Heavy metals

Heavy metal applies to any metal or metalloid of relatively high density varying from 3 - 7g/cm^3 and is toxic at even low concentrations (Sharma and Sohn, 2009). Such metals include Zinc, Copper, Nickel, Lead, Chromium, Mercury Arsenic and Thallium. Heavy metals can pollute water bodies from both natural (geological) and anthropogenic sources. Natural sources include erosion, river flows, runoff and rock weathering, whereas sources from human activities include agricultural fertilizers, leaching, energy production, domestic wastewater, untreated industrial and urban wastewater discharge and mining (Karimian *et. al.*, 2018). While some of these metals are crucial nutrients, their high concentrations in the food web can lead to toxic effects and environmental consequences and threaten aquatic ecosystems and their consumers. Several aquatic ecosystems face concentrations of metals that surpass standards of water quality designed to protect the environment, humans and animals. The challenges are worsened because metals have a propensity to be transported with silt and sediments; they are persistent in the ecosystem and can accumulate in food chains.

2.6.8 Nutrients: Nitrates, Phosphates and Ammonia

In water bodies, nutrients particularly Nitrogen and Phosphorus are crucial parameters of water quality. The primary role of Nitrogen in species is the synthesis of protein and DNA. Plants use this element in photosynthesis too whereas Phosphorus is important for metabolic processes that require energy transfer (Smith *et. al.*, 1999). In water, Nitrogen can exist in several forms such as Nitrate, Nitrite, Ammonia and urea. Phosphorus similarly subsists in the water in numerous forms such as Phosphate, total Phosphorus, Orthophosphate and Polyphosphate. Common sources of excess Nitrates, Phosphates and Ammonia getting into lakes and streams include septic systems, fertilizers, pesticides, sewage treatment plants, storm water runoff, livestock operation, fossil fuel combustion, aqua culture and industrial wastes (Selman and Greenhalgh, 2010).

Although Nitrogen and Phosphorus are essential to biological processes in aquatic ecosystems, a huge amount of these nutrients from land-based sources to aquatic ecosystems leads to higher production of biomass, disrupting the ecological balance of all such ecosystems. The increase in large quantities of nutrients in lakes accelerates algae and plant growth accelerating eutrophication and exhausting the water body of Oxygen (Singh, 2013). They can have drastic direct or indirect effects on photosynthesis, Oxygen levels, water clarity, turbidity and sedimentation rates, depending entirely on their chemical forms.

2.7 LEGAL FRAMEWORKS AND POLICIES GOVERNING THE USE AND MANAGEMENT OF WETLANDS

2.7.1 International treaties

A variety of international agreements, conventions, and protocols offer guidelines on the sustainable conservation and protection of wetlands to promote the sustainability of their social and economic and ecological roles for current and future generations. They comprise of the Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat, UNESCO World Heritage Convention (WHC), Convention on Conservation of Migratory Species of Wild Animals (Bonn Convention or CMS), the Convention on Biological Diversity (CBD), the United Nations Convention to Combat Desertification (UNCCD), African Eurasian Water Bird Agreement (AEWA) and United Nations Framework Convention on Climate Change (UNFCCC).

The Ramsar Convention is aimed to protect the wetlands and is based on three pillars; identifying and managing wetlands of international importance; the sensible use of these wetlands through national land use plans, effective policies and laws, conservation activities and public education; and the promotion of international cooperation and commitment to transboundary wetlands (Ramsar Convention Secretariat, 2004). By January 2019 the Ramsar Convention had 170 contracting parties (Ramsar Convention Secretariat, 2019). Kenya is committed to making sure the good use of wetlands while includes aspects of wetland protection in planning frameworks, creating wetland natural reserves and prioritizing capacity building in wetland science, maintenance and wardening. The country is also committed to designating eligible wetlands as Ramsar sites. Ultimately, Kenya is committed to international collaboration; advising partner states in particular on transboundary wetlands (MEMR, 2012).

Even though the Ramsar Convention is the main international platform for the management of wetlands, Kenya is a party to several other important conventions. The Bonn Convention is the only international forum concentrated on land, marine and avian migratory species, their habitats including their migration pattern routes. The Convention's goal is to ensure that wildlife migration across different parts of the world is continued through multilateralism. The Convention was adopted by Kenya on 1st May 1999 (CMS/UNEP, 2002).

The CBD was ratified by Kenya on 11th June 1992 and came into effect on 26th July 1994. Embraced in 1993, the Convention's key goals are to ensure the protection of species diversity; the efficient use of biological diversity products and the fair and equal provision of benefits resulting from the use of resources (CBD, 1992). On the other hand, the WHC was implemented in Paris in 1972 and entered into force in 1975. The goal is to create an effective system of collective preservation of the exceptional fundamental value of cultural, historic, and natural assets. On 5th June 1991, Kenya joined the WHC and currently has six sites under the WHC, the lake system in the Great Rift Valley being one of them (UNESCO, 2019).

Lake Nakuru was designated as Kenya's first Ramsar site and a UNESCO designated World Heritage Site. This position has added value to the protection of the lake by facilitating national-level implementation of decisions and measures for the sustainable use of the wetland. It allows access to expert guidance on regional and site-related wetland, protection and management challenges. Being listed as a Ramsar site also provides access to information and guidance on the implementation of the universally agreed principles of the Conventions, such as guidelines on the application of the principle of wise use. International recognition reinforces the scientific value of the lake for research, awareness and education, and helps to promote international cooperation, site twinning, global data sharing, and creating networks.

2.7.2 National frameworks and policies

2.7.2.1 Policy Framework

Kenya has taken many steps in order to reduce and stop the deterioration and destruction of wetlands. There are no provisions in the Kenyan Constitution regulating environmental management on wetland resources specifically however it enshrines a range of policies which may substantially improve the management of wetlands. Lauded as a "Green Constitution", the new

Kenyan Institution declared in 2010 includes extensive rules with thoughtful implications for sustainability (GoKb, 2010). They extend from environmental values to the right to a safe, clean and healthy environment as laid down in the Bill of Rights (Odote *et. al.,* 2008).

The National Wetlands Conservation and Management policy (2015) aims at ensuring the wetlands' benefits are well secured. It also attempts to provide a legislative framework for resolving adverse issues affecting wise use and protection of Kenya's wetlands. It focuses on the protection of wetlands from degradation, invasive alien species and misuse and abuse via public awareness, public engagement, and traditional knowledge use and conservation plans and strategies implementation. The policy also satisfies Kenya's obligations under the Ramsar Convention, as well as the group of East Africa (GoK, 2015). Various other policies related to wetland management in Kenya include the National Environment Policy (GoK, 2013a) National Wildlife Conservation and Management Policy (GoK, 2012d) and Forest Policy (GoK, 2014).

2.7.2.2 Legal Framework

Environmental management and all its elements are governed by Kenya's environmental structural law, the Environmental Management and Coordination Act (EMCA). Furthermore, for almost every sector there are certain regulations. The Act recognizes NEMA as the overall and main body with the responsibility of ensuring cooperation for sound environmental management in the execution of national policy. The goals of EMCA's wetland regulations include, inter alia, ensuring the safe use and protection of wetlands and its resources, protecting wetlands as habitats of many species, regulating and preventing siltation and pollution, as well as providing a mechanism for public participation in managing these habitats (EMCA, 1999).

The Water Act (2016) which effectively repealed Water Act (2002) is a Parliament Act that exists for the protection, storage, use as well as regulation of water sources and the acquisition and enforcement of water rights; controlling and maintaining water supply and wastewater services (GoK, 2016). This Act has importance to wetland management in Kenya as it describes a wetland as an area whose attributes include water presence and therefore the significance (Odote *et. al.*, 2008). The Wildlife Conservation and Management Act (2013) enforces wildlife protection and management in Kenya. It is important for wetland conservation in Kenya because it has designated the KWS as the national focal institution for the adoption of the Ramsar Convention since Kenya ratified the Convention.

Other legal frameworks that are vital for wetland management in Kenya include the Forest Act (GoK, 2005), the Fisheries Act (GoK, 2012b), Environmental Management and Co-ordination (Wetlands, River Banks, Lake Shores and Sea Shore Management) Amendment Regulations (GoK, 2017), National Museums and Heritage Act (GoK, 2006), the Land Act (GoK, 2012c) and the Agricultural Act (GoK, 2012a).

2.7.2.3 Institutional Framework

In Kenya, various institutions are at the forefront of wetland management. These range from ministries of the national government, semi-autonomous government agencies, county government divisions, non-governmental organizations, community based establishments, research institutes, universities and international partners. Many ministries are responsible for the management of the environment, land and water resources, biodiversity, protection of the ecosystem, climate change and economic development. Some of the ministries accountable for wetland management include the Ministry of Environment and Natural Resources, Ministry of Water and Irrigation, Ministry of Agriculture, Livestock and Fisheries, Ministry of Tourism and County governments. Semi-autonomous government agencies comprise numerous institutions. The major ones in charge of Lake Nakuru include Water Resources Management Authority (WRMA), NEMA, KWS, Kenya Meteorological Service (KMS) and Kenya Forest Service (KFS).

KWS is the national authority responsible for a range of environment conventions to which Kenya is a member state. It is the national focus point for the Ramsar Convention and CMS, as it is mandated to conserve Kenya's natural land and water resources in the designated protected areas. Furthermore, KWS is the lead institution for managing wetlands in the country and also authorized to license, monitor and oversee the protection and management of all species outside the protected areas. Other institutions that are engaged in management of Lake Nakuru include the World Wide Fund for Nature (WWF) located in LNNP, Municipal council of Egerton University (Thampy, 2002; Gichuhi, 2008).

2.8 STUDY GAPS

A considerable number of studies on Lake Nakuru have been conducted for various purposes. Lake Nakuru is situated in a heterogeneous drainage basin with very many external hydrological pressures. The implications of water management on environmental and socioeconomic aspects of Lake Nakuru are rarely addressed and still remain unclear. Land use practices and regulations have a significant effect on Lake Nakuru, creating the need for stronger multi-sectoral communication concerning the water and land management. The provincial water quality management system for Lake Nakuru isn't transparent. This acts as a barrier to having to fill the knowledge gaps identified in the literature that could be surmount through either municipal and public integrity and bilateral communication among state officials, researchers, and the general population. There have been no exhaustive studies on the lake's recent threats and vulnerabilities. This study filled the knowledge gap by presenting data regarding the current state of the lake, key threats, water quality and heavy metal analysis. It also addresses issues of governance, consciousness of legal knowledge and sustainable development in a comprehensive perspective.

2.9 THEORETICAL FRAMEWORK

The study is rooted on the Sustainable Water Resources Management (SWRM) theory. According to a UN (1987) report, Sustainable Development is “the development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. SWRM is an intersection and interface between the environmental, technological, social and cultural sectors (Figure 2-2). In short, sustainable development aims to establish and strike a balance seen between challenges facing societies as well as the capacity of natural ecosystems. In order for the system to really be environmentally sustainable, it should establish a secure resource base, minimize the exploitation of renewable resources and limit the depletion of natural resources.

As specified in the first phrase of the Global Water Development 2015 report, "water is at the heart of sustainable development" which is clearly tied to the access and usage of adequate quantity and quality of water for the protection of healthy ecosystems and is crucial to social, economic and human growth. SDG 6 argues for the provision and effective management of water and sanitation for everyone. In specific, it calls for equitable access to safe water (Target 6.1) and hygiene (Target 6.2), enhancing quality of the water by minimizing water pollution (Target 6.3), increasing water efficiency in all sectors (Target 6.4), controlling water resources in an integrative manner (Target 6.5) and sustaining water-related habitats (Target 6.6).

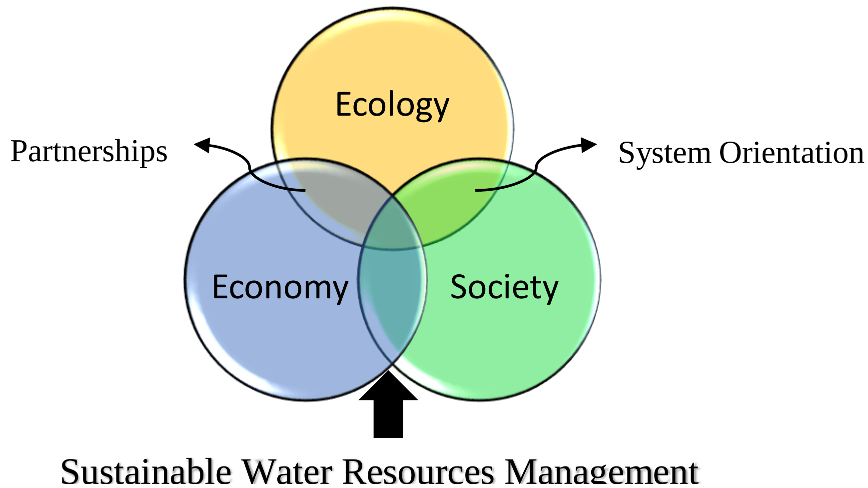


Figure 2-2: Integrations of sectors for SWRM

Source: Researcher (2019)

SWRM's main objective is to balance the extraction of natural resources, technological advancement and institutional change by encouraging integrated development and governance of land, water and associated resources with a view to increasing socioeconomic well-being in a sustainable manner without sacrificing the sustainability of critical ecosystems in the present or future.

The SWRM theory fits well into this study as threats continue to rise in Lake Nakuru requiring a holistic approach for good management. Over the last 15 years, there have been more than 20 uncoordinated environmental management programs and campaigns. There is currently no joint panel to discuss issues of mutual interest in lake management with about 19 sector development projects currently underway. There is minimal flow and sharing of information between both the academic institutions and stakeholders. Sustainable management will only be achieved through a transdisciplinary action between the government, local institutions and nationals for the protection of the environment and for economic development.

2.10 CONCEPTUAL FRAMEWORK

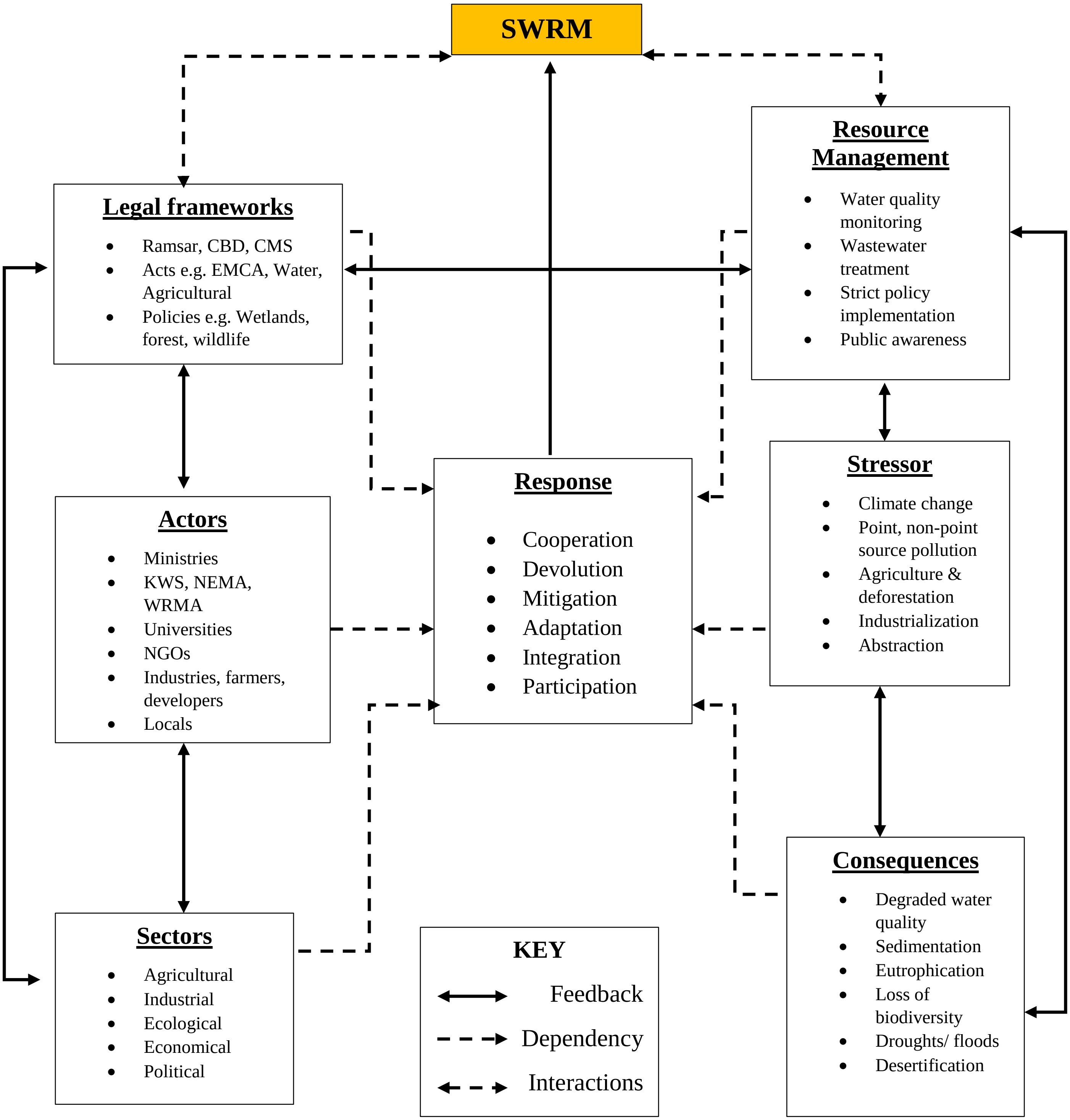


Figure 2-3: Conceptual framework for Sustainable Water Resources Management

Source: Researcher (2019)

The conceptual framework (Figure 2-3) is featuring linkages between natural and aquatic bodies, human activities, impacts, institutions and actors. The effect of water quality in this study is conceptualized using the integration of the human and physical environment leading to environmental degradation. Major lakes of the world are getting degraded through activities such as land clearing, agriculture, removal of riparian vegetation, waste disposal, industrialization, climate change and recreation. These activities are thereby posing a great threat to the ecosystem and have paved several ways for the entry of pollutants to the surface water. Increased pollution has deteriorated the water quality in terms of the chemical and physical state leading to several consequences such as eutrophication and siltation, aquatic loss, habitat changes, acidification and overall degradation of the ecosystem. Poisonous chemicals used in agricultural activities such as pesticides, in addition with artificial fertilizers are silently destroying beneficial microbes that maintain the bio-geochemical cycles, biodiversity and habitats in the feeding rivers and the lake (Thampy, 2002).

Lake conservation involves an understanding of its water systems, drainage patterns, runoff, groundwater inflows, adjacent wetlands, watercourses and pollutant channels. SWRM's core idea is to take a systematic, multidisciplinary, and pragmatic approach in discussing water management problems, including their societal, political, fiscal, technological, and environmental aspects. To ensure efficient and sustainable management and governance of water resources, there needs to be synergistic linkages and interactivity, as well as relationships between systems and actors. To do this, a thorough and systemic combination of all components which includes; legal and policy frameworks, institutions, actors and stakeholders and an environment management system is necessary for decision-making and planning in a coherent way.

SWRM is a process of trial and error; continuously changing policies, management and strategies are ideal for SWRM. Systems are highly connected and therefor understanding this is central to management; combos of abiotic-biotic predictive models and integrated catchment information can be useful. This framework is ideal for creating partnerships between science and management and lastly managing and implementing a "wealth of research" as well as ensuring it impacts active management.

CHAPTER THREE: STUDY AREA

3.1 INTRODUCTION

This study was conducted in and around Lake Nakuru, Kenya. This site was chosen because it is one of the most significant sites for flamingos, and IBA, Kenya's first Ramsar Site and a World Heritage Site. This chapter gives an analysis of the study area. It starts by looking at the physical aspects which include the location, size, climate, topography, geology, soils, drainage and hydrology. The biological features such as vegetation and wildlife characteristics will also be discussed.

3.2 PHYSICAL CHARACTERISTICS

3.2.1 Location and size

Lake Nakuru, commonly named as "the lake with a million flamingos" is a shallow hyper-eutrophic, alkaline and saline endorheic lake located in Rift Valley's eastern arm lying between longitude 36°04'-36°07 E and latitude 0°19'- 0°24' S as shown in Figure 3-1 (Vareschi, 1982; Raini, 2009). The lake occupies an area of 45 km^2 and forms the lowest point in the catchment basin at 1800 km^2, with an average depth of one meter at above the sea level at an elevation of 1759 meters. It is enclosed by the Mau Escarpments to the west and Bahati Highlands to the east. The northern edge includes the Menengai Caldera and the Eburru Volcano separates the Nakuru-Elementaita from the Naivasha basin to the south. It is situated 60 km to the south of the Equator (Ballot *et. al.*, 2004).

3.2.2 Topography

The key topographic features in the area are the Rift Valley floor, the Menengai Crater of altitude 2240 meters forming the northern rim of the catchment, the Mau Escarpment reaching an altitude of 3000 meters giving the highest point within the catchment and lastly the Bahati Escsarpment. The plains to the south and east gradually rise to the ridge above Lake Nakuru which are the lowest points within the catchment at an altitude of roughly 1758 meters as well as above Lake

Elementaita and to the Eburru Mountains, a branch of the Mau Escarpments at an altitude of 2750 meters (Vareschi, 1982; KWS, 2004).

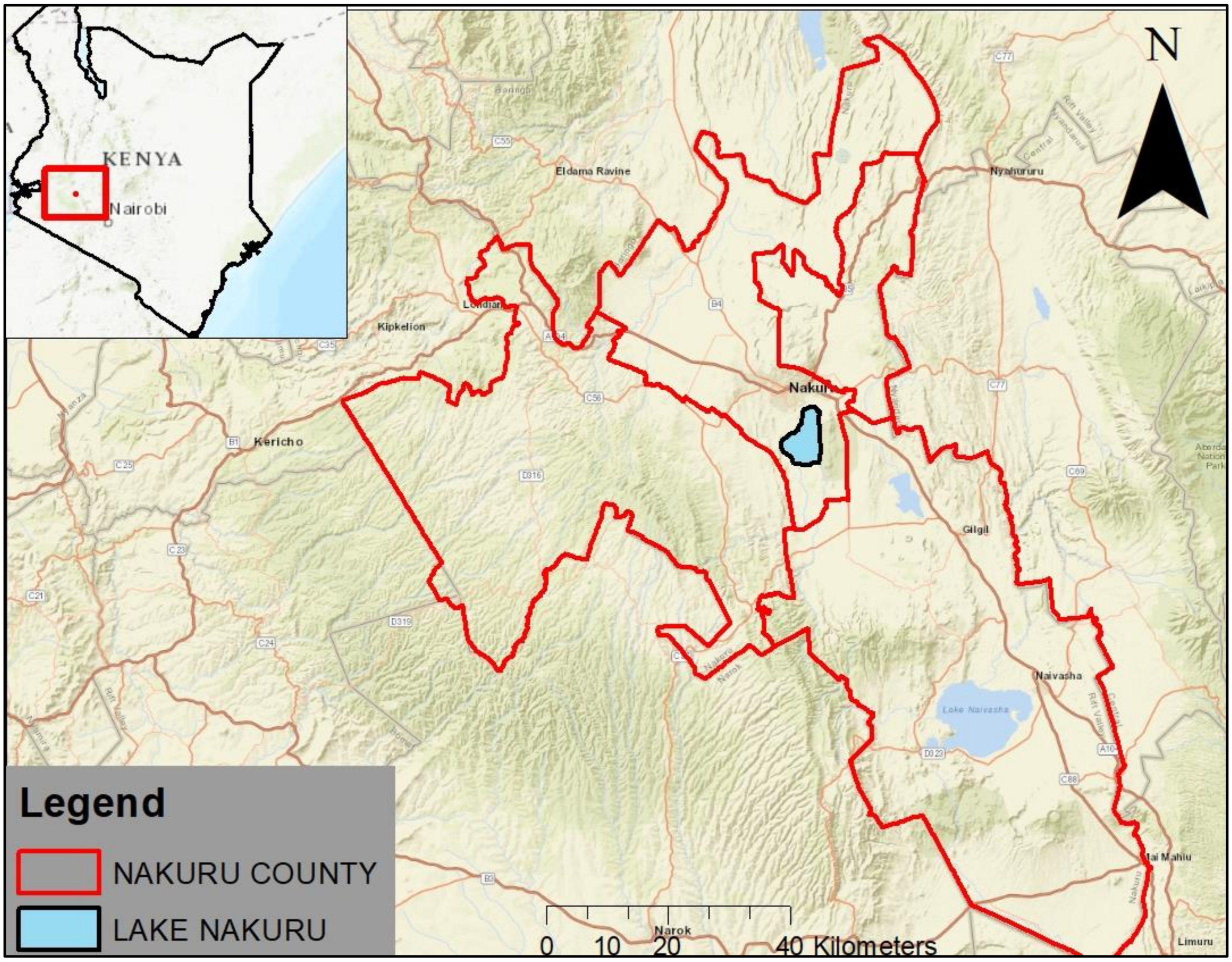


Figure 3-1: Location of Lake Nakuru

Source: Researcher (2019)

3.2.3 Drainage and hydrology

Lake Nakuru is a closed drainage basin with a shoreline of 27 km. The basin is drained by the rivers namely Njoro, Makalia, Naishi, Nderit, Lamdiac and Ngosur Rivers as well as treated wastewater from Nakuru town. Rivers Njoro, Lamdiac, Makalia and Nderit are seasonal (Odada *et. al.*, 2006). River Njoro drains the utmost and wettest western side that rises to the Eastern Mau Escarpment, giving a vital source of constant surface inflow to the lake and recharge to the local groundwater basin. River Ngosur is a permanent stream that drains from the Bahati Highlands to the North Eastern end of the catchment. The catchment basin depends on the amount of water supply hence varies in volume from season to season. The lake has a mean depth of 2.5 meters and a maximum depth of 4.5 meters. The long term mean volume recorded is 92 x 10^6 cubic meters (Odada *et. al.,* 2006).

It also receives discharge from Baharini Springs which flows permanently in the lake with the water originating from the Subukia area to the east of the lake (Shah, 2016). The Baharini springs as well as other springs located on the eastern shoreline contribute approximately 0.6 m^3/s to the lake. The entire basin is alienated into three basins namely Nakuru East, Nakuru West and Nakuru North. Nakuru West consists of various streams passing through it and it also contributes a big part of the catchment area which drains into Lake Nakuru. On the other hand Nakuru East has fewer rivers.

The main water sources in this region consist of shallow wells and boreholes. Nakuru North has a few streams and rivers however they have very small flows during the dry seasons. Groundwater acts as a tank from which water seeps into Lake Nakuru via the lake’s bed sediments, in response to the change in elevation head between the lake’s surface level and the adjacent groundwater table. Groundwater occurrence is flexible and somewhat localized, though the pattern is overlaid on a regional flow pattern controlled by the diverse topography of the Rift Valley (Jenkins *et. al.,* 2009).

3.2.4 Climate

The climate varies within the lake catchment due to differences in altitude. It varies from hot and moist to the usual Rift Valley floor, semi-arid and arid. The lake receives most of its precipitation during the long April to May rains and the short rains in November (Gichuhi, 2007). The average amount of annual precipitation is 908 mm (Figure 3-2). Natural rainfall on the lake adds more to its drainage than the incoming water from the feeding rivers since they have become erratic in their flow, running for about three to four months in a year. The mean annual maximum temperature is 26.0^{o}C and the mean annual minimum temperature is 9.0^{o}C. The climate plays a big role in the quality of the lake water as it dilutes the water during the rainy season as well as increases the rate of surface water runoff, washing off pollutants directly into the lake. The salinity of the water increases during the dry seasons, causing a difference in the quality of water.

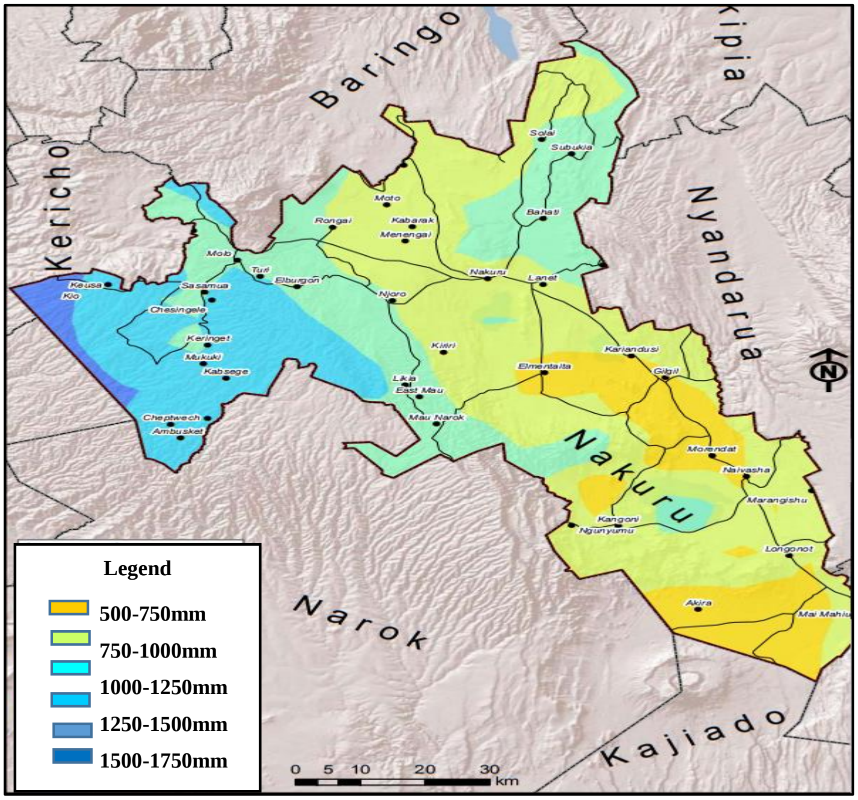


Figure 3-2: Mean precipitation map of Nakuru

Source: MoALF (2016)

3.2.5 Geology and soils

The geology of this region is connected to the activities related to the creation of the Rift Valley, including faulting and volcanic eruptions. The geology is consistent and uniform in which the rocks are volcanic in nature separated into two major groups; pyroclastics and lava flows produced by faulting in the Tertiary-Quaternary era. The major volcanic rocks include pyroclastics, basalts, trachytes and phonolites, sometimes intercalating with volcano sediments and organic sediments (Ngecu and Nyambok, 2000). Joints, fissures and faults dominate the structural geology of the region.

The soils are also volcanic characterized by a structure which is loose, porous, highly permeable such as clay, sandy clay and loam (Figure 3-3), exposing it to plummeting land, agents of fractures and erosion, after or during heavy rainfalls (Odada *et. al.,* 2006). Soils of the area influence the water quality of Lake Nakuru especially during periods of high flows as the major source of the water entering the lake is derived from surface flow from the feeding rivers which carry eroded soils from their banks leading to siltation.

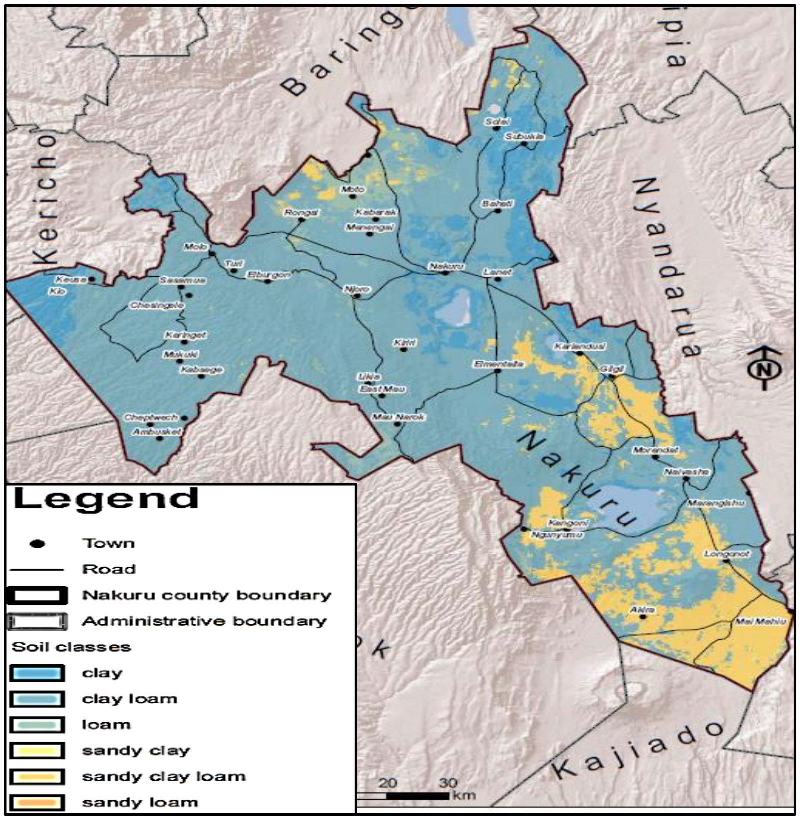


Figure 3-3: Soil classification of Nakuru

Source: MoAlf (2016)

3.3 BIOLOGICAL CHARACTERISTICS

3.3.1 Vegetation

Lake Nakuru has a wide variety of vegetation ranging from grasslands to dense forests, euphorbia forests and tarchonanthus bush lands. The catchment itself has important forests such as Eburu, Dundori and Mau. The ecosystem has approximately 556 plant species which constitute 305 genera and 85 families (GoK, 2010a). The lake hosts a thick colony of *Cyanophyte Spirulina platensis* algae that is the flamingos' main food source.

Lake Nakuru is surrounded by alkaline swamps along the rivers and springs with Cyprus, typha marshes and sedge. The adjacent regions are covered with dry season savanna with grasslands of *Sporobolus spicatus* (salt grass) changing to *Hyparrhenia hirta* grasslands in the lower areas. The higher elevated regions include dry woods and forests of *Acacia xanthophloea*, *Croton dichogamus* and the *Euphorbia candelabrum* which grow up to 15 meters high (Mutangah, 1994). The vegetation around the lake has been severely affected due to deforestation for heavy settlement and widespread cultivation. The Mau forest has reduced by 28% between the years 1966-1981. The Eburru and Dondori forests are also facing major anthropogenic threats such as charcoal burning, farming and illegal logging (Odada *et. al.*, 2006). Vegetation around the processes like nutrient cycling, evapotranspiration, runoff processes, infiltration and atmospheric inputs, which in turn impact the quality of the drainage water and thereafter the water quality of the lake.

3.3.2 Wildlife

A wide variety of fauna, spanning from birdlife to large herbivores blesses the catchment. The lake supports more than 450 bird species which include 70 different species of water birds. The most famous attractions in Lake Nakuru are the Lesser Flamingos (*Phoenicopterus minor*) and Greater Flamingo (*Phoenicopterus rubberroseus*). The lake also supports big populations of wildlife species; over 56 mammal species including hippos (*Hippopotamus amphibious)* and the globally endangered Black Rhino (*Diceros bicornis)* (Ramsar Convention Secretariat, 2012). Alterations in the lake's water quality have significantly changed the wildlife population and the ecological environment as a result of severe pollution from wastewater, farming and toxic chemicals.

CHAPTER FOUR: RESEARCH METHODOLOGY

4.1 INTRODUCTION

This chapter describes the methods that were used for the analysis of the research objectives and test the hypothesis of this study. It discusses the research design, target population, sample size, procedures of data collection, analysis and interpretation methods.

4.2 RESEARCH DESIGN

This study involved both qualitative and quantitative methods. Quantitative techniques are based upon amount or quantity measurements. They are applicable to events which can express themselves in terms of quantity. This approach describes phenomena in the form of numerical data that can be analyzed by mathematically based approaches, in particular statistics. Qualitative methods, on the other hand, are concerned with the subjective assessment of attitudes, behavior and opinions. This method produces either non-quantitative results or results that are not subject to rigorous quantitative analysis. Common techniques used in qualitative research include interviews, questionnaires and projective techniques (Kothari, 2004).

The study employed a mixed methods research design including surveys, *in-situ* measurements, laboratory experiments and observation methods. Mixed methods research design is an approach that in a single study utilizes or blends both qualitative and quantitative forms of research and methodology to address the problem statement (Shorten and Smith, 2017). Surveys were used to get information on the current status of the phenomenon and to define what happens with regards to variables or circumstances. *In-situ* measurements and laboratory experiments were involved to obtain physical and chemical parameters of the surface water and silt load of the lake.

4.3 TARGET POPULATION

The target population of the study area was **33,802** from three sub-locations Mwariki A (24,596), Mwariki B (7,268) and Pwani (1,938) (Table 4-1). *In-situ* measurements and laboratory analysis for physio-chemical tests were carried out at different surface water and sediment sampling points inside the lake.

Table 4-1: Target population of study area

Sub-location	Population
Mwariki A	24596
Pwani	1938
Mwariki B	7268
Total Population	**33802**

Source: KNBS (2009)

4.4 SAMPLING PROCEDURE AND SAMPLE SIZE

Sampling is a method used to select a subgroup from a population to participate in the study in such a way that the selected participants represent the big number from which they were selected. (Taherdoost, 2016). The study used both purposive sampling and simple random sampling.

4.4.1 Respondents

4.4.1.1 Households

The population data obtained from KNBS (2009) was sorted in terms of locations and sub-locations neighboring the selected study sites. For the household surveys, three sites around Lake Nakuru were considered namely Mwariki A, Mwariki B and Pwani. These three sites were chosen due to their close proximity to the lake hence first-hand information was obtained from the respondents. A total of 196 respondents, 104 (53%) males and 92 (47%) females were chosen from the three sites (Table 4-2). Random selection of the sub-locations was done, from which households were selected randomly (Appendix IV). The determination of sample size of the respondents was done using Cochran's (1963) formula as illustrated in the equation below.

$$n = \frac{Z^2 p\, q}{e^2}$$

n = sample size

z = Critical value of 95% confidence level

p = Estimated proportion of the attribute present in the population

q = 1-p

e = desired level of precision

Therefore: p = 0.5 and hence q =1-0.5 = 0.5; e = 0.07; z =1.96

$$n = \frac{(1.96)^2(0.5)(0.5)}{(0.07)^2}$$

$$= 196$$

Simple random sampling was carried out for the household surveys. This was done using the hat method where each household was given a number written on a paper. Picking of the numbers one after the other without any replacement took place until the required sample size which represents the total population was achieved.

Table 4-2: Sample components for questionnaires around Lake Nakuru

County	Division	Location	Sub-location	Population		Total	Sample		Respondents
				M	F		M	F	
Nakuru	Nakuru	Kaptembwo	Mwariki A	12045	12551	24596	70	73	143 (73%)
Nakuru	Lare	Naishi	Pwani	988	950	1938	6	5	11 (6%)
Nakuru	Lanet	Lanet	Mwariki B	4782	2486	7268	28	14	42 (21%)
Total				17815	15987	33802	104 (53%)	92 (47%)	196 (100%)

Source: KNBS (2009)

4.4.1.2 KWS staff

Purposive sampling was carried out for the KWS staff members. Purposive sampling, also referred to as judgment sampling, is the careful choice of the participant on the basis of the qualities possessed by the participant (Tongco, 2007). In this study, the respondents were chosen on the basis of availability and willingness to participate. A total of eleven respondents were selected inside LNNP.

4.4.2 *In-situ* measurements and laboratory experiments

This study was designed during the wet and dry seasons to collect surface water samples from selected sites within the lake. All the sampling sites were purposively selected based on the presence of any form of emissions, contamination and pollution, inflows, accessibility and drainage patterns. Based on these, ten sampling points were selected (at least 300 meters away from each other) which included the old main gate (lake center), Baharini springs, Nyati camp, Hippo spring, mouth of River Nderit, Nderit point, T junction, Block 7, mouth of Lamdiac River and the storm drain (Figure 4-1). Four sediment samples were collected at different points (Hippo Spring, Baharini Spring, Nderit and storm drain) for heavy metal analysis. Samples were collected in two different seasons; wet and dry in May and October before 10 am as there is no mixing of waters in the morning. A handheld Global Positioning System (GPS) was used to determine the elevation and geographic coordinates of each sample (Table 4-3).

Table 4-3: Coordinates for water and sediment samples at Lake Nakuru

POINT	SITE	GPS CORDINATES
A	**Old Main Gate (Lake Center)**	37M 0175521 UTM 9965038
B	**Baharini Springs**	37M 0178059 UTM 9965831
C	**Nyati Camp**	37M 0178770 UTM 9962910
D	**Hippo Spring**	37M 0179343 UTM 9959102
E	**Mouth Of Nderit**	37M 0178545 UTM 9955417
F	**Nderit**	37M 0178547 UTM 9955546
G	**T Junction**	37M 0174331 UTM 9954329
H	**Block 7**	37M 0173518 UTM 9955446
I	**Lamdiac**	37M 0174145 UTM 9962892
J	**Storm Drain**	37M 0176607 UTM 9966052

Source: Researcher (2019)

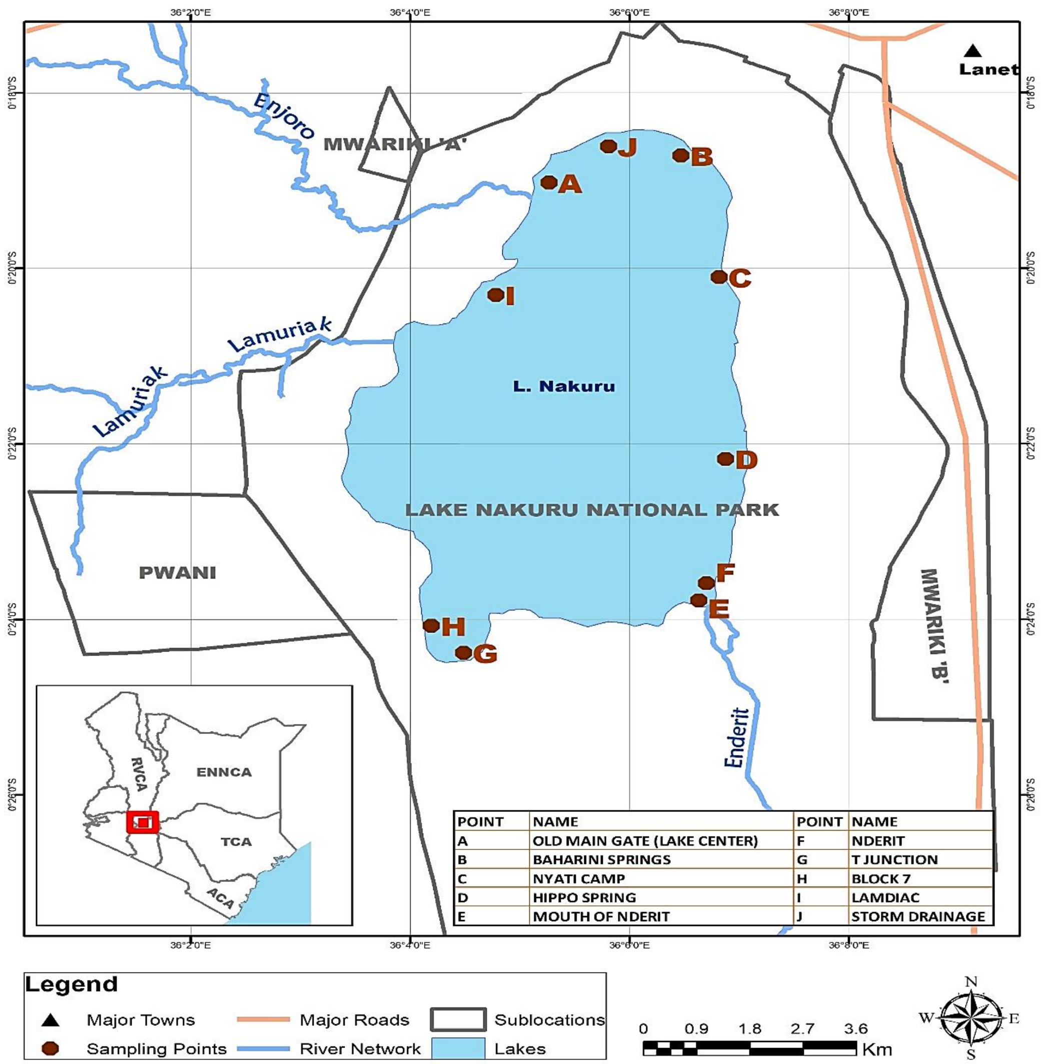


Figure 4-1: Lake Nakuru sampling points

Source: Researcher (2019)

In-situ measurements were taken at each point for temperature, pH, DO and depth of water. Three measurements were taken at each point and the average was taken as the final value. For laboratory analysis, one liter plastic bottles were used to collect samples. In order to ensure that they were representative of the conditions of the lake water, the sampling bottles were rinsed twice with the water prior to collection. At each point, water filled, capped securely and labelled. The sediment samples were collected using a stainless steel scoop and transferred into zip locker bags (Figure 4-3, 4-4). The collected samples were placed in a cooler box, protected from direct sunlight before being transported to the laboratory for analysis (Figure 4-2).

Figure 4-2: Water samples collected for analysis at the laboratory

Source: Researcher (2019)

Figure 4-3: Sediment collection at Baharini Springs

Source: Researcher (2019)

Figure 4-4: Sediment sample

Source: Researcher (2019)

4.5 DATA COLLECTION INSTRUMENTS AND METHODOLOGY

4.5.1 Primary data collection

The study included both primary and secondary data however it mainly relied on primary data collected through field work.

4.5.1.1 *In-situ* measurements and laboratory analysis

For the in-situ measurements of the depth, pH, DO and temperature, a one meter wooden ruler, a WTW Multi 350i pH meter, a H19146 DO meter and a mercuric thermometer were used respectively. The current study employed the American Public Health Association (APHA), (2005) analytical methods for laboratory analysis for the physio-chemical parameters summarized in Table 4-4 below. APHA (2005) is an enhanced version of the methods used previously and is simple, inexpensive, quick and assures the immediate preservation of irreversible reactions.

Table 4-4: Analytical methods used for laboratory analysis

PARAMETER	INSTRUMENT	METHOD
TSS	Vacuum pump, filter disks, funnel	APHA Standard Method 2450D Colorimetric method
TDS	Filtration unit, balance, oven	APHA Standard Method 2540C
ALKALINITY	Titration vessel, magnetic stirrer, volume flask, pipette, burette	APHA Standard Method 2320B Titration method
HEAVY METALS IN WATER	Atomic absorption spectrophotometer	AA5 Direct Air-Acetylene method
HEAVY METALS IN SEDIMENT	Atomic absorption spectrophotometer	APHA Standard Method Direct flame atomic method
NITRATES	Reduction column, spectrophotometer	APHA Standard Method 4500-NO3-E Cadmium reduction method
PHOSPHATES	Autoclate hotplate, spectrophotometer	APHA Standard Method 4500-PE Absorbic acid method
AMMONIA	Spectrophotometer	APHA Standard Method 4500-NH_3-D Phenate method

Source: APHA (2005)

4.5.1.2 Questionnaires

The instruments used for both the surveys were in the form of questionnaires. Questionnaires contain a collection of questions and other prompts for information to be received from the respondents. They have various advantages including its ability to collect data over a large sample. Two different sets of standard questionnaires were used in the study. One for the KWS staff and the other for the households. They included both open-ended and closed-ended questions. Questionnaires were used to collect data on the aspects related to the value of the lake, threats faced by the lake and the conservation measures.

4.5.1.3 Observation sheet and photographs

The researcher employed an observation sheet and photographs to assess any physical changes in Lake Nakuru such as changes in color, smell, clarity, algal blooms or dead aquatic life noticed in the water during fieldwork.

4.5.2 Secondary data collection

Secondary data was obtained from a review of relevant published and unpublished literature including books, journals, online materials, statistics from the government, environmental audit reports of industries, previous projects reports. Relevant official and non-official documents within KWS and NAWASSCO were also examined to obtain information.

4.6 DATA ANALYSIS AND PRESENTATION

The first phase involved quality assurance, in which the researcher categorized, organized and optimized both respondents' questionnaires. The data was subsequently coded in the reference book accompanied by data entry using the Statistical Package for the Social Sciences (SPSS version 23.0) as well as Excel. Many data sets such as personal information, threats to the lake, value of the lake and management were fed into the statistical package. The data was analyzed using descriptive statistics and was further summarized into percentages and frequencies and subsequently in form of charts, tables, figures and graphs.

Advanced analysis was carried out by using inferential statistics to test the null hypothesis. A two tailed t-test was used to test the hypothesis. This test is used to compare if the mean difference in two groups is really significant. Important assumptions made when performing a two tailed t-test include those concerning measurement scale, normal distribution of data, random sampling, sample size adequacy and standard deviation variance equality. Selection of this test was supported by Kothari (2004) who noted that the two tailed t-test was the most appropriate statistical tool for evaluating the significance in difference in means between two groups. It was computed using the formula below.

$$t = \frac{X_1 - X_2 - \Delta}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}}$$

Where: X_1 and X_2 = Means of the two samples, Δ = Hypothesized difference, S_1 and S_2 = Standard deviations of the two samples and n_1 and n_2 = Sample sizes

CHAPTER FIVE: RESULTS AND DISCUSSION

5.1 INTRODUCTION

This chapter focuses on describing and interpreting the research results on which conclusions were drawn. This evaluates the data obtained in the field as well as in the laboratories in detail. It also discusses the outcomes examined in the questionnaires, deliberates the findings and tries to address the research questions the study posed at the outset. This chapter is divided into four segments. It first discusses the socio-demographic features of the respondents according to gender, age, occupation and education. Secondly, it addresses the value of the lake. It then goes on to discuss the existing risks to Lake Nakuru, factors leading to water quality deterioration and possible sources of pollution. It describes the physio-chemical parameters of water and sediment samples. The data gathered from the present study laid the foundation for discussions on correlations and differences with existing literature reviewed and criticized from international, regional and local territories.

5.2 SOCIO-DEMOGRAPHIC CHARACTERISTICS OF THE RESPONDENTS

5.2.1 Household respondents

This section dealt with the respondents' demographic characteristics. This was intended to provide the basis for understanding the households' composition and to assess their age, gender, level of education, occupation and duration of stay at the location. The household respondents consisted of 104 (53%) males and 92 (46%) females in total from all three sub-locations. Majority of the respondents (73%) were from Mwariki A. Of the 196 households in the three sub-locations, 44.9% were between 20 and 29 years of age, 40.3% were between 30 and 39 years of age, 9.7% were between 40 and 49 years of age and only 5.1% were above 50 years of age as indicated in Figure 5-1. Several studies in quantitative literature found that older aged respondents may react and respond with less specificity than younger respondents in a survey or could be more biased by the specific format used for questioning (Andrew and Herzog, 1986). Resultantly, the age groups between 20 and 40 were appropriate to gather information on the lake.

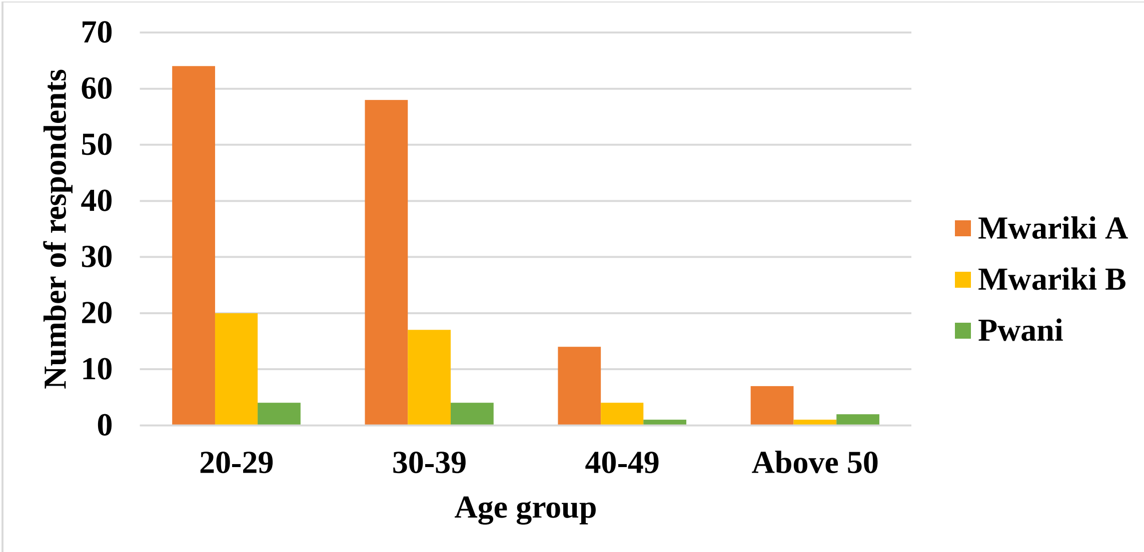


Figure 5-1 Age distribution of household respondents

Source: Researcher (2019)

Majority of the household respondents (51%) had secondary education and only 2% did not attend school (Table 5-1). This means that almost all respondents had a sufficient level of academic education that enabled them to recognize the threats to Lake Nakuru. In addition their level of literacy enabled them to provide valuable information regarding issues of Lake Nakuru.

Table 5-1: Education level of household respondents

Level of education	Frequency	Percent
Primary	38	19.4
Secondary	101	51.5
Tertiary	53	27
None	4	2
Total	196	100

Source: Researcher (2019)

A significant proportion (54%) of the household respondents in Mwariki A had up to secondary level education, a quarter of them attended primary school (25.2%) and only a fifth (20%) of them had attended university or college. However in Mwariki B, more than half (52%) of the households had some form of tertiary education (Figure 5-2).

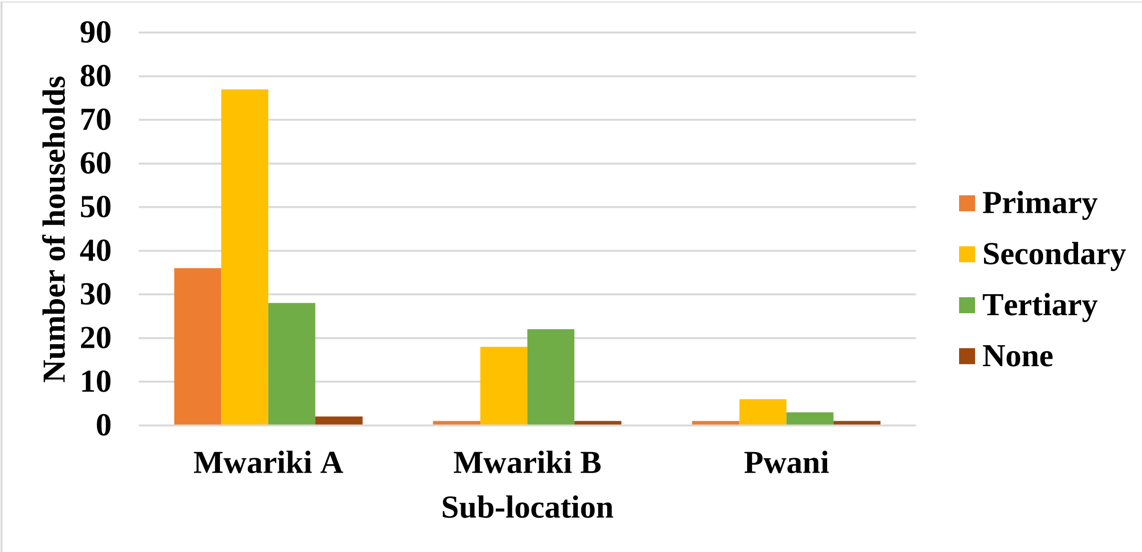


Figure 5-2: Education levels of household respondents at study sites

Source: Researcher (2019)

The study shows that the key occupation of the majority of household respondents (108) was linked to business. A small proportion (10 respondents) were farmers, all of them over 50 years of age. Around 5% of them work as civil servants while the others included students, medical workers, teachers, mechanics, housewives, domestic helps, vegetable vendors, carpenters etc. (Figure 5-3).

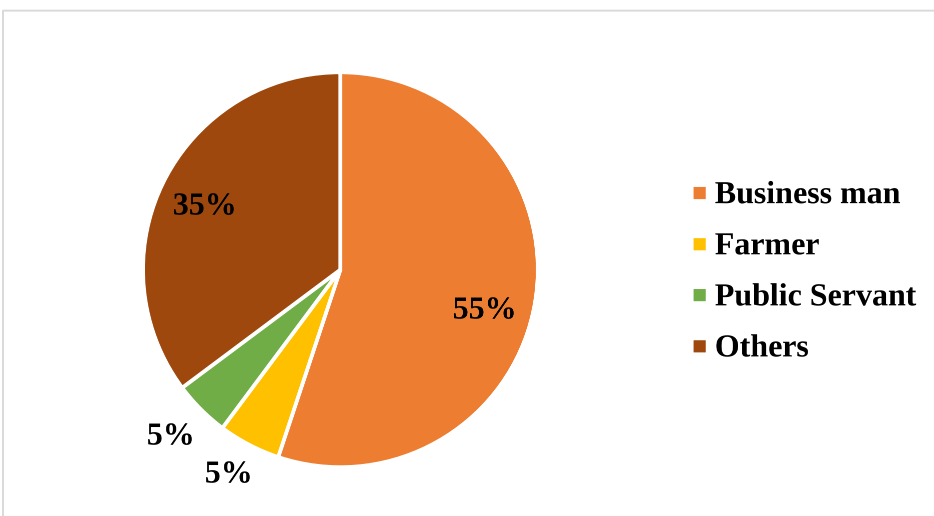


Figure 5-3: Occupation of household respondents

Source: Researcher (2019)

Agriculture is not actually a sustainable profession due to insufficient drainage and irrigation in these communities. Furthermore owing to irregular weather patterns and weak infrastructure in the sampled areas, farming remains unprofitable. This may be one of the factors why most households are working in different sectors other than agriculture.

The study even looked at the length of stay of residences around Lake Nakuru. This was to support additional information on the threats to Lake Nakuru. 44 respondents (22.4%) have been residing around the lake for 0-5 years, 71 respondents (36.2%) for 6-10 years, 46 respondents (23.5%) for 11-20 years and 35 respondents (17.9%) for more than 20 years (Figure 5-4). The high proportion of households who resided in the study area for more than five years (total of 77.6%) made it suitable for this research as it gave assurance that most of the respondents had a vital knowledge for this study because of their long stay in the region.

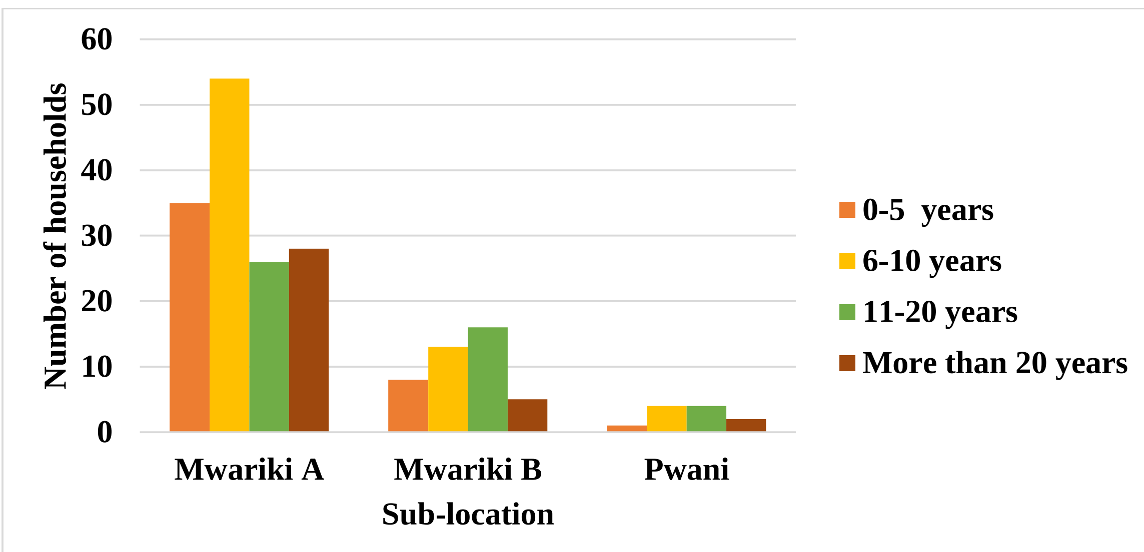


Figure 5-4: Duration of stay of household respondents around Lake Nakuru

Source: Researcher (2019/2020)

5.2.2 KWS respondents

A total of 11 KWS staff respondents were purposively chosen which included five males and six females. For the KWS staff members, there were four categories of education levels which were diploma, bachelors, masters and PhD (Figure 5-5). Around 55 % (six respondents) had a diploma, 36% (four respondents) had a bachelor's degree, one respondent had a master's degree, and no respondent had a doctorate degree.

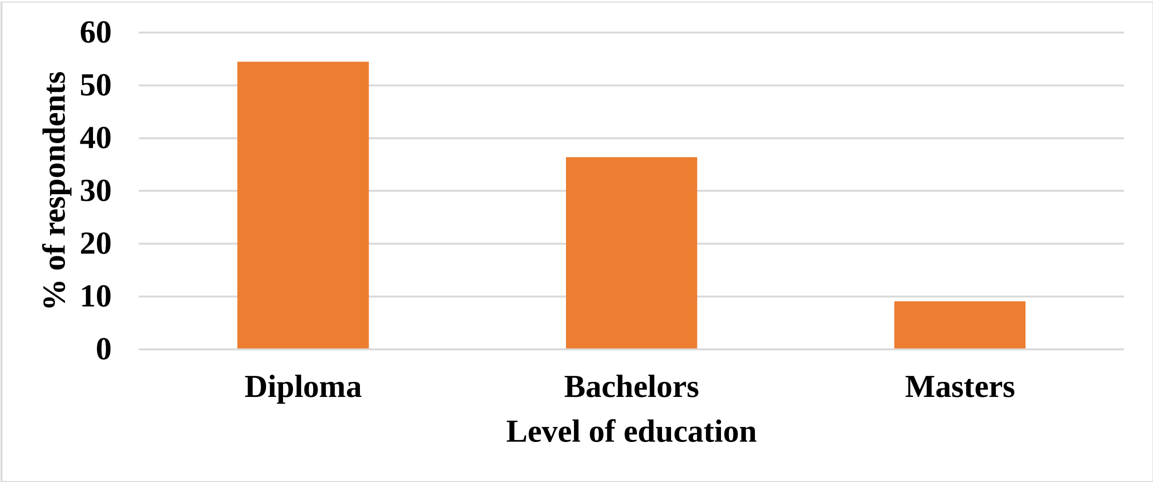


Figure 5-5: Education levels of KWS respondents

Source: Researcher (2019)

Of the 11 respondents interviewed, five were scientists, two were supervisors, three were officials and one was the senior LNNP warden. Majority of them (64%) had been working for KWS for 5-10 years (Figure 5-6). A propensity to work for a longer period, along with procedural complexity, may mean that staffs are more likely to be aware of, or to follow information, be familiar with management policies, and practices.

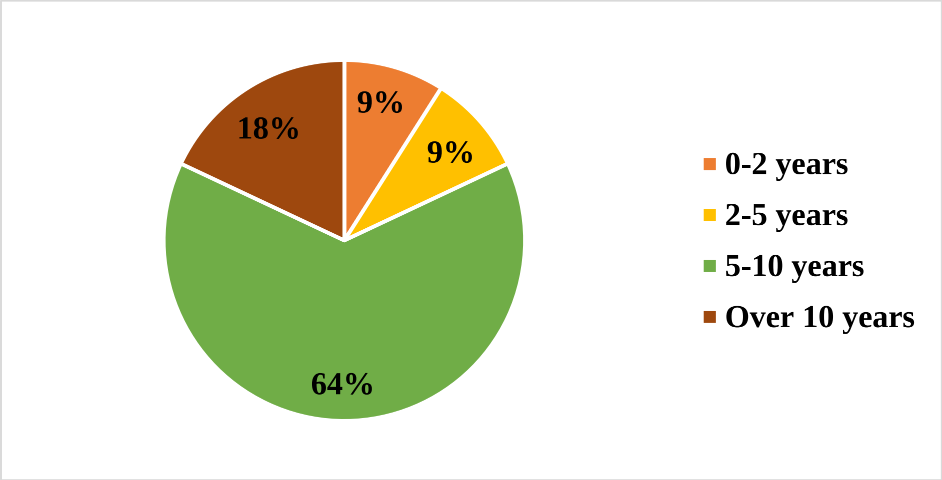


Figure 5-6: Years KWS respondents worked at LNNP

Source: Researcher (2019)

5.3 VALUE OF LAKE NAKURU TO THE RESIDENTS

The researcher sought to determine if Lake Nakuru was of any importance to the respondents. A total of 91% of household respondents indicated that it had a certain value and only 9% felt that the lake had no value for them. They were further asked which functions or roles are valued by them. A huge proportion of the household respondents (75.5%) thought the lake was playing the highest role in tourism and leisure, followed by biodiversity habitat, which were 89 respondents in all. Control of floods and prevention of soil erosion were valued by 25 and 17 household respondents respectively (Figure 5-7).

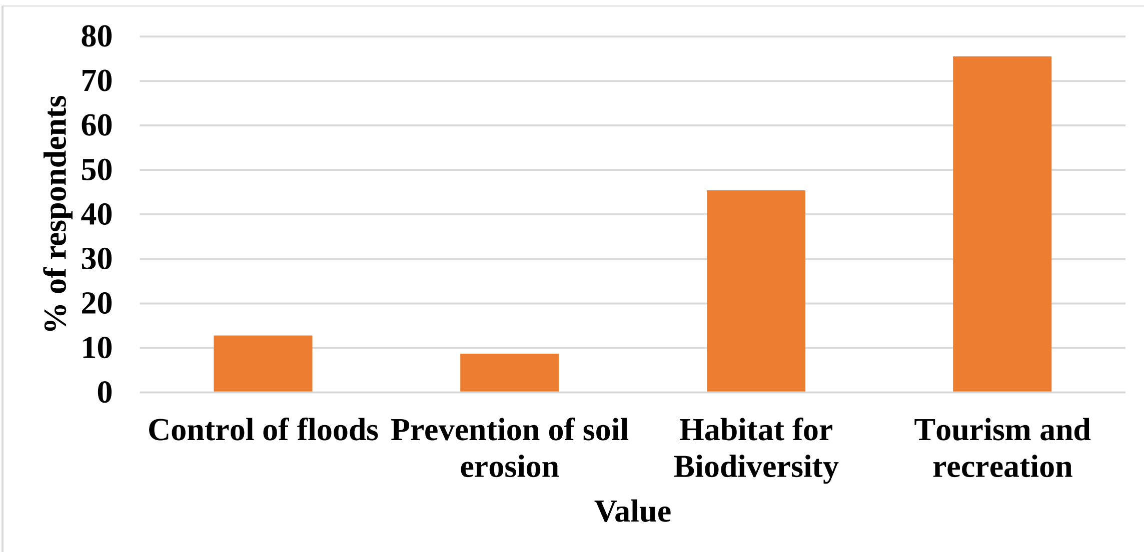


Figure 5-7: Lake Nakuru's value to the residents

Source: Researcher (2019)

Lakes are desirable opportunities for tourism. Worldwide, lakes have been used for recreational tourism, eco-tourism, athletics, and conference and generally attract thousands of tourists. They contribute significantly to the socio-economic development of the region. LNNP is currently by local and international tourists the most visited park. It receives annually almost 200,000 visitors crossing over US$ 4.6 million per year. Visitors explore the lake to see the wildlife attractions particularly the Greater and Lesser Flamingos, the endangered rhinos, mammals and the beautiful landscape. The park has also contributed to the socio-economic development of Nakuru town and its surroundings through tourism growth, restaurants, hotels, curio sales as well as other entrepreneurial activities in addition to generating government revenue (Ariya *et. al.*, 2017).

Tourism's greatest benefit to any local community is that it inevitably generates skilled and unskilled jobs. Souvenir traders, food vendors and supermarkets will of course pop up in the area since they are certain that tourists would need the services.

5.4 THREATS FACING LAKE NAKURU

The respondents were asked to rank the threats facing Lake Nakuru in order of the highest threats. A total of ten threats were identified out of which seven were common between both the respondents (1-9; 1-highest 9-lowest) (Table 5-2). These were industrial, agricultural and sewage pollution, soil erosion and sedimentation, climate change, deforestation and flooding.

Table 5-2: Community and institutional identified threats ranked

THREATS	KWS STAFF	HOUSEHOLDS
Industrial pollution	4	2
Agricultural pollution	6	3
Sewage pollution	1	1
Soil erosion and sedimentation	3	5
Over abstraction of water from feeding river		8
Climate change	5	7
Deforestation	2	6
Drying rivers		9
Flooding of lake	7	4
Invasive species	8	

Source: Researcher (2019)

Sewage pollution was observed to be the greatest threat to the lake by both the household (60.7%) as well as the KWS respondents (70%) (Figure 5-8). Both groups of respondents found industrial pollution, sedimentation and deforestation to be a major threat too. Tourism and overgrazing was not identified as a threat by both the respondents. KWS officials did not recognize over abstraction of water from rivers as a threat whereas the households did not think occurrence of invasive species was a threat to the lake.

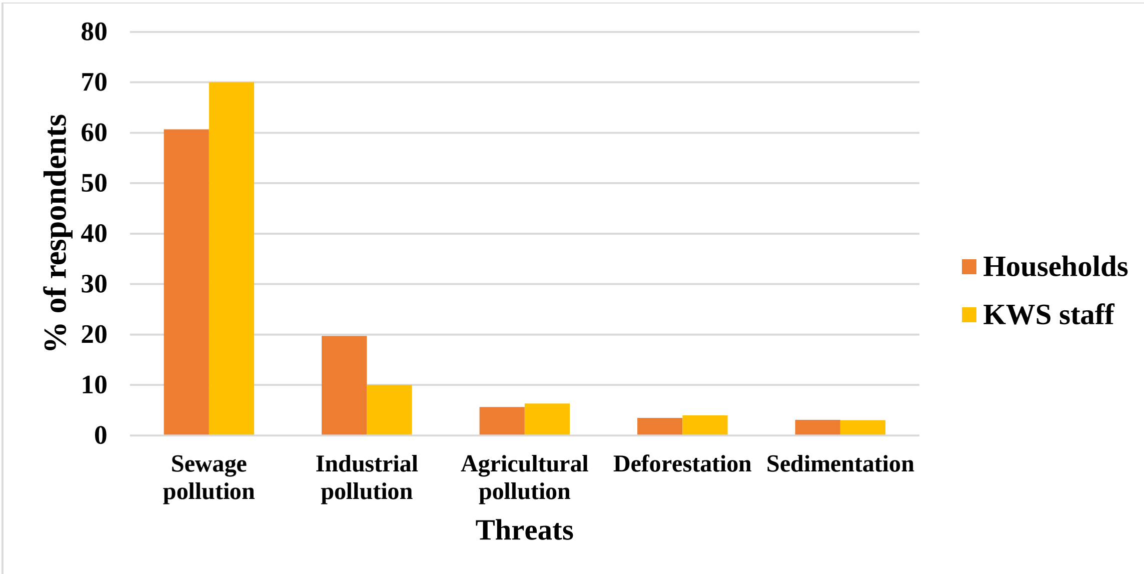


Figure 5-8: Highest threats identified by respondents to the lake

Source: Researcher (2019)

Threats encircling many wetlands emerge from rapid population growth leading to pollution, illegal hunting and deterioration of the ecosystem. The ecosystem rich areas correlate with the growing world population where there is a stronger need for agriculture and settlement which has resulted in land use changes around protected areas like Lake Nakuru that has caused changes in ecological functions and decrease in biodiversity. In their study, Okello and Kiringe (2004) identified ecosystems and management threats in Kenya, and their proliferation around protected areas. The major threats identified during the study were pollution, human encroachment and land use changes, loss of wildlife, tourism and human-wildlife conflicts. The threats are quite similar compared to the current study, but they are more concentrated and accentuated on water pollution.

A similar study conducted in the Ramsar site, Lake Nakuru by Shah (2016), revealed similar results (Table 5-3). A total of fourteen threats were identified. There were eight common threats between the KWS and the household respondents. These were climate change, invasive species, water pollution, community being hostile, poaching, illegal harvesting of wood, over-abstraction of water and deforestation. Deforestation was observed to be the main threat to the lake by both the household respondents and the KWS officers. Both groups of respondents found water pollution to be a major threat also. According to KWS fire was not a threat. Bush meat, trophy, poisoning, population growth and development projects were not considered as threats to the lake by the community respondents.

Table 5-3: Community and institutional identified threats ranked

THREATS	KWS STAFF	HOUSEHOLDS
Climate change	1	7
Invasive species	4	6
Water pollution	5	3
Development Projects	6	
Community being hostile	7	4
Poaching	8	8
Illegal harvesting of wood	9	1
Bush meat	10	
Trophy hunting	11	
Poisoning	12	
Over-abstraction of water	13	9
Fire		5
Population growth	3	
Deforestation	1	1

Source: Shah (2016)

In comparison with the current study, the ranking of the highest threats changed. Water pollution in specific; sewage, industrial and agricultural were identified amongst the highest threats in the present study whereas Shah (2016) identified climate change and illegal harvesting of wood as the top threat. Deforestation was the top threat identified by both respondents by Shah (2016), however in the present study, the households did not rank it amongst the top five threats. Climate change still remains at the same level (not in the top five threats) (Table 5-2, Table 5-3). This may be due to the fact that the households are still to understand the issue and the consequences. Threats such as flooding of the lake, soil erosion and sedimentation were not identified in the previous studies.

5.5 FACTORS CONTRIBUTING TO WATER QUALITY DETERIORATION

Due to the threats, water quality was also being deteriorated. Respondents were asked to give reasons why the water quality was deteriorating. The reasons varied from solid waste, agricultural waste, industrial waste, sewage, soil erosion and sedimentation and storm water runoff. The majority of the respondents (73%) stated that sewage was the main cause of deterioration followed by industrial waste (22.4%) and solid waste (14.3%) (Figure 5-9).

In many developing countries, increase in population requires a serious long term solution in the planning and development of sewage facilities, specifically in urban lake drainage basins such as Lake Nakuru. Just 27% of the population of Nakuru is linked to the sewerage network of the area, emphasizing the need for a safer way of disposing of the high quantities of sewage produced every day. Nakuru's danger to water contamination is significant, as sewage is often deposited into storm drains and waterways, or sunk in small-income areas.

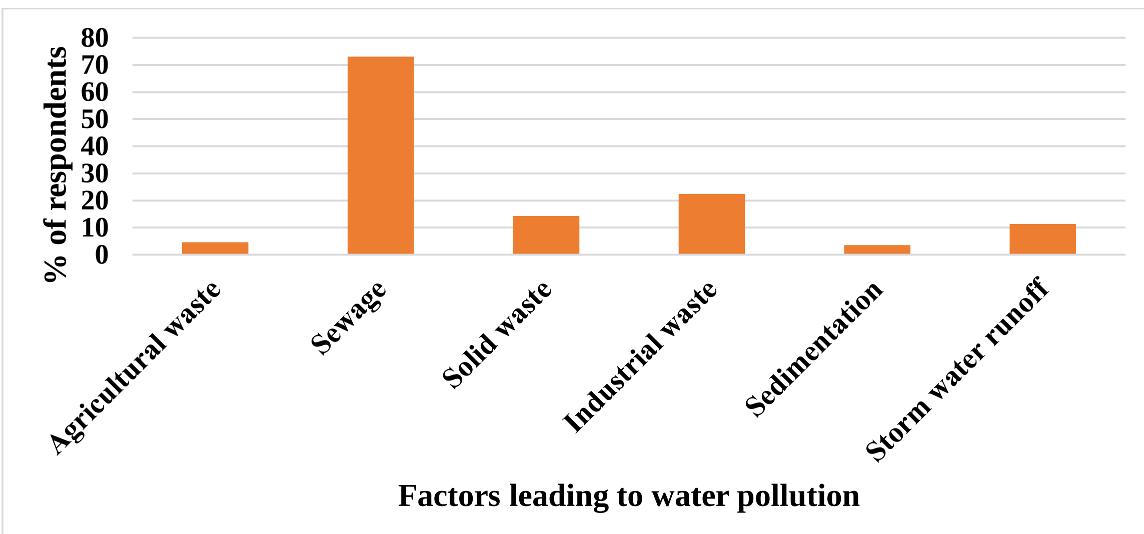


Figure 5-9: Factors contributing to water quality deterioration

Source: Researcher (2019)

An investigation involving Nakuru sewage treatment plant by Ngari *et. al.*, (2011) revealed that the final drainage filter line effluents did not comply with the criteria and standards set for the lake discharge. Effluents were polluted chemically and biologically, with high levels of pathogenic microorganisms that present a major threat to the wetland. The mean Ammonia, Nitrogen and Phosphorus concentrations in the final effluent were also much higher than the environmental emission limits. Studies have reported that wildlife susceptibility to human pathogens has led to higher occurrences of wildlife infectious diseases. About two rhinos and more than 500 buffaloes perished in June 2015 after an anthrax epidemic, all of which was linked with water pollution (Gachohi *et. al.*, 2019).

According to a report by WHO (2014), almost 90% of wastewater from factories in developing countries is released directly into streams, lakes and oceans without any treatment, a factor that contributes significantly to the deterioration of water quality. Industries are amongst the highest sources of pollution worldwide, producing toxins which are incredibly harmful to the environment. Estimated 300 million tons of synthetic chemicals used in industries make their way gradually into surface waters. Nakuru town has roughly 70 industries such as food and milk processing, textiles, chemical processing, pyrethrum, battery, bleaching, tannery and paint manufacturing. Many of these factories are in Njoro such as Njoro canning factory, where untreated or partially treated waste water is discharged into River Njoro that eventually enters LNNP. A study by Muwanga and Barifaijo (2006) revealed that industrial effluents was the major pollutant in Uganda's Lake Victoria Basin.

The rise of the population and the rapid growth in solid waste generation have emerged as one of the most pressing problems; especially in third world countries (Ferronato and Torretta, 2019). The issues can be even more prominent in medium sized towns like Nakuru. Over 250 tons of solid waste is generated daily in Nakuru County, of which at least 540 kg is collected at the LNNP daily (Mwanzia *et. al.,* 2013; Cherono *et. al.,* 2019). During heavy rains and storm, the situation is exacerbated and the solid waste eventually finds its way into the lake. The type of waste ranges from plastic, rubber, glass, wood, leather and tins (Figure 5-13). The findings show a repugnant condition of some areas around the lake, as most of the garbage is spread within and around the lake with little or no proper disposal strategy. Other contributors to the lake's solid waste comprise of tourists activities and lodges within the park. In 2015, a total of 20 tons of solid waste was collected around the lake.

Storm water runoff is a top contributor to pollution in Lake Nakuru. Along with solid waste, storm water carries tons of sediments, nutrients such as Phosphates and Nitrates, pathogens, heavy metals, radioactive waste, domestic effluents and fecal waste. Effluents flowing from the storm water into the lake usually have a low pH around 5-7, making it unfit for the lake and the wildlife. Storm water pollution can lead to deposition of excessive sediment, eutrophication, and toxicity from heavy metals, depleted DO and increased water temperatures. A study by Raini (2005), on the long term trends in water quality and quantity in Lake Nakuru determined that the storm water channel and the sewage channel entering the lake had the highest concentrations of toxic metals such as Titanium, Nickel, Lead, Chromium, Cadmium, Silver, Mercury as well as maximum amount of pesticide concentrations compared to other parts of the lake. The situation after 15 years still remains the same; storm water runoff and sewage are recognized as major pollutants in Lake Nakuru.

Data on the physical changes of Lake Nakuru such as color, oduor, and algal blooms, changes in water quantity and clarity and death of species was obtained by the households as well as through physical observations by the researcher. A total of 33 (16.8%) household respondents observed changes in water color of Lake Nakuru (Figure 5-11). The researcher observed mostly a brownish unpleasant color at the sampling sites (Figure 5-10). Dissolved and suspended particles in water usually have an influence in its color. Increased soil erosion and runoff yields a number of shades like red, brown or even grey. However, the most common cause of water color is the presence of various minerals. Red, brown colors are usually as a result of high concentration of Iron, Manganese as well as organic matter. Intensely colored water, apart from being aesthetically undesirable, restricts the penetration of light which reduces the supply of DO and the production of planktons that support the subsistence of fish and other species in aquatic environments.

A total of 101 (51.5%) household respondents recorded a different smell at Lake Nakuru (Figure 5-11). Oduor contamination is an environmental change factor which has an impact on the well-being of the ecosystem and its surroundings. Wastewater treatment plants, sewage treatment plants, municipal waste landfills, composting, propagation of domestic manure may generate pungent smells (Sakawi *et. al.*, 2013). The researcher also smelled a sewage like and musky smell at some of the sampling points. This could be potentially attributed to the Njoro sewage treatment plant, the old town sewerage as well as toxic waste draining into the lake from the storm drain. Oduor might not cause direct harm to local residents, but intense oduor are hazardous and can contribute to health problems like diarrhea, insomnia, nasal inflammation and asthma.

Figure 5-10: Observations on water color at sampling sites

Source: Researcher (2019)

Only a few (15) household respondents indicated that they had previously observed algal blooms in Lake Nakuru (Figure 5-11). The researcher however did not come across any algal blooms during field work. 34 (17.3%) household respondents recorded changes in water quantity of Lake Nakuru. It has become quite high that a large portion of LNNP is submerged, with in fact a section of the KWS building at the entrance to the park. After 2011, all the lakes in the Rift Valley of Kenya have experienced major rises in water levels, and the volume keeps rising to levels never seen in the past 50 years. The meteorological department stated that the monthly rainfall patterns are pretty normal within the Rift Valley and its catchment areas, while the Ministry of Land, Water and Natural Resources has attributed the rising levels to increased lake siltation due to deterioration of the catchment areas. Empirically, the rise in levels of water could also be purely a result of geographical volcanic activity and tectonic movements that creates convective and tensional pressure and possibly seepage of water. Although the real cause of Lake Nakuru's high water levels may be elusive, the effects on the environment are evident.

A total of eight household respondents had observed dead species in and around the Lake (Figure 5-11). The researcher had observed dead fish species around the shores of Lake Nakuru in particular the Hippo point and Baharini springs. The surface water quality that the researcher observed was foamy at various sampling points around the shore (Figure 5-12). Foam may accumulate when plants decompose in the water and most often develop in waters that are heavy in organic content. However, they may also accumulate as a result from human activities such as waste from textile industries, fertilizers and pesticides (Schilling and Zessner, 2011).

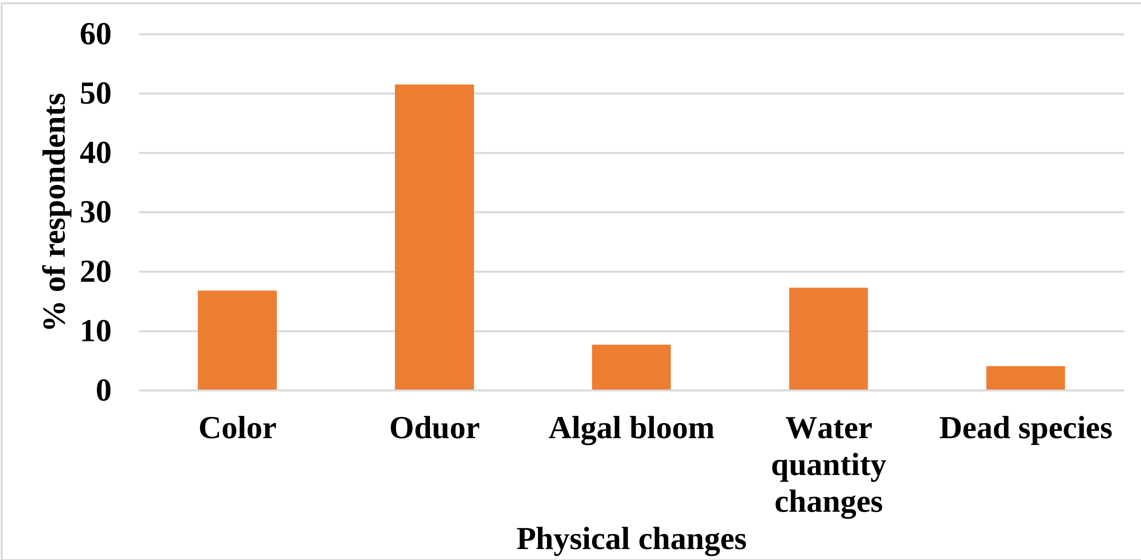


Figure 5-11: Physical observations at Lake Nakuru

Source: Researcher (2019)

The researcher also observed a large number of solid waste deposited around the feeding rivers and the lake (Figure 5-13). In recent years' solid waste and the quality of water have become serious environmental issues, particularly in developing countries. Solid waste is often carried through storm water runoff in urban areas. They are sometimes illegally dumped in urban as well as rural areas directly into a water body or wetland. Majority of the waste present in Lake Nakuru is from the feeding rivers and tourist activities in the park.

Figure 5-12: Surface water quality at sampling sites

Figure 5-13: Solid waste disposal in LNNP

Source: Researcher (2019)

The household respondents also stated why the factors were prevailing. Their reasons ranged from; lack of education and awareness, lack of policies, lack of implementation of policies, limited dumping resources (e.g. poor sewage facilities), lack of man power spot checks, poor attitudes, no fines/ weak fines and corruption (Figure 5-14). The highest factor revealed by the households was lack of dumping resources (64%).

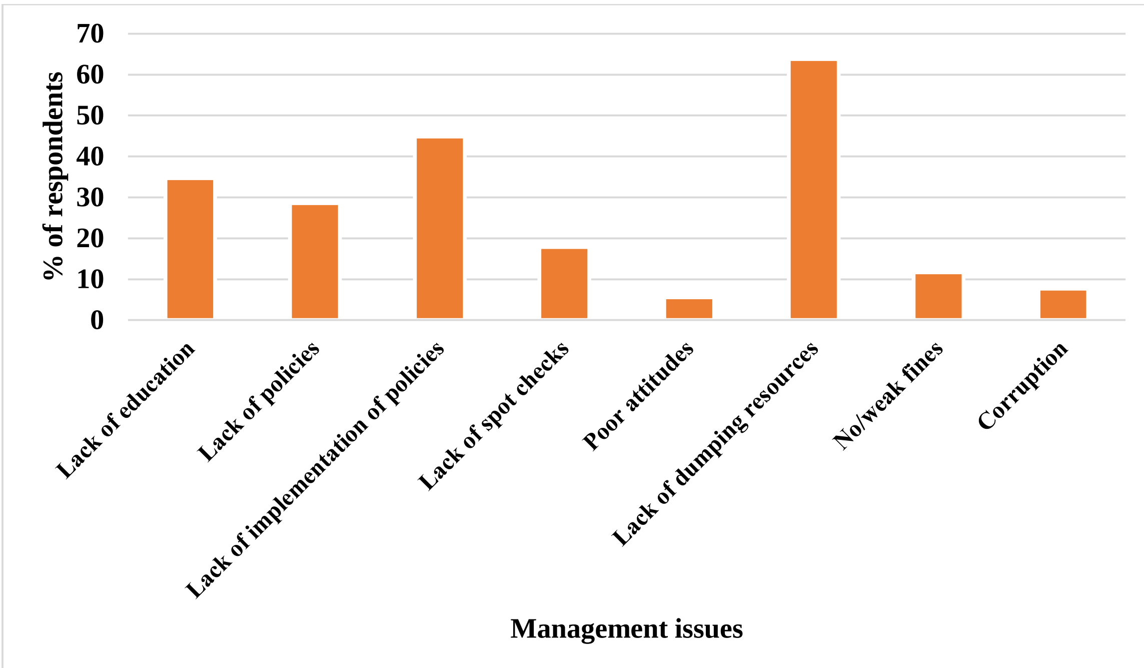


Figure 5-14: Justifications on why factors are prevailing

Source: Researcher (2019)

Upon asking the KWS staff the management constrains of Lake Nakuru, their reasons varied from; less distribution of resources, public/private and internal politics, bureaucracy, unskilled personnel, lack of funds and resources, poor communication to staff, regular transfers of managers, communities around the lake, lack of implementation of policies and extreme pollution. The researcher also attempted to assess if the households were conscious of any laws or policies that dealt with the management of Lake Nakuru management. Out of a total of 196 household respondents, only 47 (24%) were mindful of any laws and policies (Figure 5-15). The respondents who said “yes” were further asked to name the policies or laws they were aware of. The answers ranged from NEMA laws, KWS laws and community laws. The respondents were only aware of the institutions and not any specific law or policy in particular.

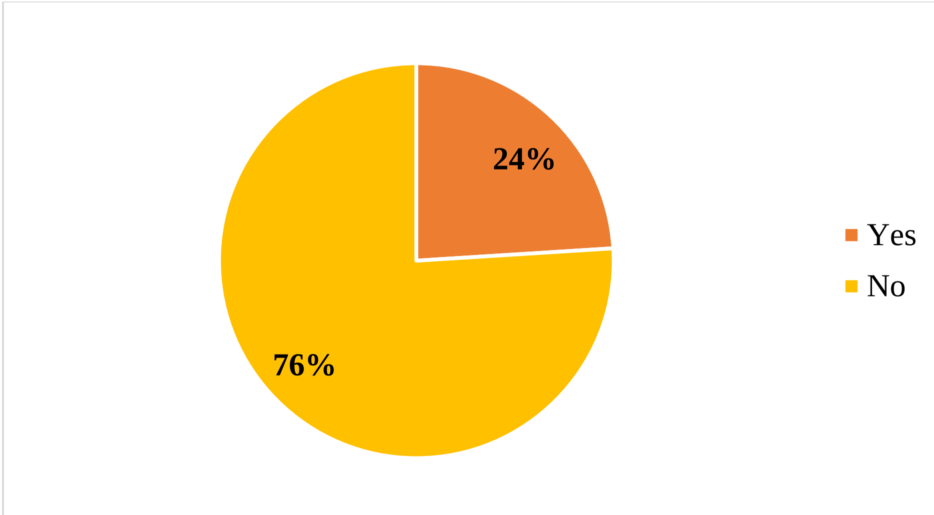


Figure 5-15: Awareness of existing laws and policies

Source: Researcher (2019)

Nakuru town has grown its population dramatically in recent years. Over the past four decades, Nakuru town's population expanded from 47,151 in 1969 to 309,425 in 2009, making it the fourth biggest town in Kenya, with such a factor of six. The increase in population leads directly to an increase in the generation of waste. Issues related to dumping waste are rising, not only due to the rise in waste associated with rapid urbanization, a growing economy, improved standards of living, and changing patterns of consumption, but mostly due to the lack of an effective waste disposal system.

Due to economic difficulties, the allocation of the budget by the national government has still not completely covered the costs necessary for the proper management of waste worsening the situation of the lake. Similar situations have been observed in African lakes such as Lake Jipe, Lake Chala, Lake Victoria Lake Sibaya and Lake Manantali (UNEP, 2006). While considerable attempts have been undertaken in many developing nations during the last few decades, technologically and financially sponsored by international organizations and developed countries, significant changes in the management of waste have not yet been achieved.

Policy development should not be directly linked in with implementation. There are no shortage of policies in Kenya in fact, there is an innovative and sustainable Constitution and a series of recent legislation aimed at making the vision of the Constitution a truth. The main players in the conservation of wetlands, namely KWS, NEMA and WRA, have very well-defined accountabilities and the jurisdiction to conduct them. Policy development, however, implies that resources and funds must also be allocated to meet the objectives and priorities identified by policy makers to implement them. Kenya has decided to embark on a long-term strategy but how the Ramsar Convention central focus indicates; there are no funds for implementing it (Harmsen, 2018).

Among the most general problems are the funds available to carry out fundamental management activities, including environmental regulations. Managers will find a lack of financing counterproductive. Even if the enabling environment facilitates effective governance, a lack of funding implies that various departments and territories are not integrated; resource allocation decisions really aren't taken or made on the basis of insufficient information and technology. Development of whatever local source of funds is available takes significant amount of time, and in poorer countries, national funds are generally in limited supply.

Additional financing is typically used for investment in infrastructure where the national state funding is supplemented. In order for these jointly funded projects to be entirely successful, there must be a transparent understanding between the government and the sponsor on how to implement their respective commitments, and a process to ensure that each party fulfills its commitment. For example, the government of Japan had supported the upgrade of the sewage treatment plant in Nakuru town to tackle any subsequent surge in effluents discharged into the lake. Nevertheless, the results from these projects are not properly understood as the government of Kenya hasn't really completely fulfilled its obligations to finance the requisite infrastructure for reticulation.

In a UNESCO (2012) report, findings identified that the key factor contributing to water body challenges in Africa is the lack of skills and qualified professionals for effective water management, in particular education research, technological and institutional constraints. The consequences of corporations and government lack of action in tackling water pollution are not surprisingly profound public resentment. While citizens have little tolerance for polluting industries, they often have limited grasp of the legal rights, and lack adequate accessibility to key pollution facts to support their arguments. Although the laws and regulations are in existence, without simple initiatives such as social reform mechanisms, consensus buildings and shared goal planning, it does not assure positive outcomes. The very first step to ensuring a successful execution of a management program is to develop and strengthen the administrative, institutional and technical capability of policymakers and government officials (Harmsen, 2018).

From the questionnaire findings, 55% of KWS respondents stated that the enforcement level on pollution control was poor, 27% stated it was satisfactory and 18% stated it was good. Furthermore it was also noted that the institution was not frequent with monitoring the water quality and quantity (a few answered yearly, and the rest stated it was done every 3-6 months). Besides legislation, there is a need for a better monitoring mechanism to improve awareness of the physical, biological and chemical properties of the wetland, its values and a deeper understanding of the dynamics.

Impact assessments play a crucial role in informing about the implications of development projects on water quality. Nevertheless, pressures on water resources also indicate effects on the ecological, social and economic environment, in addition to effects on the physical environment. Consequently, risk assessments on quality of water should also be seen as an integral component of an Environmental Impact Assessment (EIA). Sustainable awareness is a key factor in solving such issues.

Management based on comprehensive knowledge and better awareness of wetland problems affecting all stakeholders and all ecosystem components tends to sustain long-term conservation. Coordination between different sectors is the most critical aspect of good management. Some success stories of such an approach have been proven in Lake Biwa, North American Great Lakes and Urmia Lake. Involving the communities in decisions that will affect them is also very essential. The advantages include improved decision taking, strengthened compliance, often decreased costs, and support for greater group government involvement.

LNNP is a case where there are a large number of stakeholder groups and biophysical work has also been conducted into the lake and its drainage basin water quantity and quality issues. The situation is also characterized as ‘the constraints to lake management are now widely recognized as being mostly social, economic and institutional’. The KWS developed an integrated ecosystem management plan for LNNP and the town council of Nakuru developed a conceptual structural plan for the town. There is, however, no overall strategy for the basin which sets out negotiated resource sharing.

Legislations enforce social values and standards, and are therefore guidelines that regulate social behavior towards each other, or public or private property. Legal knowledge and awareness are important building blocks for meaningful action to address the world's environmental issues for a sustainable future. There are no schemes in the official sector for wetland resources. That has resulted to inadequate law enforcement which has led to inadequate knowledge and awareness of the laws.

5.6 STATUS AND SEASONAL VARIATIONS OF WATER QUALITY IN LAKE NAKURU

5.6.1 Temperature

The study indicated that the temperatures of Lake Nakuru varied from a minimum of 22.00^oC at the storm drain (J) to a maximum of 29.70^oC at the Lamdiac point (I) with an average of 23.81^oC in the wet season. The temperatures slightly varied in the dry season with a minimum of 23.70^oC at the storm drain (J) and a maximum of 33.10^oC at the lake center (A) with an average of 25.93^oC (Table 5-4) Majority of the sampling points were within the EPA limit (25^oC) of aquatic ecosystems in the wet however 70% of the temperatures in the dry season were above the EPA limit.

Water temperature is a crucial factor in quality of water and the hydrodynamic conditions which is anticipated to affect the rates of many ecosystems functions. It is among the variables that influence the composition of aquatic environments as it impedes with the metabolism of the organism, influences the reproduction, accelerates the velocity of the reactions and increases the rate of organic matter degeneration. The primary factors impacting the temperature of the lake's water include weather conditions, river inflows, topography and the temperature of effluents entering the water. Mean temperatures of the surface water increased by almost 3^oC in the dry season. This may be due to multiple factors namely sun exposure/solar radiation, atmospheric heat transfer, confluence of feeding rivers and turbidity. The increased temperatures may also be due to wastewater discharges into the feeding rivers from industries and sewage treatment plants for example around the Baharini Springs (B) situated in close proximity to the mouth of River Njoro.

The high temperatures recorded at the lake center could be possibly as a result of tectonic activities that may be heating up the water.

Table 5-4: Surface water temperatures in wet and dry season

SAMPLING SITE	TEMPERATURE (^{O}C)	
	WET SEASON	DRY SEASON
A	23.40	33.10
B	24.00	26.30
C	22.00	25.60
D	25.30	26.00
E	22.50	25.20
F	23.20	25.00
G	23.00	25.00
H	23.00	26.30
I	29.70	23.70
J	22.00	24.10
Mean	23.81	26.03
EPA limit	25	

Source: Researcher (2019/2020)

The temperatures of Lake Nakuru surface water have generally ranged between 25^{o}C - 27^{o}C and this still hasn't changed much over the last two decades (Vareschi, 1982; Raini, 2009). In comparison with other alkaline lakes in Africa the ranges of Lake Nakuru (23.00^{o}C – 33.10 ^{o}C) are similar to surface water temperatures of Lake Turkana (25^{o}C - 30^{o}C), Lake Chilwa (23^{o}C - 27^{o}C) and Lake Manyara (19 ^{o}C - 35 ^{o}C) (Njaya *et. al*., 2011; Kihwele *et. al.*, 2015; Morrissey *et. al*., 2017). Findings from study conducted by Otieno (2010) in Lake Victoria showed that the temperatures were also significantly higher ($p < 0.01$) in the dry season.

5.6.2 pH

Study findings of the pH from this study are in line with the previous studies. The mean pH was 9.90 with a minimum of 7.60 at the storm drain (J) to a maximum of 10.50 at Nyati camp (C) in the wet season. With similar results in the dry season, the lowest pH value recorded was 7.90 at the storm drain (J) and the highest was 10.20 at Block 7 (H) with an average of 9.70 (Table 5-5). The pH values for majority of the samples were not within the EPA limit for aquatic systems which range from 5 to 9.

Table 5-5: pH values of Lake Nakuru in wet and dry season

SAMPLING SITE	pH	
	WET SEASON	DRY SEASON
A	10.20	10.00
B	10.06	10.06
C	10.50	9.97
D	10.06	8.67
E	10.21	10.05
F	10.22	10.00
G	10.30	10.10
H	10.42	10.20
I	10.38	10.09
J	7.60	7.94
Mean	9.9	9.7
EPA limit	5-9	

Source: Researcher (2019/2020)

As the pH levels disperse from their operating range, wildlife ecosystems can be disrupted and hatching and survival rates reduced. The more the value is outside the optimized range of pH., the relatively high the fatality rate. PH values of approximately 9-10.5 provide the perfect conditions for growth of *Spirulina platen*sise and *Arthospira fusiform*is, types of cyanobacteria consumed by the flamingos. Extreme changes in the pH values along with other factors have previously led to massive flamingo deaths (Kotut *et. al.,* 2010). PH values were the lowest in the storm drain. This could have been possibly as a result of discharge of chemicals used from the nearby areas such as from detergents, fertilizers, chemicals used in printing, solutions used in metal plating, acidic chemicals from textile industries as well as sewerage.

The extreme pH of Lake Nakuru give this lake a fundamental difference of exhibiting a severe chemical and physical environment that appears to interact in defining the existence and structure of organisms' autotrophic assemblages in this aquatic system. The mean pH calculated in Lake Nakuru at eight sites by Raini (2009) was 10.2 ± 0.7. In comparison with this study (9.9) similar mean pH values were also observed in Lonar alkaline lake in India (10) and other East African Alkaline, saline lakes like Elementeita (9.4), Big Momela (10.4), Manyara (10.3) and Reshitani (9.2).

5.6.3 Dissolved Oxygen

The mean DO levels at the sampling sites were 10.58 mg/L and 8.72 mg/L during the wet and dry seasons respectively. The highest levels of DO recorded were at the storm drain with values 13.20 mg/L in the wet season and 10.80 mg/L in the dry season. The lowest value recorded in the wet season was 8.00 mg/L at the Hippo Spring (D) and in the dry season; 6.20 mg/L at the Baharini Springs (B) (Table 5-6). The DO values for most of the samples were within the EPA limit for aquatic systems which range from 9 to 12. The lake had a high DO concentration in the wet season than that of the dry season by around 1.9 mg/L. Oxygen levels are higher in cold water compared to warm water, hence the result of variations in DO concentrations in both seasons. The lower DO values obtained during the wet season at sampling sites D and G may be due to the increase of phytoplankton and the decomposition of organic materials.

Dissolved oxygen in surface water is often used by all aquatic species, so this factor is widely used to estimate the quality of lakes (Diaz and Breitburg, 2009). For ideal wellbeing of aquatic species, a concentration of 5 mg/L of DO is recommended. However, fish species such as the *Sarotherodon alcalicus grahami* in Lake Nakuru, are known to tolerate DO levels as low as 3 mg/L. Though the productivity of *Arthrospira fusiformis* which is a key diet for the Lesser Flamingos significantly decreases at DO levels below 2 mg/L. In August 2004, a massive fish kill emerged in Lake Nakuru due to drastic oxygen depletion.

The Oxygen concentration of water declines when organic materials and nutrients from industrial effluents, sewage discharges, and surface water runoff from land increase. This could be possibly be the reason of Oxygen depletion at the storm drain. A study conducted by Lugomela *et. al.*, (2006) in Lake Momela and Lake Natron found similar mean DO concentrations (9.3 mg/L and

7.8 mg/L respectively) in these alkaline lakes. He ascribed the levels of DO may be affected by the photosynthetic activity, depth, wind action and organic matter decomposition.

Table 5-6: Dissolved Oxygen levels of Lake Nakuru in wet and dry season

SAMPLING SITE	DO (mg/L)	
	WET SEASON	DRY SEASON
A	11.00	10.70
B	10.00	6.20
C	10.20	8.60
D	8.00	7.70
E	12.30	9.80
F	12.10	8.80
G	8.20	6.70
H	10.50	8.70
I	10.30	9.20
J	13.20	10.80
Mean	10.58	8.72
EPA limit	9-12	

Source: Researcher (2019/2020)

5.6.4 Alkalinity

Alkalinity is not really a chemical within water, but instead an attribute that relies on the existence of several other chemicals in water, such as hydroxides, carbonates and bicarbonates. The alkalinity characteristic is its capacity to neutralize acid. In water, therefore, it is essential in that it allows buffering to resist variations in pH. From the results analyzed (Figure 5-16), the maximum alkalinity detected in the wet season was 4000 mg/L at the lake center (A) and Nderit (F) and minimum was 3650 mg/L at the T junction (G) and Block 7 (H). During the dry season however, the highest alkalinity was 4800 mg/L at the Lamdiac shore (J) and the lowest was 2600 mg/L at the Baharini springs (B).

The mean total alkalinity was slightly lower (3745 mg/L) in the dry season compared to the wet season (3850 mg/L) in the present investigation. The low alkalinity at some sampling sites the can be explained by dilutions with fresh water. Above average alkalinity were observed at the storm drain (J) for both the seasons. This could possibly be because of domestic, industrial and agricultural effluents. Many factors could be responsible for the disparity in alkalinity at the different sampling sites in both seasons, such as the variation of geology and soils along the feeding rivers, the flow of the water, weathering and agricultural activities around the lake. This could also explain the highest alkalinity level from both the seasons recorded at the Lamdiac shore (J).

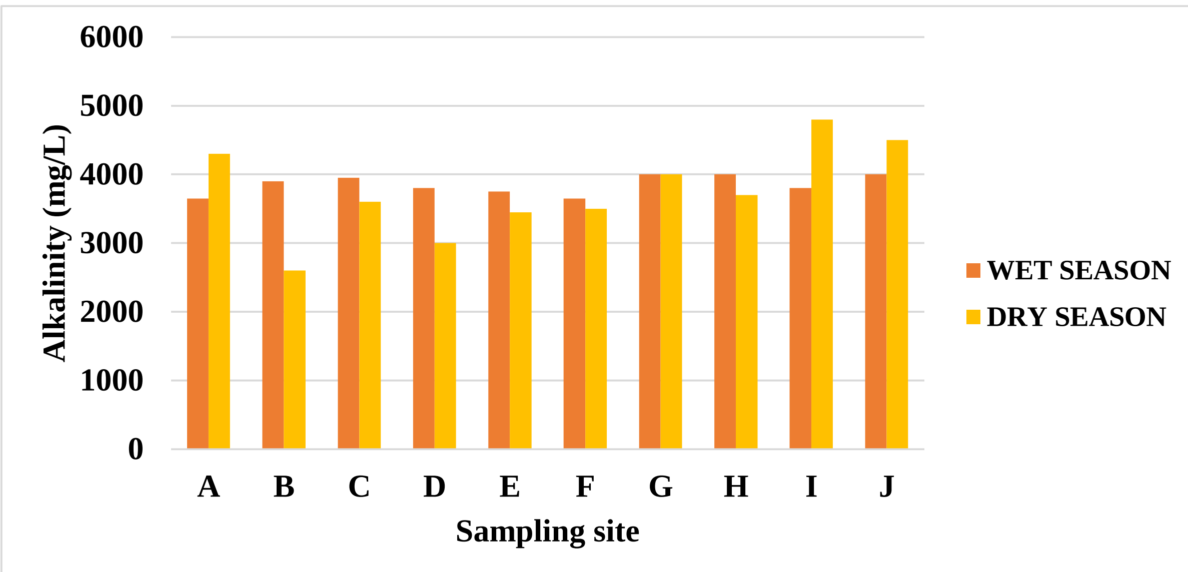


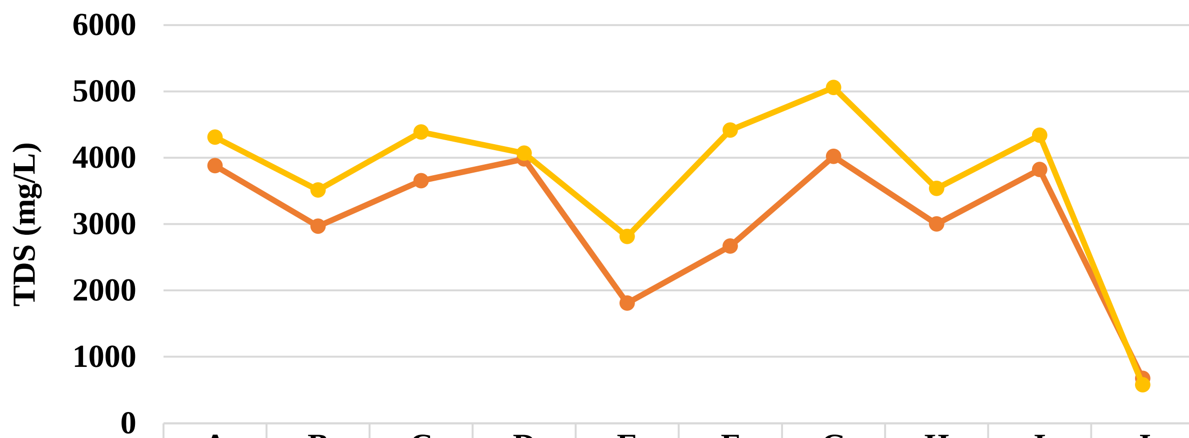
Figure 5-16: Alkalinity levels of Lake Nakuru in wet and dry season

Source: Researcher (2019/2020)

The dilute inflows into East African basins obtain much of its alkalinity via the accelerated hydrolysis of readily weathered rock and lava covering most of the landscape. Acidic water can't fully promote growth of zooplankton, phytoplankton and diterous bacteria, all of which are essential for maintaining a fish-growing in alkaline environments (Kiprutto *et. al.*, 2012). In the case of Lake Nakuru, alkalinity is essential for the growth of the blue-green algae; a key diet for the Lesser Flamingos.

5.6.5 TDS and TSS

TDS is the term that describes inorganic salts and small quantities of organic matter in water solution. They typically constitute of anions of Sodium, Potassium, Calcium, Carbonates, Magnesium, Hydrogen Carbonate, Nitrate, Chloride and Sulfate (Hecky and Kilham, 1973). The measured TDS values ranged from 672 mg/L to 4020 mg/L with an average of 3046 mg/L in the wet season and 578 mg/L to 5055 mg/L with an average of 3700 mg/L in the dry season (Figure 5-17). Apart from the storm drain, all the other sites had very high levels of TDS which were above the EPA recommended limit (1000 mg/L).



	A	B	C	D	E	F	G	H	I	J
WET	3880	2965	3650	3980	1810	2670	4020	3000	3820	672
DRY	4310	3510	4385	4065	2810	4415	5055	3535	4340	578

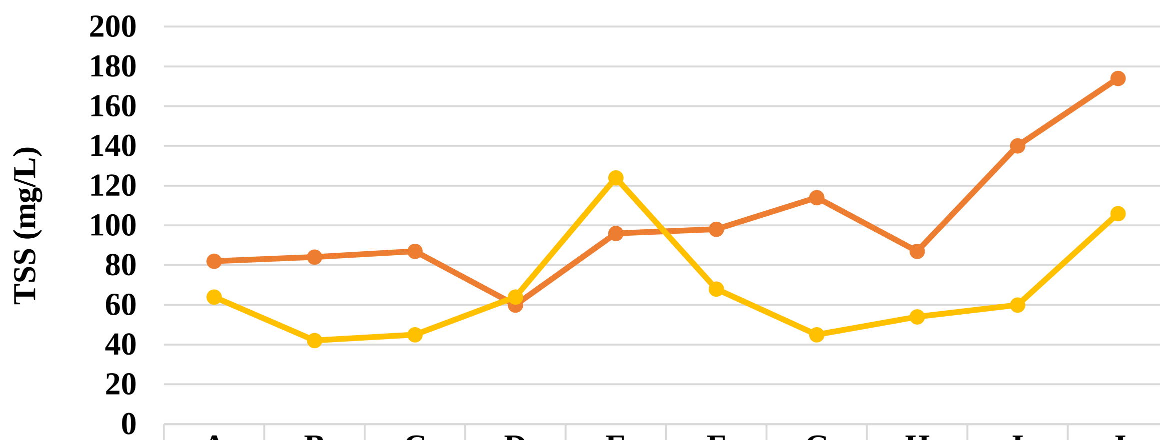
Figure 5-17: TDS concentrations of Lake Nakuru in wet and dry season

Source: Researcher (2019/2020)

The values of TDS concentrations indicate high levels of pollution in Lake Nakuru which are all probably related to pollution through the discharge into the feeding rivers from industrial effluents (textiles, food, paint, oil and battery), municipal wastewater, agricultural runoffs and sewage wastewater. The high TDS can also be attributed to depositional site erosion. Increased TDS amounts can reduce the overall clarity, limit photosynthesis, react with toxic substances and heavy metals, and increase the water temperature. Average TDS concentrations were higher in the dry season than the wet season by approximately 650 mg/L. This might have been due to greater temperatures observed during the hot period that stimulated mechanisms of dissolution, ion exchange, evaporation, and weathering. Similar results for seasonal variations were found in Lake

Manito and Lake Muskiki in Canada whereby the TDS levels were much higher in the dry season compared to the rainy season.

TSS are both inorganic and organic solids that have been suspended in liquid. These comprise sediment, plankton and toxic pollutants which do not pass through filters (Brosett, 1979). The TSS levels recorded at Lake Nakuru in the wet season ranged from 60 mg/L to 174 mg/L and 42 mg/L to 124 mg/L in the dry season (Figure 5-18). Out of the ten sampling sites, nine of them had a TSS value higher than the EPA recommended limit (50 mg/L).



	A	B	C	D	E	F	G	H	I	J
WET	82	84	87	60	96	98	114	87	140	174
DRY	64	42	45	64	124	68	45	54	60	106

Figure 5-18: TSS levels of Lake Nakuru in wet and dry season

Source: Researcher (2019/2020)

The highest TSS levels were present at the mouth of Nderit and the storm drain. This could potentially be as a result of urban runoff, soil erosion, effluent wastewater and sewer systems, decomposing plants and animals, nutrient transport, agricultural practices and construction sites. The measured mean value for the TSS amount was high during the wet season by 35 mg/L. This is most usually related to the massive erosion and storm water loads of particulate matter. As TSS levels rise, water body's starts to lose their ability to sustain diversity of aquatic life. Suspended solids radiate heat from sunlight that increases water temperature and consequently reduces the DO levels. The study area results are consistent with (Ashraf *et. al.*, 2010) who found the level of

TSS in Varsity Lake in Malaysia to be higher than that of the allowable limit as a result of increased anthropogenic activities.

5.6.6 Nutrients

The highest Nitrate value recorded in Lake Nakuru during the wet season was 5.42 mg/L at the storm drain (J), lowest was 0.05 mg/L at the lake center (A), Baharini Springs (B) and the Hippo point (D). In the dry season, the Nitrate values ranged from 0.75 mg/L at the Nyati camp (C) to 3.39 mg/L at the lake center (Table 5-7). All the values within the ten sampling sites for both the months were within EPA limit (50 mg/L) and suitable for the aquatic species.

Table 5-7: Nutrient levels of Lake Nakuru in wet and dry season

Sampling site	NITRATE (mg/L)		PHOSPHATE (mg/L)		AMMONIA (mg/L)	
	WET SEASON	DRY SEASON	WET SEASON	DRY SEASON	WET SEASON	DRY SEASON
A	0.05	3.39	0.35	1.10	0.35	0.96
B	0.05	1.14	1.08	0.11	0.46	0.11
C	0.06	0.75	1.10	1.48	0.55	0.39
D	0.05	1.14	0.54	1.31	0.41	0.36
E	0.62	1.47	0.47	1.70	0.22	1.10
F	0.14	0.75	0.31	1.52	0.09	0.97
G	1.21	1.49	0.59	1.08	0.33	0.56
H	1.10	1.43	0.62	1.62	0.56	0.49
I	3.50	1.05	0.53	1.66	0.11	0.65
J	5.42	1.21	2.33	3.67	7.00	22.10
Mean	1.22	1.38	0.79	1.52	1.01	2.77
EPA limit	50		0.7		0.5	

Source: Researcher (2019/2020)

The study showed Phosphate values ranged from 0.31 mg/L to 3.70 mg/L in the wet season and 0.11 mg/L to 3.67 mg/L in the dry season (Table 5-7). 90% of the values recorded were above the acceptable EPA limit which is 0.7 mg/L. of the lake water in both seasons. The Ammonia levels ranged from 0.09 mg/L to 7.00 mg/L in the wet season and 0.11 mg/L to 22.10 mg/L in the dry season. Of the ten samples in the wet season most were within the permissible limit (0.5 mg/L) however in the dry season, only three were within the permissible limit.

Nitrates usually come in from fertilizers and pesticides, sewage and animal waste to the ecosystem. The maximum of nitrates recorded were at the storm drain indicating high amounts of organic load potentially from Nakuru town. The average Nitrate levels were in reality higher in the dry season. It can be explained by the fact that Nitrates are generally built up in dry seasons and that high Nitrate levels can be detected during the early wet months. That's because the first rains flush out trapped Nitrates into waterways from near-surface soils however as the wet season continues, the levels start to decrease. The low levels of Nitrate in the lake can be interpreted by the assumption that it could have been absorbed during the study period by aquatic plants such as phytoplankton and macrophytes. Nitrate levels in Lake Nakuru have been slightly increasing as seen from the KWS statistics in the last few years; 0.3 mg/L (2012), 0.42 mg/L (2014), 0.5 mg/L (2016), 0.5 mg/L (2017) and 1.3 mg/L (2018).

The maximum concentration of Phosphate and Ammonia was tested at the storm drain in both seasons. Phosphates reach waters via man-made sources like farm waste, sewerage, petrochemical industries, processing of vegetables and fruit, pesticide and fertilizer development, and cleaning products. Adding significant amounts of Phosphates to lakes accelerates the growth of algae and plants, increases eutrophication and depletes the Oxygen in the water (Singh, 2013). The toxic concentrations of Ammonia depend on both pH and temperature. As the pH and temperature increases, toxicity tends to increase. The extreme high Ammonia amounts in the storm drain could be from fertilizers, ineffective septic tanks, waste water treatment plant discharges, animal waste and industrial effluents. Similar situation was observed in Oranga Lake, New Zealand where the Ammonia concentrations were much higher in the storm drain compared to the lake. This was mainly attributed to pollutants from anthropogenic sources such as human, industrial and agricultural waste (Tempero and Hamilton, 2014).

5.7 HEAVY METALS IN SURFACE WATER AND SEDIMENTS IN LAKE NAKURU

The most prominent toxic substances in Lake Nakuru are heavy metals that originate from a variety of sources and are transported into the lake. The concentration of Zinc in the water samples ranged from 0.001 mg/L to 0.09 mg/L with a mean of 0.003 mg/L. The highest concentration was found at the storm drain (J) and the lowest at Nyati camp (C). Of the ten samples, five of them had no concentration of Zinc. All the values of the Zinc of the samples analyzed were within the EPA limit (5.0 mg/L) (Table 5-8).

Lead concentrations ranged from 0.11 mg/L to 0.17 mg/L with an average of 0.13 mg/L. The lowest concentrations were at the T junction (G) and the Nyati camp (C) whereas the highest was at the Nderit (F). All the sampling sites had Lead values above the EPA limit (0.05 mg/L) for aquatic ecosystems. The average Copper concentration was 0.0045 mg/L which was only detected at one sampling point that was within the EPA limit (1.0 mg/L). There was no detection of Copper in 90% of the results analyzed at the ten sampling points (Table 5-8). The concentration of Chromium was present in all ten samples ranging from 0.04 mg/L to 0.08 mg/L with a mean of 0.06 mg/L. out of the ten samples, eight exceeded the EPA limit (0.05 mg/L) of Chromium concentrations on aquatic ecosystems (Table 5-8).

Table 5-8: Heavy metals in surface water at sampling sites

SAMPLING SITE	LEAD (mg/L)	COPPER (mg/L)	CHROMIUM (mg/L)	ZINC (mg/L)
A	0.13	ND	0.07	ND
B	0.12	ND	0.08	ND
C	0.11	ND	0.07	0.01
D	0.13	ND	0.08	ND
E	0.17	ND	0.06	0.04
F	0.14	0.004	0.06	ND
G	0.11	ND	0.07	ND
H	0.16	ND	0.04	0.01
I	0.13	ND	0.06	0.01
J	0.13	ND	0.05	0.09
Mean	0.133	0.004	0.064	0.016
EPA limit	0.05	1.00	0.05	5.00

Source: Researcher (2019/2020)

Lake sediments were examined for heavy metal content, so that the researcher could assess the concentration of heavy metals. Examination of lake sediments can also help to understand pollutant sources within the aquatic environment. Zinc concentration in the sediments averaged between 16.1 mg/kg to 136.57 mg/kg. There was a huge difference in the level of Zinc concentrations across all four sites. The highest level recorded was at the storm drain at a concentration of 136.57 mg/kg. Lead concentration had an average of between 20.33 mg/kg across all sites. There was no huge difference between the four sites apart from a relatively high concentration at the storm drain of 49.71 mg/kg. The lowest concentration of lead was at the Hippo point of 7.41 mg/kg (Figure 5-19).

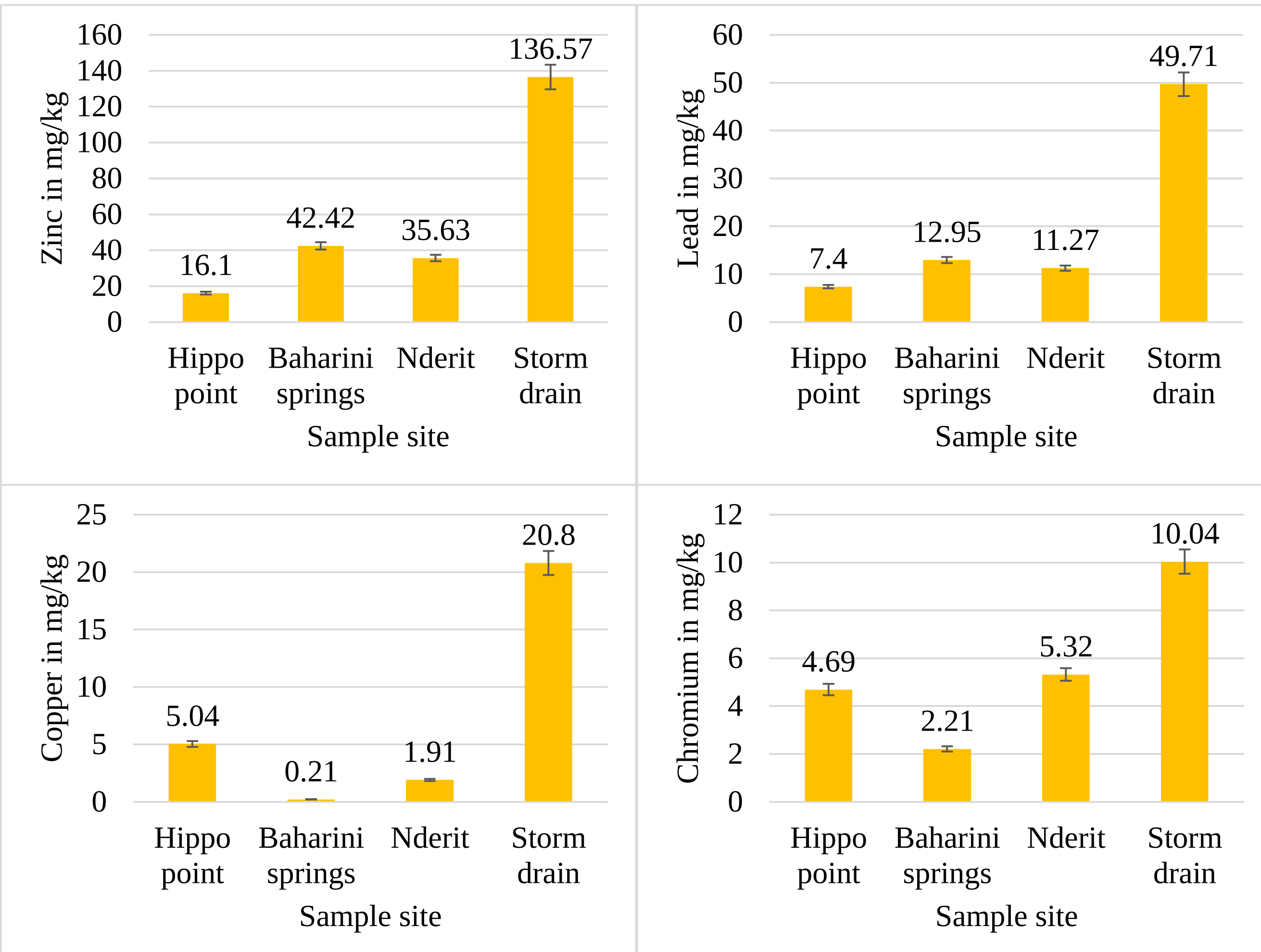


Figure 5-19: Heavy metals in sediments at sampling sites

Source: Researcher (2019/2020)

Analysis of Chromium in the sediment was the highest at the storm drain with a concentration of 10.04 mg/kg and the lowest at Baharini springs at a concentration of 2.21 mg/kg. Concentration of Copper levels highly varied across all four sites ranging from 0.21 mg/kg to 20.80 mg/kg. The maximum concentration of Copper was at the storm drain and minimum at the Baharini springs (Figure 5-19). Presence of Copper and Chromium in the sediments were within the WHO threshold limit; 25 mg/kg and 37.5 mg/kg respectively. Concentration of Lead and Zinc in the sediments were within the WHO threshold limits except for the sediments analyzed at the storm drain (Figure 5-19). Spatial variability in the concentration of heavy metal in the lake sediments could be due to contamination of the sediments from different sources and variations in sources of pollution.

When compared with concentration of heavy metals present in the surface water, the results indicated that the lake sediments had a much higher concentration of heavy metals compared to the surface water (Table 5-9). This could be due to the accumulation and oxidation of heavy metals onto the sediments and leaching of oxides into the soil. Water has some effects of dilution and therefore the presence of low concentration of heavy metals in the surface water samples compare to the sediment samples.

Table 5-9: Comparison of mean concentration of heavy metals in Lake Nakuru surface water and sediments

Heavy metal parameters	Water samples (mg/L)	EPA threshold limit (mg/L)	Lake sediments (mg/kg)	WHO threshold limit (mg/kg)
Zinc	0.031	5	57.68	123
Lead	0.134	0.05	20.34	35.2
Copper	0.004	1	6.99	25
Chromium	0.064	0.05	5.57	37.5

Source: Researcher (2019/2020)

Pollution of heavy metals in the aquatic ecosystem has drawn global attention due to its prevalence, intensity and toxicity towards the ecosystem. Both physical and human activities are liable for plentiful heavy metals in the environment. Anthropogenic activities, however, can easily generate heavy metals in sediments and water which contaminate the aquatic ecosystem. Waters and sediments contaminated act as reservoirs of metals which can trigger lethal or sub lethal effects to the metabolism of macro invertebrates, fish and other greater life forms through the transition of food chains Increased runoff, pesticide and fertilizer leaching, operations such as drainage of untreated chemical effluents and domestic waste results in increased heavy metal concentrations.

Zinc occurs naturally in the soil, but artificially, due to anthropogenic additives, Zinc amounts are rapidly increasing. Concentration of Zinc can be attributed to waste waters from textile industries, fungicides and pesticides, batteries, alloys like bronze and brass, steel combustion, mining activities, printing and dyeing. High Zinc concentrations can have a significant impact on local aquatic environments, accumulating in organisms and poisoning species which eat them afterwards. Many soils are highly Zinc contaminated and are found in regions where Zinc is extracted or processed or where waste sludge from industrial zones has been used as fertilizers. Potential sources of Zinc in Lake Nakuru could be as a result of nearby wastewater of industrial plants.

Lead was detected in all the water and sediment samples. Different environmental conditions, such as temperature, alkalinity, and pH, as well as palmitic and alginic acid concentration affect the absorption and accumulation of Lead by sediments and water (Prosi, 1989). Industries produce about 2.6 million tons of lead worldwide each year. Potential sources of Lead could be from sheathing pigments, batteries, gasoline, plastic stabilizers, and oil and gas pipelines. Lead can also reach water sources primarily from industrial sites, domestic uses, waste disposal facilities, and wastewater treatment plants. High levels of Lead may damage the liver, kidneys, respiratory, reproductive and nervous system, both in aquatic vertebrates and invertebrates (Baby *et. al.,* 2011).

Copper was detected in very small amounts at only one point of the lake water. Even its concentration in the sediments did not exceed the threshold limit. Copper is the world's third most commonly used metal. Quarrying, metallurgy and commercial applications are major environmental sources of access to copper. It is also released in small amounts from insecticides, algaecides and fungicides (Prego *et. al.,* 2013).

The toxicity of Chromium in aquatic ecosystems relies on both microbial and abiotic conditions. Chromium contamination is directly linked to concentrations and temperature, slight change in these factors enhances its toxicity, i.e. it increases with high concentration and temperature, but declines with raised salinity and concentration of sulfates. It can reach the water bodies through sources such as leather and garment production, also through commercial applications like electro coating and chemical development (Oliviera, 2012). Potential sources of Chromium entering Lake Nakuru water and sediments may be as a result of the nearby wastewater from textile industries and sewage treatment plants. These results suggest that the origin of the majority of these metals are from anthropogenic sources in water and sediments.

5.8 HYPOTHESIS TESTING

A two tailed t-test was used to determine if there is any significant difference between the means of the physio-chemical parameters of the lake in the wet and dry season. The parameters that were subjected to the test included temperature, pH, DO, TDS, TSS, alkalinity, Nitrates, Phosphates and Ammonia. All the tests were tested at. 95% confidence level ($\alpha = 0.05$). A higher t-value suggested that the difference between both the group means is larger than the cumulative standard error, implying a greater discrepancy between the groups. Values of $p < 0.05$ showed that there was a significant difference between the mean values in the wet and dry season, thus rejecting the null hypothesis.

5.8.1 Hypothesis testing for seasonal variations in temperature

The current study indicated that the mean surface water temperatures was higher in the dry season. The researcher however undertook a two tailed t-test to determine whether there was a significant difference in temperatures between both the seasons. The following hypothesis was therefore tested:

H_1: There is a significant difference in seasonal mean concentration of surface water temperature

H_o: There is no significant difference in seasonal mean concentration of surface water temperature

Table 5-10: Two tailed t-test for temperature

	Wet season	Dry season
Mean	23.81	25.93
Standard deviation	2.287	2.692
t value	0.63321	
p value	0.03581	

There was a significant difference ($p < 0.05$) in the lake water temperatures in both the seasons. Therefore, rejecting the null hypothesis and adopting the alternative hypothesis, there is a significant difference in seasonal mean concentration of surface water temperature.

5.8.2 Hypothesis testing for seasonal variations in pH

The current study indicated that the mean pH values were higher in the wet season. The researcher however undertook a two tailed t-test to determine whether there was a significant difference in the pH between both the seasons. The following hypothesis was therefore tested:

H_1: There is a significant difference in seasonal mean concentration of pH

H_o: There is no significant difference in seasonal mean concentration of pH

Table 5-11: Two tailed t-test for pH

	Wet season	Dry season
Mean	9.95	9.71
Standard deviation	0.86	0.76
t value	0.66233	
p value	0.51615	

There was no significant difference ($p < 0.05$) in the pH in both the seasons. Therefore, failed to reject the null hypothesis and that there is no significant difference in seasonal mean concentration of pH.

5.8.3 Hypothesis testing for seasonal variations in DO

The current study indicated that the mean DO values were higher in the wet season. The researcher however undertook a two tailed t-test to determine whether there was a significant difference in the DO concentration between both the seasons. The following hypothesis was therefore tested:

H_1: There is a significant difference in seasonal mean concentration of DO

H_o: There is no significant difference in seasonal mean concentration of DO

Table 5-12: Two tailed t-test for DO

	Wet season	Dry season
Mean	10.58	8.72
Standard deviation	1.6731	1.532
t value	2.59235	
p value	0.018393	

There was a significant difference ($p < 0.05$) in the DO values in both the seasons. Therefore, rejecting the null hypothesis and adopting the alternative hypothesis, there is a significant difference in seasonal mean concentration of DO.

5.8.4 Hypothesis testing for seasonal variations in alkalinity

The current study indicated that the mean alkalinity was higher in the wet season. The researcher however undertook a two tailed t-test to determine whether there was a significant difference in the alkalinity between both the seasons. The following hypothesis was therefore tested:

H_1: There is a significant difference in seasonal mean concentration of alkalinity

H_o: There is no significant difference in seasonal mean concentration of alkalinity

Table 5-13: Two tailed t-test for alkalinity

	Wet season	Dry season
Mean	3850	3745
Standard deviation	139	674
t value	0.482	
p value	0.635	

There was no significant difference ($p < 0.05$) in the alkalinity in both the seasons. Therefore, failed to reject the null hypothesis and that there is no significant difference in seasonal mean concentration of alkalinity.

5.8.5 Hypothesis testing for seasonal variations in TDS

The current study indicated that the mean TDS values were higher in the dry season. The researcher however undertook a two tailed t-test to determine whether there was a significant difference in the TDS concentration between both the seasons. The following hypothesis was therefore tested:

H_1: There is a significant difference in seasonal mean concentration of TDS

H_o: There is no significant difference in seasonal mean concentration of TDS

Table 5-14: Two tailed t-test for TDS

	Wet season	**Dry season**
Mean	3046	3700
Standard deviation	1095	1261
t value	1.23696	
p value	0.231997	

There was no significant difference ($p < 0.05$) in the TDS values in both the seasons. Therefore, failed to reject the null hypothesis and that there is no significant difference in seasonal mean concentration of TDS.

5.8.6 Hypothesis testing for seasonal variations in TSS

The current study indicated that the mean TSS values were higher in the wet season. The researcher however undertook a two tailed t-test to determine whether there was a significant difference in the TSS concentration between both the seasons. The following hypothesis was therefore tested:

H_1: There is a significant difference in seasonal mean concentration of TSS

H_o: There is no significant difference in seasonal mean concentration of TSS

Table 5-15: Two tailed t-test for TSS

	Wet season	**Dry season**
Mean	102.2	67.2
Standard deviation	32.93	27.08
t value	2.596	
p value	0.0183	

There was a significant difference ($p < 0.05$) in the TSS values in both the seasons. Therefore, rejecting the null hypothesis and adopting the alternative hypothesis, there is a significant difference in seasonal mean concentration of TSS.

5.8.7 Hypothesis testing for seasonal variations in Nitrates

The current study indicated that the mean Nitrate values were higher in the dry season. The researcher however undertook a two tailed t-test to determine whether there was a significant difference in the Nitrate concentration between both the seasons. The following hypothesis was therefore tested:

H_1: There is a significant difference in seasonal mean concentration of Nitrates

H_o: There is no significant difference in seasonal mean concentration of Nitrates

Table 5-16: Two tailed t-test for Nitrates

	Wet season	Dry season
Mean	1.22	1.38
Standard deviation	1.821	0.753
t value	0.565	
p value	0.579	

There was no significant difference ($p < 0.05$) in the Nitrate values in both the seasons. Therefore, failed to reject the null hypothesis and that there is no significant difference in seasonal mean concentration of Nitrate.

5.8.8 Hypothesis testing for seasonal variations in Phosphates

The current study indicated that the mean Phosphate values were higher in the dry season. The researcher however undertook a two tailed t-test to determine whether there was a significant difference in the Phosphate concentration between both the seasons. The following hypothesis was therefore tested:

H_1: There is a significant difference in seasonal mean concentration of Phosphates

H_o: There is no significant difference in seasonal mean concentration of Phosphates

Table 5-17: Two tailed t-test for Phosphates

	Wet season	Dry season
Mean	0.79	1.52
Standard deviation	0.60	0.89
t value	2.16	
p value	0.045	

There was a significant difference ($p < 0.05$) in the Phosphate values in both the seasons. Therefore, rejecting the null hypothesis and adopting the alternative hypothesis, there is a significant difference in seasonal mean concentration of Phosphate.

5.8.9 Hypothesis testing for seasonal variations in Ammonia

The current study indicated that the mean Ammonia values were higher in the dry season. The researcher however undertook a two tailed t-test to determine whether there was a significant difference in the Ammonia concentration between both the seasons. The following hypothesis was therefore tested:

H_1: There is a significant difference in seasonal mean concentration of Ammonia

H_o: There is no significant difference in seasonal mean concentration of Ammonia

Table 5-18: Two tailed t-test for Ammonia

	Wet season	**Dry season**
Mean	1.01	2.1
Standard deviation	2.77	6.80
t value	0.78	
p value	0.0444	

There was a significant difference ($p < 0.05$) in the Ammonia values in both the seasons. Therefore, rejecting the null hypothesis and adopting the alternative hypothesis, there is a significant difference in seasonal mean concentration of Ammonia.

CHAPTER SIX: SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

6.1 INTRODUCTION

In this chapter, along with a range of conclusions, the most relevant concerns highlighted in the previous chapters have been summed up. Recommendations are addressed, too.

6.2 SUMMARY OF FINDINGS

This section summarizes the results of the study objectives. The research objectives to determine the natural and anthropogenic threats facing the lake; to identify the major sources of water pollution and the factors contributing to water quality deterioration; to evaluate the status of water quality in terms of physio-chemical parameters in Lake Nakuru; to investigate the seasonal variations in the physio-chemical parameters of Lake Nakuru and to assess the levels of toxic heavy metals (Pb, Zn, Cu, and Cr) in the surface water and sediments of Lake Nakuru.

A total of ten threats were identified out of which seven were common between both the respondents. These were industrial, agricultural and sewage pollution, soil erosion and sedimentation, flooding of the lake, deforestation and climate change. Sewage pollution was ranked as the topmost threat by 61% of the households and 70% of the KWS staff members. Tourism and overgrazing was not identified as a threat by both the respondents. KWS members did not recognize over abstraction of water from rivers as a threat whereas the households did not think occurrence of invasive species was a threat to the lake.

The respondents were are asked to give reasons on the causes of water pollution. Their reasons varied from solid waste, agricultural waste, industrial waste, soil erosion, and sedimentation and storm water runoff. Majority of the respondents (73%) stated that discharge of sewage was the main cause of water pollution followed by industrial waste (22.4%) and solid waste (14.3%). Changes in water quantity, dead species, foul smell, algal blooms, and color were observed by the households. Additionally, the researcher also found a significant amount of solid waste deposited across the rivers and the lake. Around 52% of the households recorded a different oduor, 17% observed changes in quantity, 17% changes in water color, 7.7% noticed algal blooms and only 4.1% saw dead species around the lake.

Moreover, the households also stated why these factors were prevailing. Their reasons ranged from lack of education and awareness, lack of policies, lack of implementation of policies, lack of dumping resources, shortage of man power, poor attitudes and weak fines. The highest factor revealed by the households was lack of dumping resources. The researcher attempted to assess whether the households were conscious of any laws and policies that dealt with the management of Lake Nakuru. Out of 196 households, only 46 were mindful of the laws and policies.

Temperatures of the surface water ranged from 22^{o}C to 30^{o}C in the wet season and 24^{o}C to 33^{o}C in the dry season. The pH values ranged from 7.6 to 10.5 in the wet season and 7.9 to 10.2 in the dry season. The mean DO levels were 10.6 mg/L and 8.7 mg/L in the wet and dry season respectively. Alkalinity concentrations ranged from 3650mg/L – 4000 mg/L in the wet season and 2600 mg/L – 4800 mg/L in the dry season. The highest TDS values recorded were 4020 mg/L and 5055 mg/L in the wet and dry season respectively. TSS values ranged from 60 mg/L to 174 mg/L in the wet season and 42-124 mg/L in the dry season. The average Nitrate values were 1.22 mg/L in the wet season and 1.38 mg/L in dry season. Phosphate values had a mean concentration of 0.79 mg/L and 1.52 mg/L in the wet and dry season respectively. From the results, it is seen that the highest level of pollution was in the storm drain, Lake Center, mouth of River Nderit and Lamdiac.

The physio-chemical properties of the surface water varied in both seasons. Average temperature, TDS and Nutrient values were greater in the dry season and alkalinity DO and TSS values were greater in the wet season. Average surface water temperatures increased by 3^{o}C in the dry season. DO concentrations were greater during the wet season by 3 mg/L. Mean TDS levels were higher in the dry season by approximately 650 mg/L. The mean TSS levels were higher by 35 mg/L in the wet season. The nutrients; Nitrates, Phosphates and Ammonia were all greater in the dry season There was a significant difference ($p < 0.05$) in the means of DO, Phosphate, Ammonia and TSS concentrations between both the seasons.

Presence of toxic heavy metals were tested in surface water and sediments. Zinc concentrations were not detected at five points whereas the other five values were detected in very minor values. Lead concentrations ranged from 0.11 mg/L to 0.17mg/L. The average Copper concentration was 0.0045 mg/L which was only detected at one sampling point. Chromium was present in all ten sampling sites ranging from 0.04 mg/L to 0.08 mg/L. In the sediments tested, there was presence of all four heavy metals with the highest concentrations at the storm drain exceeding the recommended limits.

6.3 CONCLUSION

Lakes are perhaps the most spectacular and quaint elements of our global ecosystem, have an abundance of resource assets and are essential elements of the water cycle. They support human livelihoods, provide habitats for plant and animal species, promote economic activities and provide significant aesthetic and religious values. Whilst lakes provide vital goods and services, they sometimes are overlooked or even neglected. Over the decades, several forms of environmental stresses have become apparent. Water pollution in the form of non-point and point sources has rigorously deteriorated the salty lake causing an imbalance of the natural state of the water. Anthropogenic activities including industrial wastes, agrochemicals, soil erosion from overgrazed lands, degraded catchments and infrastructural developments such as road networks and unmanaged storm water from urban centers have highly affected the water quality, quantity and biodiversity of Lake Nakuru Pollution control at Lake Nakuru is essential in order to achieve SWRM as well as to sustain the ecology of the lake. This requires assurance that practices along the feeding rivers and the lake are environmentally sustainable and can still maintain the communities' source of revenue.

6.4 RECOMMENDATIONS

6.4.1 Recommendations targeted for programs and policies

The following recommendations may be suggested on the basis of the results of this study:

- In informal settlements, there are no adequate waste disposal amenities that lead in the direct disposal of unsegregated solid waste into the feeding rivers. There is need for the County Government of Nakuru town to develop and implement an effective solid waste management plan and to upgrade the sewage systems of informal settlements. For areas with insufficient sanitation and sewerage networks, well-built pit latrines should be provided away from the banks of the rivers. This will effectively solve the problem of uncontrolled pollution of raw sewage into the waterways and thus deteriorate the water quality.

- In order to regulate pollution, NEMA can strengthen law enforcement. Legal actions such as prohibition order, compound violations, and strict fines are essential to limit or eradicate the excessive emission of pollutants into the water bodies, thus minimizing their impact. Constant monitoring of the water quality should be carried out within LNNP by KWS and NAWASSCO. Regular and random impact evaluations are needed to check the water discharged from sewage treatment plants are of required standards. Deliberate pollutant monitoring should be conducted at sources of the rivers, the springs, in lake water and sediments. Water quality monitor should be built at each chemical discharge wastewater outlet to confirm that no unauthorized pollutants are released into the river during the day or at night. This should also be enforced in all the lodges inside the park.
- Communities should be educated via training and awareness-raising forums to understand their role in lake management and to learn about alternative steps to ensure sustainable management and use in the region and integration among all applicable interested parties and stakeholders in the lake sector. This can be brought about through environmental education, since it is important to improve, spread awareness and aid communities in protecting the integrity and complexity of nature and insure that use of valuable resources is rational and environmentally sustainable. It allows citizens to acquire understanding of their environment by gaining and sharing information, values, abilities, insights and commitment that will enable them to work collectively to address different environmental issues at their local level. Legal knowledge can be spread through seminars, camps, conferences, and immersive workshops or training programmes on the fundamental laws of the environment. Both the Ministry of Education and KWS must try educating the local population in order to raise awareness of Lake Nakuru conservation.

6.4.2 Recommendations for future research

The following recommendations may be suggested for future research:

- Further research should be carried out on the assessment of the water quality discharged into the feeding rivers and the lake, in particular from sewage treatment plants with more parameters (physical, chemical and biological).

- A comprehensive geological assessment of the lake's catchment should be carried out to identify the cause of the lake water levels rising, that cannot be transcribed from the current hydro-meteorological and land-use evidence only.

REFERENCES

Alcocer. J. and Hammer. U. T., (2008). Saline lake ecosystems of Mexico. *Aquatic Ecosystem Health and Management* 1(3):291-315.

Andrews. F. and Herzog. A., (1986). The quality of survey data as related to age of respondent. *Journal of the American Statistical Association* 81(394):403-410.

APHA., (2005). *Standard methods for the examination of water and waste water* (21st Ed). APHA, Washington.

Ariya. G., Sitati. N. and Wishitemi. B., (2017). Tourists' perceived value of wildlife tourism product at Lake Nakuru National Park, Kenya. *European Journal of Tourism, Hospitality and Recreation* 8(2):147-156.

Ashraf. M., Maah. M. and Yusoff. I., (2010). Water quality characterization of Varsity Lake, University of Malaya, Kuala Lumpur, Malaysia. *E-Journal of Chemistry* 7(1):245-254.

Baby. J., Raj. J., Biby. E., Sankarganesh. P., Jeevitha. M., Ajisha. S. and Rajan, S., (2011). Toxic effect of heavy metals on aquatic environment. *International Journal of Biological and Chemical Sciences* 4(4).

Ballot. A., Kotut. K., Wiegand. C., Metcalf. J., Codd. G. and Pflugmachers. S., (2004). Cyanobacteria and cyanobacterial toxins in three alkaline Rift Valley lakes of Kenya - Lakes Bogoria, Nakuru and Elementaita. *Journal of Plankton Research* 26(8):925-935.

Bhateria. R. and Jain. D., (2016). Water quality assessment of lake water: A review. *Sustainable Water Resources Management* 2(2):161-173.

BirdLife International., (2019). *Important Bird Areas factsheet: Lake Nakuru National Park.* Available at http://www.birdlife.org (Accessed on 24th February 2019).

Boudaghpour. S., (2011). The effect of pollutants dissolved oxygen and temperature change, case study of Ghezel-Ozen River. *Journal of Water Sciences Research* 3(1):27-35.

Bourhane-Eddine. B., Victor. F., Amel. D., Souad. T. and Lotfi. A., (2013). What factors determine trace metal contamination in Lake Tonga (Algeria)?. *Environmental Monitoring and Assessment* 185(12):9905-9915.

Bowman. J. and Sachs. J., (2008). Chemical and physical properties of some saline lakes in Alberta and Saskatchewan. *Saline Systems* 4(1):3.

Brillo. B. B., (2015). The status of Philippine Lake studies: Scholarly deficit on social science studies and on small-lake research. *Asia-Pacific Social Science Review* 15(1):78-101.

Brosset. C., (1979). Factors influencing pH in lake water. *Water, Air, and Soil Pollution* 11(1):57-61.

Carpenter. S. R. and K. L. Cottingham., (1997). Resilience and restoration of lakes. *Conservation Ecology* 1(1).

Carpenter. S., Stanley. E. and Vander Zanden. M., (2011). State of the world's freshwater ecosystems: Physical, chemical, and biological changes. *Annual Review of Environment and Resources* 36(1):75-99.

CBD., (1992). *Convention on Biological Diversity*. CBD, Rio de Janeiro.

Chebet. C., (2019). KWS launches bid to reclaim park's glory. Standard Newspaper, Digital, 27th May 2019.

Cherono. S., Mwangi. M. and Maosi R., (2019). Under threat: Lakes being driven to deathbed by human activities. Nation Newspaper, Digital, 21st May 2019.

CMS/UNEP., (2002). *Convention on the Conservation of Migratory Species of Wild Animals. Report of the First Meeting of Signatory States to the Memorandum of Understanding Concerning Conservation Measures*. UNEP, Bonn, Germany.

Cochran. W. G., (1963). *Sampling techniques* (2nd Ed.). John Wiley and Sons Inc, New York.

Daniels. R. and Bassett. T., (2002). The spaces of conservation and development around Lake Nakuru National Park, Kenya. *The Professional Geographer* 54(4):481-490.

Davidson. N., (2014). How much wetland has the world lost? Long-term and recent trends in global wetland area. *Marine and Freshwater Research* 65(10):934.

Diaz. R. J. and Breitburg. D. L., (2009). The hypoxic environment. *Fish Physiology. Hypoxia* 27(2):24.

Ding. J., Jiang. H., Wu. X., Zhang. S., Mamitiana. R. and Zou. H., (2019). Investigation and assessment of environmental pollution in Gonghu Bay, Taihu Lake, China: A year-long study. *Human and Ecological Risk Assessment: An International Journal* 1-15.

Dokulil. M. T., (2013). Environmental impacts of tourism on lakes. *Eutrophication: Causes, Consequences and Control* 2:81-88.

Dudgeon. D., Arthington. A., Gessner. M., Kawabata. Z., Knowler. D. and Lévêque. C., (2005). Freshwater biodiversity: Importance, threats, status and conservation challenges. *Biological Reviews* 81(2):163.

EPA., (2001). *Parameters of Water Quality: Interpretation and Standards.* EPA, Ireland.

Fayomi. G., Mini. S., Fayomi. O., Owodolu. T., Ayoola. A. and Wusu. O., (2019). A Mini Review on the Impact of Sewage Disposal on Environment and Ecosystem. *Earth and Environmental Science* 331.

Ferronato. N. and Torretta. V., (2019). Waste mismanagement in developing countries: A review of global issues. *International Journal of Environmental Research and Public Health* 16(6):1060.

Gachohi. J., Gakuya. F., Lekolool. I., Osoro. E., Nderitu. L. and Munyua. P., (2019). Temporal and spatial distribution of anthrax outbreaks among Kenyan wildlife, 1999–2017. *Epidemiology and Infection* 147.

Gichuhi. M. W., (2007). Ecological Management of Lake Nakuru Catchment Area. In: Senegupta. M. and Dalwani R. (Ed.): 12th World Lake Conference. *Proceedings of the TAAL 2007, 12th World Lake Conference*, 29 October to 2 November 2007, pp.960-964. Ministry of Environment and Forest, Jaipur, India.

GoK., (1999). *Environmental Management and Coordination Act (EMCA).* Government Printer, Nairobi.

GoK., (2005). *Forest Act.* Government Printer, Nairobi.

GoK., (2006). *National Museums and Heritage Act.* Government Printer, Nairobi.

GoK., (2007). *Lake Bogoria National Reserve Integrated Management Plan 2007 – 2012.* Government Printer, Nairobi.

GoK., (2010a). *Kenyan Lakes System in the Great Rift Valley (Elementaita, Nakuru, Bogoria)*. Government Printer, Nairobi.

GoK., (2010b). *National Constitution of Kenya*. Government Printer, Nairobi.

GoK., (2012a). *Agricultural Act.* Government Printer, Nairobi.

GoK., (2012b). *Fisheries Act.* Government Printer, Nairobi.

GoK., (2012c). *Land Act.* Government Printer, Nairobi.

GoK., (2012d). *The National Wildlife Conservation and Management Policy.* Government Printer, Nairobi.

GoK., (2013a). *Draft Environment Policy.* Government Printer, Nairobi.

GoK., (2013b). *Wildlife Conservation and Management Act*. Government Printer, Nairobi.

GoK., (2014). *Forest Policy*. Government Printer, Nairobi.

GoK., (2015). *Draft National Wetlands Conservation and Management Policy.* Government Printer, Nairobi.

GoK., (2016). *Water Act.* Government Printer, Nairobi.

GoK., (2017). *Draft Environmental Management and Co-ordination (Wetlands, River Banks, Lake Shores and Sea Shore Management) Regulations.* Government Printer, Nairobi.

Gupta. A., (2016). Water pollution- sources, effects and control. *Environmental Earth Sciences* 7(8):4.

Hadwen. W., (2007). Lake tourism: An integrated approach to lacustrine tourism systems. *Annals of Tourism Research* 34(2):555-556.

Hammerle. M., Heimur. T., Maggard. K., Paik. J. and Valdivia. S., (2010). *The Fishing Cluster in Uganda*. Master's Thesis, Harvard Business School, Cambridge, UK.

Harmsen. H., (2018). *Kenyan wetlands: Going, going, gone.* Wangari Maathai Institute for Peace and Environmental Studies Technical Report. Nairobi, Kenya.

Hassan. Z., Shah. J., Kanth. T. and Pandit. A., (2015). Influence of land use/land cover on the water chemistry of Wular Lake in Kashmir Himalaya (India). *Ecological Processes* 4(1).

Hecky. R. and Bugenyi. F., (2017). Hydrology and chemistry of the African Great Lakes and water quality issues: Problems and solutions. *SIL Communications* 23(1):45-54.

Hecky. R. and Kilham. P., (1973). Diatoms in alkaline, saline lakes: Ecology and geochemical implications. *Limnology and Oceanography* 18(1):53-71.

Holas. J. and Hrncir. M., (2002). Integrated watershed approach in controlling point and non-point source pollution within Zelivka drinking water reservoir. *Water Science and Technology* 45(9):293-300.

Hoverman. J. T. and Johnson. P. J., (2012). Ponds and lakes: A journey through the life aquatic. *Nature Education Knowledge* 3(6):17.

ILEC., (2005). *Managing Lakes and their Basins for Sustainable Use*. A report for Lake Basin managers and stakeholders. ILEC, Japan.

IUCN., (2014). *Kenya Lake System in the Great Rift Valley*. IUCN, Nairobi, Kenya.

IWMI., (2014). *Wetlands and People.* IWMI, Colombo, Sri Lanka.

Jackson. R. A. and Kulecho. A., (2008). Lake Nakuru-Kenya: A review of environmental impacts of land use changes. *Proceedings of the TAAL 2007: The 12th World Lake Conference*, *1*, 2241-2245.

Jenkins. M., McCord. S. and Edebe. J., (2009). Sustaining lake levels in Lake Nakuru, Kenya: Development of a water balance model for decision making. *Sustainable Management of Rural Watersheds* 1(1):67-77.

Jirsa. F., Gruber. M., Stojanovic. A., Omondi. O. S., Mader. D., Körner. W. and Schagerl. M., (2013). Major and trace element geochemistry of Lake Bogoria and Lake Nakuru, Kenya, during extreme drought. *Chemie der Erde*, 73:275-282.

Kamau. J., Gachanja. A., Ngila. C., Kazungu. J. and Zhai. M., (2008). Anthropogenic and seasonal influences on the dynamics of selected heavy metals in Lake Naivasha, Kenya. *Lakes & Reservoirs: Research & Management*, 13(2):145-154.

Karimian. T. A., Pimentel. N., Jahandari. A. and Wang. G., (2018). Mineralogy, composition and heavy metals' concentration, distribution and source identification of surface sediments from the saline Maharlou Lake (Fars Province, Iran). *Environmental Earth Sciences* 77(19):4.

Khmelenina. V., Shchukin. V., Reshetnikov. A., Mustakhimov. I., Suzina. N., Eshinimaev. B. and Trotsenko. Y., (2010). Structural and functional features of methanotrophs from hypersaline and alkaline lakes. *Microbiology* 79(4):472-482.

Kihwele. E., Lugomela. C., Howell. K and Emmanue. H., (2015). Spatial and temporal variations in the abundance and diversity of phytoplankton in Lake Manyara, Tanzania. *International Journal of Innovative Studies in Aquatic Biology and Fisheries* 1:1-14.

Kiprutto. N., Munyao. C., Ngoriarita. J., Kangogo. M. and Kiage. E., (2012). Tracing the possible root causes for fleeing flamingos in Kenya's Lake Nakuru National Park. *Journal of Natural Sciences Research* 2(10):23-28.

KNBS., (2009). *Kenya National Bureau of Statistics*. Government Printer, Nairobi.

KNBS., (2015). *Nakuru County Statistical Abstract*. Government Printer, Nairobi.

Kooi. B. W., Bontje. D. and Liebig. M., (2008) Model analysis of a simple aquatic ecosystems with sub lethal toxic effects. *Mathematical Biosciences & Engineering* 5(4):771-787.

Kothari. C., (2004). *Research Methodology: An Introduction*. New Age International Publishers Ltd, Delhi.

Kotut. K. and Krienitz. L., (2010). Fluctuating algal food populations and the occurrence of lesser flamingos (*phoeniconaias minor*) in three Kenyan Rift Valley Lakes. *Journal of Psychology* 46:1088–1096.

Kraus. D., (2018). *One of the world's most threatened lakes is in Canada, and we can save it*. Available at https://www.huffingtonpost.ca/the-nature-conservancy-of-canada/one-of-the-worlds-most-threatened-lakes-is-in-canada-and-we-can-save-it_a_23391839/. (Accessed on 5th July 2019).

Kulecho. A. and Muhandiko. V., (2005). Water quality trends and input loads to Lake Nakuru, Kenya. In: Odada. E. O., Olago. D. O., Ochola. W., Ntiba. M., Wandiga. S., Gichuki. N. and Oyieke. H. *Proceedings of the 11th World Lakes Conference*, 31st October to 4th November 2005, Nairobi, Kenya, pp.529-533. ILEC, Nairobi, Kenya.

KWS., (2004). *Eco-tourism Potential and Development within Lake Nakuru National Park and its Catchment*. KWS, Nairobi, Kenya.

Larsen. S., Andersen. T. and Hessen. D., (2011). Climate change predicted to cause severe increase of organic carbon in lakes. *Global Change Biology* 17(2):1186-1192.

Lugomela. C., Pratap. H. and Mgaya. Y., (2006). Cyanobacteria blooms-a possible cause of mass mortality of Lesser Flamingos in Lake Manyara and Lake Big Momela, Tanzania. *Harmful Algae* 5(5):534-541.

Macharia. J. M., Thenya. T. and Ndiritu. G. G., (2010). Management of highland wetlands in central Kenya: the importance of community education, awareness and eco-tourism in biodiversity conservation. *Biodiversity* 11(1-2):85-90.

Mahaney. W., Wardrop. D. and Brooks. R., (2005). Impacts of sedimentation and nitrogen enrichment on wetland plant community development. *Plant Ecology* 175(2):227-243.

MEMR., (2012). *Kenya Wetlands Atlas*. MEMR, Nairobi, Kenya.

Messager. M., Lehner. B., Grill. G., Nedeva. I. and Schmitt. O., (2016). Estimating the volume and age of water stored in global lakes using a geo-statistical approach. *Nature Communications 7*(1):1-11.

MoALF., (2016). *Climate Risk Profile for Nakuru. Kenya County Climate Risk Profile Series.* MoALF, Nairobi, Kenya.

Morrissey. A., Scholz. C. and Russell. J., (2017). Late Quaternary TEX86 paleotemperatures from the world's largest desert lake, Lake Turkana, Kenya. *Journal of Paleolimnology* 59(1):103-117.

Mutangah. J., (1994). The vegetation of Lake Nakuru National Park, Kenya: a synopsis of the vegetation types with annotated species list. *Journal of East African Natural History* 83(1):71-96.

Mutuku. C., Okemo. P. and Hamadi. B., (2014). Metal pollutants distribution within Lake Victoria basin and their influence on the native and transient microbial flora. *Agricultural and Biological Science* 9(4):127-133.

Muwanga. A. and Barifaijo. E., (2006). Impact of industrial activities on heavy metal loading and their physico-chemical effects on wetlands of the Lake Victoria basin (Uganda). *African Journal of Science and Technology* 7(1):51-63.

Mwanzia. P., Kimani. S. and Stevens L., (2013). Integrated solid waste management: Decentralized service delivery case study of Nakuru municipality, Kenya. *Paper presented at 36th WEDC International Conference.* Nakuru, Kenya.

NAWASSCO., (2015). Available at http://nakuruwater.co.ke/?q=content/waste-water-treatment. (Accessed on 20th March 2019).

Ndetei. R. and Muhandiki. V., (2004). Mortalities of lesser flamingos in Kenyan Rift Valley saline lakes and the implications for sustainable management of the lakes. *Lakes & Reservoirs,* 10:51–58.

NEMA., (2018). *Lake Ol Bolossat declared as a Wetland protected area.* NEMA, Nairobi, Kenya.

Ngari. J., Kotut. K. and Okemo. P., (2011). Potential threat to wildlife posed by enteric pathogens from Nakuru sewage treatment plant. *African Health Sciences* 18(1):85-95.

Ngecu. W. and Nyambok. I., (2000). Ground subsidence and its socio-economic implications on the population: A case study of the Nakuru area in Central Rift Valley, Kenya. *Environmental Geology* 39(6):567-574.

Ngodhe. S. O., Nyamai. D. and Owato. G., (2016). Detecting changes, causes and future prospects of Kenyan wetlands and their conservation. *International Journal of Fisheries and Aquatic Studies* 4(5):24-29.

Njaya. F., Snyder. K., Jamu. D., Wilson. J., Howard-Williams. C., Allison. E. and Andrew. N., (2011). The natural history and fisheries ecology of Lake Chilwa, southern Malawi. *Journal of Great Lakes Research* 37:15-25.

Njiru. J., Waithaka. E. and Aloo. P., (2017). An overview of the current status of Lake Naivasha Fishery: Challenges and management strategies. *The Open Fish Science Journal* 10(1):1-11.

Nyarumbu. T. and Magadza. C., (2016). Using the Planning and Management Model of Lakes and Reservoirs (PAMOLARE) as a tool for planning the rehabilitation of Lake Chivero, Zimbabwe. *Environmental Nanotechnology, Monitoring & Management* 5:1-12.

Ochuka. M., Ikporukpo. C., Ogendi. G. and Mijinyawa. J., (2019). Temporal Variations in Nutrients Loading in Lake Baringo Basin, Kenya. *SDRP Journal of Earth Sciences & Environmental Studies* 4(4):668-680.

Odada. E. O., Raini. J., & Ndetei. R. (2006). Lake Nakuru: Experience and lessons learned brief. *Lake Basin Management Initiative* 299-321.

Odote. C., Ochieng. B. and Makoloo. M., (2007). The Implications of Property Rights for Sustainable Management of Wetlands in Kenya. *Paper presented at 12th Biennial Conference of the International Association for the Study of Commons: Governing shared resources: connecting local experience to global challenges*, University of Gloucestershire, Cheltenham, England.

Oguttu. H., Bugenyi. F., Leuenberger. H., Wolf. M. and Bachofen. R., (2008). Pollution menacing Lake Victoria: Quantification of point sources around Jinja Town, Uganda. *Water SA* 34(1):89-98.

Okello. M. M. and Kiringe. J. W., (2004). Threats to biodiversity and the implications in protected and adjacent dispersal areas of Kenya. *Journal for Sustainable Tourism* 12(1):55-69.

Oketch. M., (2006). The potential role of constructed wetlands in protection and sustainable management of lake catchments in Kenya. 11th World Lakes Conference. *Proceedings Volume II of the 11th World Lakes Conference,* 31 October to 4 November 2005, ILEC, Nairobi, Kenya, pp.41-46.

Oliveira. H., (2012). Chromium as an environmental pollutant: Insights on induced plant toxicity. *Journal of Botany* 2(2):1-8.

Oswald. C. J. and Rouse. W. R., (2004). Thermal characteristics and energy balance of various size Canadian Shield Lakes in the Mackenzie River Basin. *Hydrometeorology* 5(1):129-144.

Otieno. O. S., (2010). *Physio-chemical and bacteriological quality of water from five rural catchment areas of Lake Victoria basin in Kenya*. Master's Thesis, University of Nairobi, Nairobi, Kenya.

Ouma. H. and Mwamburi. J., (2014). Spatial variations in nutrients and other physicochemical variables in the topographically closed Lake Baringo freshwater basin (Kenya). *Lakes & Reservoirs: Research & Management* 19(1):11-23.

Peterson. C. and Gustin. M., (2008). Mercury in the air, water and biota at the Great Salt Lake (Utah, USA). *Science of the Total Environment* 405(1-3):255-268.

Prasad. B., Srinivasu. P., Varma. P., Raman. A. and Ray. S., (2014). Dynamics of dissolved oxygen in relation to saturation and health of an aquatic body: A case for Chilka Lagoon, India. *Journal of Ecosystems* 1-17.

Prego. R., García. A. and Bernárdez. P., (2013). Copper in Galician ria sediments: Natural levels and harbour contamination. *Scientia Marina* 77(1):91-99.

Prestigiacomo. A., Effler. S., O'Donnell. D., Hassett. J., Michalenko. E., Lee. Z. and Weidemann. A., (2007). Turbidity and suspended solids levels and loads in a sediment enriched stream: Implications for impacted lotic and lentic ecosystems. *Lake and Reservoir Management* 23(3):231-244.

Prosi. F., (1989). Factors controlling biological availability and toxic effects of lead in aquatic organisms. *Science of the Total Environment* 79(2):157-169.

Raini. J. A., (2005). Long-term trends in water quality, water quantity and biodiversity at Lake Nakuru, Kenya. *Lake Basin Management Initiative* 57-59.

Raini. J. A., (2009). Impact of land use changes on water resources and biodiversity of Lake Nakuru catchment basin, Kenya. *African Journal of Ecology* 47(Supplementary 1):39-45.

Råman Vinnå. L., Wüest. A. and Bouffard. D., (2017). Physical effects of thermal pollution in lakes. *Water Resources Research* 53(5):.3968-3987.

Ramsar Convention Secretariat., (2004). *The Ramsar Convention Manual: a Guide to the Convention on Wetlands (Ramsar, Iran, 1971)*. Ramsar Convention Secretariat, Gland, Switzerland.

Ramsar Convention Secretariat., (2012). *A Ramsar Case Study on Tourism and Wetlands.* Wetland Tourism: Kenya – Lake Nakuru. Ramsar Convention Secretariat, Nairobi, Kenya.

Ramsar Convention Secretariat., (2015). *National Report on the Implementation of the Ramsar Convention on Wetlands*. Ramsar Convention Secretariat, Gland, Switzerland.

Ramsar Convention Secretariat., (2016). *An Introduction to the Convention on Wetlands.* Ramsar Convention Secretariat, Gland, Switzerland.

Ramsar Convention Secretariat., (2019). *The List of Wetlands of International Importance*. Ramsar Convention Secretariat, Gland, Switzerland.

Ramsar., (1971). Convention on Wetlands of International Importance especially as the Waterfowl Habitat. *Paper presented at International Conference on the Conservation of Wetlands and Waterfowl,* 30 January- 3 February 1971, Ramsar, Iran.

Rossi. L., Fankhauser. R. and Chèvre. N., (2006). Water quality criteria for total suspended solids (TSS) in urban wet-weather discharges. *Water Science and Technology* 54(6-7): 355-362.

Sakawi. Z., Ismail. L., Ariffin. M. and Abdulla. N., (2013). Odour pollution measurement from refuse derive fuel operations using odour concentration meter (OCM) XP-329. *Current World Environment Journal* 8(1).

Scheren. P., Zanting. H. and Lemmens. A., (2000). Estimation of water pollution sources in Lake Victoria, East Africa: Application and elaboration of the rapid assessment methodology. *Journal of Environmental Management* 58(4):235-248.

Schilling. K. and Zessner. M., (2011). Foam in the aquatic environment. *Water Research* 45(15):4355-4366.

Schindler. D., Hecky. R. and McCullough. G., (2012). The rapid eutrophication of Lake Winnipeg: Greening under global change. *Journal of Great Lakes Research* 38:6-13.

Schwarzenbach. R., (2006). The challenge of micro pollutants in aquatic systems. *Science* 313(5790):1072-1077.

Selman. M. and Greenhalgh. S., (2010). Eutrophication: Sources and drivers of nutrient pollution. *Renewable Resources Journal* 26:19-26.

Shah. J., Pandit. A. and Shah. G., (2014). Spatial and temporal variations of nitrogen and phosphorus in Wular Lake leading to eutrophication. *Ecologia* 4(2):44-55.

Shah. P., (2016). *Domestication and Application of Biodiversity Related Multilateral Environmental Agreements (MEAs) in Kenya*. PhD Thesis, University of Nairobi, Kenya.

Sharma. S., Gray. D. K., Read. J. S., O'Reilly. C. M., Schneider. P., Qudrat. A., Gries. C., Stefanoff. S., Hampton. S. E., Hook. S., Lenters. J. D., Livingstone. D. M., McIntyre. P. B., Adrian. R., Allan. M. G., Anneville. O., Arvola. L., Austin. J., Bailey. J., Baron. J. S., Brookes. J., Chen. Y., Daly. R., Dokulil. M., Dong. B., Ewing. K., Eyto. E. D., Hamilton. D., Havens. K., Haydon. S., Hetzenauer. H., Heneberry. J., Hetherington. A. L., Higgins. S. N., Hixson. E., Izmest´eva. L. R., Jones. B. M., Kangur. K., Kasprzak. P., Köster. O., Kraemer. B. M., Kumagai. M., Kuusisto. E., Leshkevich. G., May. L., MacIntyre. S., Müller-Navarra. D., Naumenko. M., Noges. P., Noges. T., Neiderhauser. P., North. R. P., Paterson. A. M., Plisnier. P. D., Rigosi. A., Rimmer. A., Rogora. M., Rudstam. L., Rusak. J. A., Salmaso. N., Smal. N. R., Schindler. D. E., Schladow. G., Schmidt. S. R., Schultz. T., Silow. E. A., Straile. D., Teubner. K., Verburg. P., Voutilainen. A., Watkinson. A., Weyhenmeyer. G. A., Williamson. C. E. and Woo. K. H., (2015). A global database of lake surface temperatures collected by in situ and satellite methods from 1985-2009. *Scientific Data* 2:1-19.

Sharma. V. and Sohn. M., (2009). Aquatic arsenic: Toxicity, speciation, transformations, and remediation. *Environment International* 35(4):743-759.

Shorten. A. and Smith. J., (2017). Mixed methods research: Expanding the evidence base. *Evidence-Based Nursing* 20:74-75.

Singh. A., (2013). Nitrate and phosphate contamination in water and possible remedial measures. *Journal of Environmental Science* 2:45-60.

Smith. V., Tilman. G. and Nekola. J., (1999). Eutrophication: Impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. *Environmental Pollution* 100(1-3):179-196.

Taherdoost. H., (2016). Sampling methods in research methodology; How to choose a sampling technique for research. *SSRN Electronic Journal* 1(2):43-47.

Tempero. G. W. and Hamilton D., (2014). *Storm Water Inflow to Oranga Lake, University of Waikato Hamilton Campus*. Environmental Research Institute, the University of Waikato, Hamilton, New Zealand.

Thampy. R. J., (2002). Wetland conservation and development: The Lake Nakuru case study. In: Gawler, M. (Ed.): Strategies for wise use of wetlands: Best practices in participatory management. *Proceedings of a Workshop held at the 2nd International Conference on Wetlands and Development*, November 1998, Dakar, Senegal, pp.111-116. Wetlands International IUCN and WWF Publication No. 56, Wageningen.

Tongco. M., (2007). Purposive sampling as a tool for informant selection. *Ethnobotany Research and Applications 5*:147-158.

Umerfaruq. M. Q., (2015). Physico-chemical Parameters of Water in Bibi Lake, Ahmedabad, Gujarat, India. *Journal of Pollution Effects & Control* 3(2):50-55.

UN., (1987). *Our Common Future*. UN. Oxford, United Kingdom.

UNEP., (2004). *Wetlands Bordering the South China Sea.* UNEP/GEF/SCS, Bangkok, Thailand.

UNEP., (2006). *Africa's Lakes: Atlas of Our Changing Environment*. UNEP. Nairobi, Kenya.

UNEP., (2009). *Kenya: Atlas of Our Changing Environment.* UNEP, Nairobi, Kenya.

UNEP., (2010). *Lake Nakuru. Environmental Change Hotspots. Division of Early Warning and Assessment (DEWA).* UNEP, Nairobi, Kenya.

UNEP., (2016). *A Snapshot of the World's Water Quality: Towards a global assessment.* UNEP, Nairobi, Kenya.

UNEP., (2018). *The Tale of a Disappearing Lake*. UNEP, Nairobi, Kenya.

UNEP/WHO., (1988). *Global Environmental Monitoring System: Assessment of Freshwater Quality*. UNEP, Nairobi, Kenya.

UNESCO., (2012). *Skills Challenges in the Water and Wastewater Industry*. UNESCO, Bonn, Germany.

UNESCO., (2019). *Convention concerning the protection of the world cultural and natural heritage: State of conservation of properties inscribed on the World Heritage List*. UNESCO, Baku, Republic of Azerbaijan.

Valenzuela-Encinas. C., Neria-González. I., Alcántara-Hernández. R., Estrada-Alvarado. I., Zavala-Díaz de la Serna. F., Dendooven. L. and Marsch, R., (2009). Changes in the bacterial populations of the highly alkaline saline soil of the former lake Texcoco (Mexico) following flooding. *Extremophiles* 13(4):609-621.

Vareschi. E., (1982). The ecology of Lake Nakuru (Kenya). *Oecologia* 55(1):81-101.

Verpoorter. C., Kutser. T., Seekell. D. and Tranvik. L. (2014). A global inventory of lakes based on high-resolution satellite imagery. *Geophysical Research Letters* 41(18):6396-6402.

WHO., (1995). *Guidelines for drinking water quality: Recommendations*. WHO, Geneva.

WHO., (2014). *Progress on Drinking Water and Sanitation.* WHO, Geneva.

Williams. W., (2002). Environmental threats to salt lakes and the likely status of inland saline ecosystems in 2025. *Environmental Conservation* 29(2):154-167.

World Bank., (2006). *Climate Variability and Water Resources Degradation in Kenya Improving Water Resources Development and Management*. World Bank, Washington, USA.

Wurtsbaugh. W., Miller. C., Null. S., DeRose. R., Wilcock. P. and Hahnenberger. M., (2017). Decline of the world's saline lakes. *Nature Geoscience* 10(11):816-821.

Yang. Y., Wei. L., Cui. L., Zhang. M. and Wang. J., (2017). Profiles and risk assessment of heavy metals in Great Rift Lakes, Kenya. *Clean - Soil, Air and Water* 45(3):55-69.

Zacharia. M., (2013). Assessment of Land Cover Changes in Lake Olbolosat Region of the Central Kenyan Highlands using Landsat Satellite Imagery Aided by Indigenous Knowledge. *Journal of Biodiversity Management & Forestry* 2(2).

Zhao. H., You. B., Duan. X., Becky. S. and Jiang. X., (2013). Industrial and agricultural effects on water environment and its optimization in heavily polluted area in Taihu Lake Basin, China. *Chinese Geographical Science* 23(2):203-215.

APPENDICES

APPENDIX I: QUESTIONNAIRE FOR HOUSEHOLD SURVEYS

Date:
Location:
Sub-location:
Questionnaire number:
Name:

Part 1: General information:

1. What is your gender?

   A. Male B. Female

2. What is your age bracket?

   A. 20-29 B. 30-39 C. 40-49 D. Above 50

3. What is your level of education?

   A. Primary B. Secondary C. Tertiary D. None

4. What is your occupation?

   A. Businessman B. Farmer C. Public servant D. Other

5. How long have you been staying here?

   A. 0-5 years B.6-10 years C. 11-20 years D. More than 20 years

6. How far is your residency from the lake?

   A. 0-2 km B. 2-4 km C. 4-8 km D. More than 8 km

Part 2: Value of Lake Nakuru

7. Do you consider the Lake to be of any value?

   A. Yes

   B. No

8. If so, what function/values/roles of the Lake are valued by you?

   A. Control of floods

   B. Prevention of soil erosion

   C. Habitat for biodiversity

   D. Tourism and recreation attraction

   E. Others:

9. Are you aware that the lake is a Ramsar site of international importance?
   A. Yes
   B. No

Part 3: Impacts on the Lake

10. List in order of the highest threat faced to the lake

Threat	**Rank**
Pollution by industrial waste	
Pollution by agricultural waste	
Pollution by sewage	
Soil erosion and sedimentation	
Over abstraction of water from feeding rivers	
Climate change	
Overgrazing	
Deforestation	
Drying of rivers	
Flooding of the lake	
Invasive species	
Tourism and recreation	

11. What do you think are the main causes of water quality deterioration in Lake Nakuru?
    …………………………………………………………………………………………………
    …………………………………………………………………………………………………
    …………………………………………………………………………………………………
12. Why do you think water quality deterioration in Lake Nakuru is high?
    A. Lack of education and awareness
    B. Lack of policies

C. Lack of implementation of policies

D. Lack of dumping resources (e.g. poor sewage facilities)

E. Lack of man power spot checks

F. Attitudes

G. No fines/ weak fines

H. Corruption

13. How could the possible causes of pollution be managed?

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

14. Have you ever noticed any changes in Lake Nakuru in terms of color, oduor (smell), and toxic bloom, changes in water quantity or dead species?

A. Yes

B. No

15. If yes, what physical changes?

A. Color

B. Oduor (Smell)

C. Toxic bloom

D. Changes in water quantity

E. Dead species

Part 4: Conservation of Lake Nakuru

16. Are you aware of any existing laws and policies that deal with management of Lake Nakuru?

A. Yes

B. No

17. If yes, which ones do you know

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

18. a) According to your knowledge, which institution takes care of Lake Nakuru?

……………………………………………………………………………………………

b) Does this institution manage the Lake properly?

A. Yes B. No

c) What is your suggestion on better management of the lake?

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

Thank you

APPENDIX II: QUESTIONNAIRE FOR KWS OFFICERS

Name: ……………………………………
Date: ……………………………………..
Gender: ………………………………….

Part 1: Personal information

1. What is your academic qualification?
    A. High School
    B. Diploma
    C. Bachelors
    D. Masters
    E. PhD
2. How long have you worked at Lake Nakuru National Park?
    A. 0-2 years
    B. 2-5 years
    C. 5-10 years
    D. Over 10 years
3. What is your position at Lake Nakuru National Park?
    A. Director
    B. Scientist
    C. Supervisor
    D. Official
    E. Other

Part 2: Information on Lake Nakuru Ramsar Site

4. Are there any policies, acts or frameworks in regards to management of Lake Nakuru?
    A. Yes
    B. No

If yes, please state them

…………………………………………………………………………………………….

…………………………………………………………………………………………….

5. Rank the threats faced by Lake Nakuru starting from the greatest threat and the actions taken in order to prevent or reduce these threats

Threat	**Rank**	**Action taken to reduce/prevent these threats**
Pollution by industrial waste		
Pollution by agricultural waste		
Pollution by sewage		
Soil erosion and sedimentation		
Over abstraction of water from feeding rivers		
Climate change		
Overgrazing		
Deforestation		
Drying of rivers		
Flooding of the lake		
Invasive species		
Tourism and recreation		

6. What are the factors constraining effective management of Lake Nakuru?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

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

Part 3: Water quality of Lake Nakuru

7. Are there any regulations in order to prevent pollution of the lake?
   A. Yes
   B. No

   If yes, state them

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

8. How is the enforcement level on the control of the pollution in the lake?
   A. Very good
   B. Good
   C. Satisfactory
   D. Poor
   E. Absent
9. How often does the institution monitor the water quality of the lake?
   A. Weekly
   B. 3-6 months
   C. Yearly

Signature: ………………………………………………….

APPENDIX III: OBSERVATION SHEET

Characteristic		A	B	C	D	E	F	G	H	I	J
Water surface	Clear										
	Foamy										
	Natural debris										
	Trash										
Clarity	Clear										
	Cloudy/milky										
	Turbid										
Color	Clean										
	Brownish										
	Greenish										
Odor	None										
	Sewage										
	Fishy										
	Musky										
Algae cover	Present										
	Not present										
Dead species	Present										
	Not present										

APPENDIX IV: POPULATIONS OF SELECTED SITES IN NAKURU

Sub-county	Division	Location	Sub-location	Male	Female	Total	Households
Nakuru	Lanet	Lanet	Kiamunyeki	2644	1823	4467	793
			Mwariki B	4782	5155	9937	2486
		Free Area	Menengai	8892	9780	18672	5139
		Lanet	Muguga	2445	2427	4872	1370
Total				18763	19185	37948	9788
Molo	Lare	Naishi	Naishi	1887	1959	3846	801
			Pwani	988	950	1938	457
		Lare	Lare	3152	3407	6559	1576
			Ndulele	1615	1611	3226	688
		Gichobo	Gichobo	1374	1435	2809	661
			Sinendet	1606	1724	3300	757
		Bagaria	Bagaria	2670	2926	5596	1319
			Kapyemit	723	786	1509	355
			Milimani	484	524	1008	227
Total				14499	15322	29,791	6841
Nakuru Town	Nakuru	Kaptembwo	Mwariki	12045	12551	24596	8022
			Githima	8653	9336	17989	5182
		Viwanda	London	7500	5455	12955	3315
			Vivanda	2061	2135	4196	1297
		Bondeni	Milimani	3222	3210	6432	1640
			Afraha	8916	9922	18838	5162
			Baharini	8354	8724	17078	4829
			Kivumbini	10221	10353	20574	6148
Total				**60972**	**61686**	**122658**	**35595**

Source: KNBS (2019)

APPENDIX V: INSITU MEASUREMENTS

SAMPLING POINT	DIP NO.	Wet season			Dry season		
		pH	Temp	DO	pH	Temp	DO
Mouth of Nderit	1	9.8	23	12.4	10.05	22	11.9
Mouth of Nderit	2	10.3	23	12.5	10	24	11.7
Mouth of Nderit	3	10	23.5	12.7	10.05	22	11.8
Mouth of Nderit	4	10.5	22	12	10.2	24	11.9
Mouth of Nderit	5	10.6	21	12	10	23	12
Block 7	1	10.5	23	11	10.2	24	9.8
Block 7	2	10.4	23	9.8	10.4	23	9
Block 7	3	10.6	25	10.5	10	23.9	9.8
Block 7	4	10.7	22	10.8	10.2	23.8	9.8
Block 7	5	10	23	10.5	10.3	23.4	10
Storm drain	1	7.9	23	13.5	7.98	24.5	2.9
Storm drain	2	7.9	21	12.8	7.89	24.3	3
Storm drain	3	7.8	22	13.3	7.96	24.5	2.5
Storm drain	4	7.5	22	12.5	7.95	23	2.3
Storm drain	5	7	22	13.9	7.9	24	2.7
Lamdiac	1	10.6	28.3	10.6	10.2	24.1	9.5
Lamdiac	2	10	30.4	10	10.01	23.8	9.2
Lamdiac	3	10.6	32	10.6	10.1	23.3	9.2
Lamdiac	4	10.5	30.2	10.5	10.01	24	9.9
Lamdiac	5	9.8	28	9.8	10.1	23.5	8.4
Nyati Camp	1	11	22	9.8	9.97	27	8.9
Nyati Camp	2	9.8	22	10.5	9.9	25.5	8.3
Nyati Camp	3	10.5	23	10	10	25.6	8.6
Nyati Camp	4	10.8	21	10.3	10.1	24	8.9
Nyati Camp	5	10.5	22	10.6	9.9	26	8.3
T junction	1	10.6	25	7.5	11	23.4	7.2

SAMPLING POINT	DIP NO.	Wet season			Dry season		
		pH	Temp	DO	pH	Temp	DO
T junction	2	10	22	7.3	10.7	23.5	6
T junction	3	10.6	23	8.8	8.5	23	6.9
T junction	4	10.5	23	9.5	10.5	22.7	6.5
T junction	5	9.8	22	8	10	23	7
Hippo spring	1	10.08	22	8	8.9	23.5	7.2
Hippo spring	2	10.09	26	7	8.9	24	7.9
Hippo spring	3	10	27	8.8	8	23.6	8
Hippo spring	4	10.02	26.5	8	8.8	23.7	7.4
Hippo spring	5	10.02	25.3	8	8.9	23.6	7.5
Baharini spring	1	9.1	25	10	10.6	23	6.5
Baharini spring	2	9.7	26	12	10.7	23	6.6
Baharini spring	3	9.9	22	11	11	23.1	5.8
Baharini spring	4	9.8	25	10	10.4	23.6	6.2
Baharini spring	5	9.5	22	10	10.5	23.4	6
Lake center	1	9.8	22.4	12.5	12	34	6
Lake center	2	10.5	26	10.5	10	33.4	12
Lake center	3	10.6	22	11	12	35.4	12
Lake center	4	10.3	24.8	10	10	33	10
Lake center	5	10.5	22	11.5	6	30	10
Nderit lake	1	10.3	22	12	9	23.4	11
Nderit lake	2	10.6	26	12.5	11	23.5	10.9
Nderit lake	3	10.3	22	12	9	23	10.7
Nderit lake	4	10.5	24	12.6	10.8	22.7	12.2
Nderit lake	5	10	22	11.7	11	23	9

APPENDIX VI: T-TEST FOR SEASONAL VARIATION

A. PH

1). MAY: Mean: 9.949 S.d: 0.8622

2). OCT: Mean: 9.708 S.d: 0.7619

Mean difference: 0.241

S.D difference: 0.100

Calculated t = 0.66233 with 9 D.F p = 0.51615 p = <0.05 (2 sided)

B. Temperature

1). MAY: Mean: 23.81 S.d: 2.287

2). OCT: Mean: 25.93 S.d: 2.6923

Mean difference: -2.12

S.D difference: -0.4055

Calculated t = -0.63321 with 9 D.F p = 0.073581 p = <0.05 (2 sided)

C. DO

1). MAY: Mean: 10.58 S.d: 1.6731

2). OCT: Mean: 8.72 S.d: 1.532

Mean difference: 1.80

S.D difference: 0.1407

Calculated t = 2.59235 with 9 D.F p = 0.018393 p = <0.05 (2 sided)

D. Alkalinity

1). MAY: Mean: 3850 S.d: 139

2). OCT: Mean: 3745 S.d: 674

Mean difference: 105

S.D difference: -534

Calculated t = 0.482 with 9 D.F p = 0.635 p = <0.05 (2 sided)

E. Nitrate

1). MAY: Mean: 1.22 S.d: 1.821

2). OCT: Mean: 1.38 S.d: 0.753

Mean difference: -0.162

S.D difference: 1.067

Calculated t = 0.565 with 9 D.F p = 0.579   p = <0.05 (2 sided)

F. Phosphate

1). MAY: Mean: 0.79 S.d: 0.60

2). OCT: Mean: 1.52 S.d: 0.89

Mean difference: -0.733

S.D difference: -0.284

Calculated t = -2.16 with 9 D.F p = 0.045   p = <0.05 (2 sided)

G. Ammonia

1). MAY: Mean: 1.01 S.d: 2.11

2). OCT: Mean: 2.77 S.d: 6.80

Mean difference: -1.76

S.D difference: -4.69

Calculated t = -0.78 with 9 D.F p = 0.0444   p = <0.05 (2 sided)

H. TDS

1). MAY: Mean: 3046.7 S.d: 1095.146

2). OCT: Mean: 3700.3 S.d: 1261.996

Mean difference: -653.6

S.D difference: 166.85

Calculated t = -1.23696 with 9 D.F p = 0.231997   p = <0.05 (2 sided)

I. TSS

1). MAY: Mean: 102.2 S.d: 32.93

2). OCT: Mean: 67.2 S.d: 27.08

Mean difference: 35

S.D difference: 5.854

Calculated t = 2.596 with 9 D.F p = 0.0183   p = <0.05 (2 sided)

APPENDIX VII: RESEARCH PERMIT

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: **134164** | Date of Issue: **12/September/2019**

RESEARCH LICENSE

This is to Certify that Miss.. Avni Davdra of University of Nairobi, has been licensed to conduct research in Nakuru on the topic: CHALLENGES FACING LAKE WATER RESOURCES IN KENYA, CASE STUDY OF LAKE NAKURU for the period ending : 12/September/2020.

License No: **NACOSTI/P/19/1451**

134164
Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

KENYA WILDLIFE SERVICE

KWS/BRP/5001

19 September 2019

Avni Rajesh Davdra
University of Nairobi
C/O P.O. Box 39823-00623
NAIROBI
E-mail: avnidavdra@yahoo.com

Mobile: 0732759997

Dear Avni,

PERMISSION TO CONDUCT RESEARCH IN LAKE NAKURU PARK

We acknowledge receipt of your application requesting for permission to conduct research on a project titled: '**Challenges facing Lake Water Resources in Kenya. Case study Lake Nakuru** 'The study will generate data and information that will contribute to sustainable management of Lake Nakuru, specifically from anthropogenic activities.

You have been granted permission to conduct the study from **September 2019 – September 2020** upon payment to KWS academic research fees of **ksh.6,000** (Masters Study). However, you will abide by the set KWS regulations and guidelines regarding carrying out research in and outside protected areas. You will discuss the research project proposal with our Senior Scientist in-charge of Central Rift Conservation Area (CRCA) before embarking on the field work.

You will submit a bound copy of your MSc thesis to the KWS Director, Biodiversity Research and Planning on completion of the study.

Yours Sincerely

PATRICK OMONDI, PhD, OGW
DIRECTOR
BIODIVERSITY RESEARCH AND PLANNING

Copy to:

- Assistant Director, CRCA
- Senior Warden, Lake Nakuru N. Park
- Senior Scientist, CRCA

P.O Box 40241-00100, Nairobi, Kenya.
Tel: +254-020-2379407/8/9-15. Mobile: +254-735 663 421, +254-726 610 508/9.
Email: kws@kws.go.ke Website:www.kws.go.ke

APPENDIX VIII: PLAGIARISM REPORT

09/11/2020 Turnitin

Turnitin Originality Report

Processed on: 09-Nov-2020 10:52 EAT
ID: 1440596551
Word Count: 26019
Submitted: 1

STATUS AND CAUSES OF DETERIORATION OF WETLANDS IN THE EASTERN RIFTVALLEY, CASE STUDY OF LAKE NAKURU - KENYA By Avni Davdra

9TH NOVEMBER 2020

9/11/2020

Similarity Index	Similarity by Source
11%	Internet Sources: 8% Publications: 7% Student Papers: 5%

< 1% match (Internet from 07-May-2015)
http://tu-freiberg.de/fakult3/geo/foo/FOG_Vol_16.pdf

< 1% match (publications)
Alusani Manyatshe, Elvis Fosso-Kankeu, Divan van der Berg, Nico Lemmer, Frans Waanders, Hlanganani Tutu. "Metal Speciation in the Rivers Around Potchefstroom Based on Seasonality", Water Environment Research, 2018

< 1% match (student papers from 18-Nov-2016)
Submitted to North West University on 2016-11-18

< 1% match (student papers from 20-Sep-2016)
Submitted to Eiffel Corporation on 2016-09-20

< 1% match (publications)
Kim, Ki-Hyun, Richard J.C. Brown, Eilhann Kwon, Ik-Soo Kim, and Jong-Ryeul Sohn. "Atmospheric mercury at an urban station in Korea across three decades", Atmospheric Environment, 2016.

< 1% match (Internet from 08-May-2019)
http://ir.jkuat.ac.ke/bitstream/handle/123456789/800/Muchuri%20MN-PHD%20Food%20Science%20and%20Postharvest%20Technology%20%20-%202012.pdf?isAllowed=y&sequence=1

< 1% match (Internet from 25-Mar-2009)
http://www.science.uts.edu.au/des/StaffPages/PeterJones/HeavyMetalLevels.pdf

< 1% match (Internet from 26-Feb-2013)
http://www.worldlakes.org/uploads/Nakuru_4.7.04.pdf

< 1% match (student papers from 07-Feb-2020)
Submitted to Higher Education Commission Pakistan on 2020-02-07

< 1% match (Internet from 24-Oct-2019)
https://ijsdc.org/storage/e26a5b5c1d7d5b1478ab2aa824ea9952.pdf

< 1% match (publications)
Priyanka Sarkar, Mercy Salami, Yvonne Githiora, Raisa Vieira, Alma Navarro, Diana Clavijo, Maira Padgurschi. "A conceptual model to understand the drivers of change in tropical wetlands: a comparative assessment in India and Brazil", Biota Neotropica, 2020

< 1% match (student papers from 16-Oct-2020)
Submitted to Saint Paul University on 2020-10-16

< 1% match (Internet from 12-Jul-2015)
http://www.globalnature.org/bausteine.net/f/6407/WLVACTIONREPORT-FINAL_Feb_2007.pdf?fd=2

< 1% match (publications)
Temesgen Eliku, Seyoum Leta. "Spatial and seasonal variation in physicochemical parameters and heavy metals in Awash River, Ethiopia", Applied Water Science, 2018

< 1% match (Internet from 21-Oct-2020)
https://inba.info/shankar-ias-environment-pdf_5852416ab6d87f6d35fb5994.html

< 1% match (student papers from 27-Mar-2017)
Submitted to University of Portsmouth on 2017-03-27

< 1% match (Internet from 18-Dec-2019)
https://content.yudu.com/web/2v3n2/0A2v3n3/GEO6/html/270.html

< 1% match (Internet from 15-Jul-2019)
http://docshare.tips/handbook-of-the-convention-on-biological-diversity-including-its-cartagena-protocol-on-biosafety-3rd-edition-secretariat-of-the-convention-on-biological-diversity_5a23a12e08bbc51932b0cfdc.html

< 1% match (student papers from 26-Oct-2018)
Submitted to Universiti Teknologi MARA on 2018-10-26

< 1% match (student papers from 19-Jan-2012)
Submitted to University of Central Florida on 2012-01-19

< 1% match (Internet from 07-Jun-2020)
https://ru.scribd.com/document/394955334/A

< 1% match (publications)

https://www.turnitin.com/newreport_printview.asp?eq=0&eb=0&esm=0&oid=1440596551&sid=0&n=0&m=2&svr=47&r=99.92803059002935&lang=en... 1/23

UNIVERSITY OF NAIROBI
09 NOV 2020
9/11/2020
P.O. Box 30197, NAIROBI

CHAIRMAN
Department Of Geography
& Environmental Studies
UNIVERSITY OF NAIROBI
9/11/2020