

**ABATING THE EFFECTS OF DIFFERENT LAND USE
ACTIVITIES ON EUTROPHICATION OF KABAKA'S LAKE
KAMPALA - UGANDA**

BY

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APPROVAL

The undersigned approve that they have read and hereby recommend for submission to Kyambogo University a research thesis entitled: ABATING EFFECTS OF DIFFERENT LAND USE ACTIVITIES ON EUTROPHICATION OF KABAKA'S LAKE, in partial fulfilment of the requirements for the award of MASTER OF SCIENCE IN WATER AND SANITATION ENGINEERING degree of Kyambogo University.

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DECLARATION

I **MUTYABA ABEL**, hereby declare that this dissertation is submitted as my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree of the University or other institute of higher learning, except where due acknowledgement has been made in the text and reference list.

Sign.....

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Date.....25th, November, 2019.....

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DEDICATION

This study is dedicated to my late grandmother. Mrs. Mary Ssebbunza and my mother Mrs. Annet Ttendo for all her support, love, care, and encouragement towards my education values.

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LIST OF ACRONYMS

AWT	Advanced Wastewater Treatment
BSAP	Baltic Sea Action Plan
CW	Constructed Wetlands
DI	Deionised
DO	Dissolved Oxygen
FDEP	Florida Department of Environmental Protection
GPS	Global Positioning System
ISO	International Organization for Standardization
LISS	Linear Imaging Self Scanning Sensor
LSI	Landsat Satellite Images
MCA	Multi Criteria Assessment
MLR	Multiple Linear Regression
MWE	Ministry of Water and Environment
NEMA	National Environment Management Authority
NWSC	National Water and Sewerage Cooperation
PPI	Phenolphthalein Indicator
SAGA	System for Automated Geoscientific Analyses
SD	Standard Deviation
SDG	Sustainable Development Goals
STP	Sewage Treatment Plant

TN	Total Nitrogen
TP	Total Phosphorus
TSI	Trophic State Index
UBOS	Uganda Bureau of Standards
WWAP	World Water Assessment Programme

ABSTRACT

Various land uses resulting from urbanization in Kampala the capital city of Uganda, have reduced the natural pollutant filtration value of the wetlands. This has in turn led to a decline in the water quality and gradual eutrophication of available water bodies such as Kabaka's lake, characterised with green colored water, foul smells, and tastes. The aim of this study was to assess eutrophication management strategies for abatement of the effects of the different land use activities on natural water quality of Kabaka's lake. The study focused on; classification of downloaded Landsat imagery for the last 25 years, mapping of pollution hotspots and nutrient distribution with GIS, and assessment of both external (constructed wetland) and internal (dredging) eutrophication extenuation measures. Following the research showed that Kabaka's lake catchment land use has been significantly ($p < 0.005$) been redistributed, with buildup area increasing by 78.5%, vegetated area reducing by 37.2% and water reducing by 1.8%. This has not only significantly reduced the lakes receiving wetland footprint by 92.2% ($p = 0.000003$) but also increased the nutrient load in the catchment mainly from; garage oil spillages, car washing bays wastewater, and sewerage. The 80,596 m² Lake's light attenuation is currently algae dominate, limited by nitrogen and classified under oligotrophic class of lakes (Trophic State Index < 40) with a threat of eutrophication in an estimate of 25 years. Construction of a wetland in the remaining 1.34 acres of natural wetland will significant reduce Total Phosphorus by 35% and Total Nitrate by 45% ($p = 0.05$), whereas dredging the lake will reduce both by 80% ($p = 0.0005$). Watershed and proper land use management, establishment of riparian buffer vegetation and a diversion channel and community sensitization were some of the study recommendations.

Key words; Land use, Nutrient concentration, Eutrophication

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Water is a renewable resource that covers almost 70% of the earth's surface (Baker *et al.*, 2016). It plays a vital role in many natural physico-chemical processes, and is essential for the functioning of different organisms and human development (Smita *et al.*, 2015). Currently, it is estimated that the global water demand by 2050, will increase by 55% of all accessible freshwater contained in rivers, lakes and underground aquifers (World Water Assessment Programme, 2015). The increase in the pressures on the water resources are as a result of rapid urbanization and economic growth (Rashid *et al.*, 2018).

Fresh water resources in Uganda cover over a third of its surface area, with large active storage capacity in four major lakes namely; Victoria, Albert, Kyoga, and George (Nsubuga *et al.*, 2014). These are also known as the four river basins (or catchments, water management zones) since a vast network of Ugandan rivers connect to these various lakes (Pierre, 2016). Like many developing countries, Uganda is experiencing high population growth and rapid urbanization that has greatly influenced its land use, in turn impacted on the availability and quality of its fresh water bodies.

In Kampala, the Capital City of Uganda, different wetlands that are a part of lake Victoria catchment area have been reclaimed for different land use including residential development, farming, brick making and sand mining, reducing their capacity to act as

natural pollutant filters for the lakes (Gumm, 2011). Developments in Kampala have also resulted in an increase in wastes generated from the different activities while their collection, for treatment and disposal methods remain inadequate (Ngwomoya, 2018). For example industrial effluents are discharged into various streams partially treated, while poor sewerage systems and faecal sludge management have greatly affected the environment and Kampala waste collection and disposal system is characterized by low service coverage (Walakira and Okot-Okumu, 2011; Komakech *et al.*, 2014). This waste ultimately finds its way into the water bodies resulting in their contamination.

Lake's in Uganda such as; Victoria, George, Edward, Mbuoro and Saaka, have over years exhibited high concentrations of Total Phosphorus ($>100 \mu\text{g/l}$) and chlorophyll-a ($>70 \mu\text{g/l}$), depicting hypertrophic conditions with gradual eutrophication by both natural and cultural mechanisms (Busobozi, 2017). This in turn has diverse effects on the ecosystems within the water bodies and the health of people in contact with the polluted waters. Studies have found that Uganda's water-borne disease burden has increased mainly due to poor sanitation and unsafe water resources (National Environmental Mangement Authority, 2016; Pierre and Wondwosen, 2016; Murphy *et al.*, 2017).

There is thus need to establish pollution trends and strategies for management of the water quality of different water bodies for Uganda to achieve Sustainable Development Goals (SDG), specifically the sixth which targets at ensuring availability and sustainable management of water and sanitation for all. Furthermore, studies on segments of such

water bodies, specifically under the Kampala wetland water shed characterised with increasing human and infrastructure footprint could enable development of abatement management strategies of environmental degradation as the city works towards Uganda Vision 2040.

1.2 Statement of the Problem

Uganda has taken steps in management of its water bodies. In Kampala, Lake Victoria has been the main focus of studies. For example studies on microbial quality, heavy metals, nutrient contamination sediment and other parameters have been under taken (Banadda, 2011; Ogoyi *et al.*, 2011; Victoria *et al.*, 2017). Modelling the impact of climate, land use and water level changes, non-point pollution and nutrient transport have also been done (Vanderkelen *et al.*, 2018). On the other hand, studies have not been undertaken on the Kabaka's lake. The lake is positioned in a low lying area compared to its surrounding zones namely; Kayanja I & II, Kayanja, Agrey and Spier zones, the lake has been probable sink to runoff for the last 132 years. Increased lakes water shade encroachment resulting from rapid population growth, zone urbanization characterised with poverty, uncontrolled improper waste disposal and discharges along its shorelines, have consequential and gradually polluted Kabaka's lake. This is evidenced by the eutrophic and sediment nature of the water especially during storm events (Figure 1-1). Eutrophication is an indicator of high concentration of nutrients such as nitrates and phosphates which result in development of algal biomass, and leads to water quality decline through discolouration, foul smells, tastes, diurnal pH changes, temperature changes, depletion of dissolved

oxygen and degraded aesthetic values (Leng and Cooke, 2008). With a dreadful balance of nature, Kabaka's lake which is a home to hundreds of water animals, birds, and plants and a prime touristic attraction in Buganda Kingdom has been devoured. Urgent measures to improve the current situation and protect the lake from further degradation are called for, with this study looking into the means of reducing eutrophication of the Kabaka's lake.



Figure 1-1: Eutrophication on Kabaka's Lake. (a) Green algae colour of the lake water; (b) storm flow and (c) floating waste on the lake

1.3 Objectives of the study

1.3.1 Main Objective

The main objective of the study was to abate the effects of different land use activities on natural water quality of Kabaka's lake.

1.3.2 Specific Objectives

- i. To categorize the anthropogenic activities in Kabaka's lake watershed
- ii. To map the distribution of nutrients in Kabaka's lake watershed.
- iii. To assess measures of abating Kabaka's lake eutrophication.

1.4 Research Questions

- i. What are the different anthropogenic activities in Kabaka's lake watershed?
- ii. How are the nutrients distributed in Kabaka's lake watershed?
- iii. Which are Kabaka's lake eutrophication abatement measures?

1.5 Justification

Uganda's urban population has increased rapidly from 12.6 million people in 1980 to 34.6 million in 2014 indicating a more than threefold increase and projected to be 41.2 million by mid-2020 (UBOS, 2006; UBOS, 2007; UBOS, 2014). Kampala has experienced rapid growth where Kabaka's lake surrounding built area density is relatively high concentrating most of the multi-residential and commercial buildings such as; hotels, churches, schools, washing bays, parking yards, and small housing units of which, hundreds of people have encroached on its wetland. Over the years, increased urbanization in the area has sprouted into numerous non-point pollution discharges into the water ways from various water sources draining into the lake. The pollutant; characteristics, quantities, source activities and locations in the lake's watershed causing the current green colour of the water were largely unknown. The recurrent disappearance of the Kabaka's lake water shade has left the lake in dire need of the former wetland's primary ecosystem service: receiving human waste, processing nutrients in the water, natural cleaning and releasing wastewater downstream that is filtered of harmful bacteria and sediments that contaminate water downstream. This has led to recent disease outbreaks including malaria and diarrheal in the area, degradation of the living environment, and damage to lakes

ecosystems. Against a thriving ecosystem, abatement management strategies are needed that can address lakes eutrophication were hoped-for.

1.6 Significance

Identifying and characterising of the various land uses and pollution sources was aimed at understanding the Kabaka's lake watershed. The research does not only bridge the knowledge gap on Kabaka's lake watershed but also enables decision makers to formulate lake management frameworks that mitigate further contamination of the lakes' natural water quality and address issues pertaining to environmental sustainability in relation to lake's redevelopment master plan.

1.7 Scope of study

Kabaka's lake located in Lubaga Division, of Kampala District, about 7.5 kilometers from the City Centre, is the largest manmade lake in Africa that was constructed in 1887. The lake is approximately 410 meters long with a width of 173 meters at the top end and 291 meters at the bottom with the deepest point of 2.8 meters. The study was carried out between January and August 2019, and was focused on assessing eutrophication management strategies for abatement of the effects of the different land use activities on natural water quality of Kabaka's lake. The pollutants of interest were limited to total nitrates and total phosphates which support the growth of algae that stimulates eutrophication.

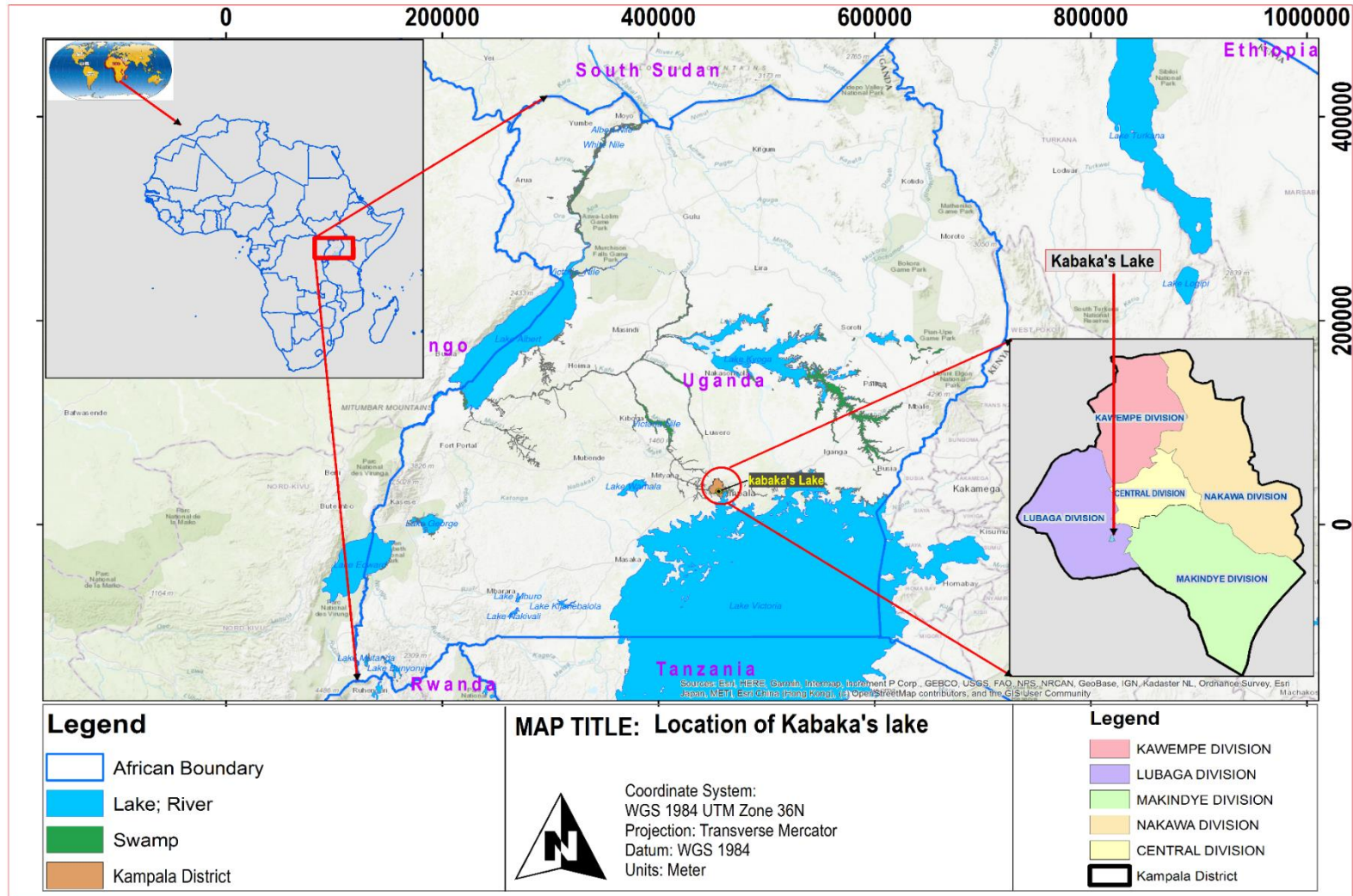


Figure 1-2: Location of Kabaka's Lake

1.8 Conceptual framework

The land use and human factors in the catchment such as agricultural practise, forestry, and building of infrastructure were driving forces for land cover change (Independent variables). These were categorised to map out the distribution of nutrients (TP and TN) and concentration of chlorophyll in the lakes watershed (Dependent variables). The intervening which were in form of policies, laws and catchment management plan were used to impose control measures. The status of land use change in turn influenced the introduction of decision variables for both land use and lakes water quality in management of lake's eutrophication.

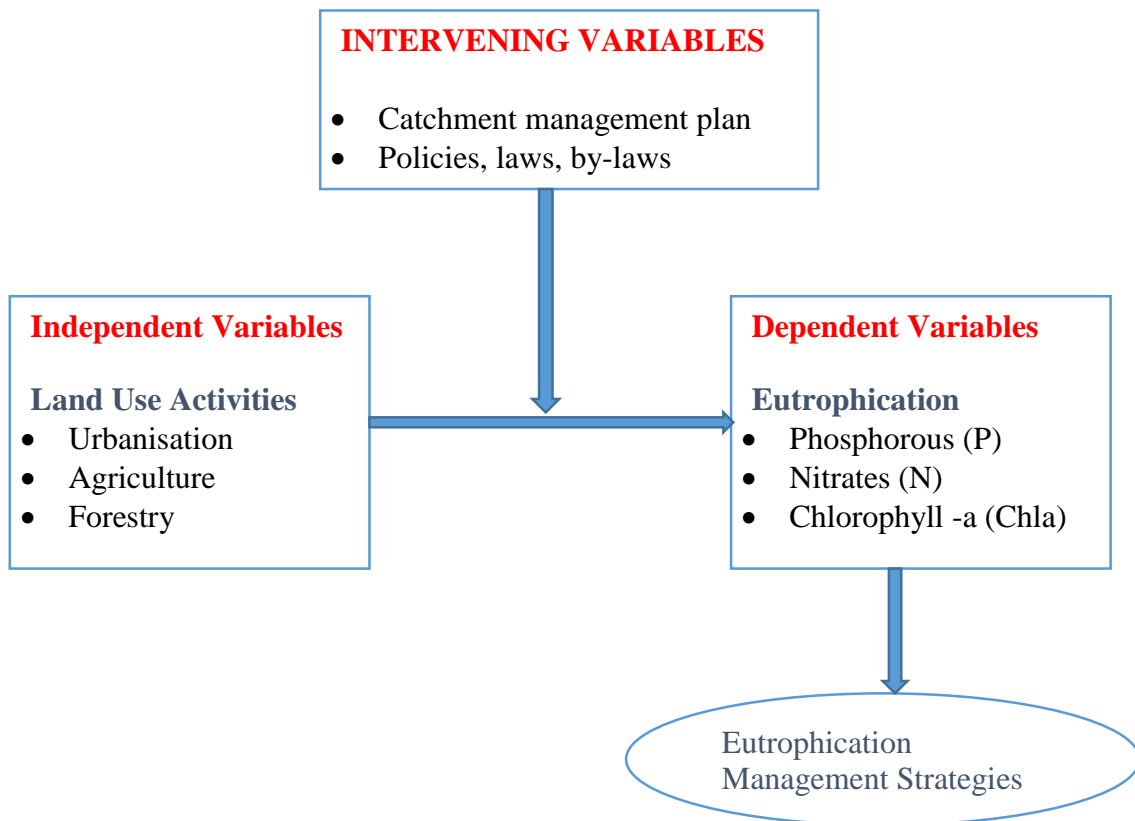


Figure 1-3: Conceptual framework

1.9 Chapter Summary

This chapter has described the water pollution problem faced by Kampala at large with Kabaka's lake as the study case, relating the land use activities (pollution sources) in the lakes water shade with distribution of nutrient concentration (eutrophication). It further details the study objective of abating the effects of different watershed activities on natural water quality of the lake by selection of the best abatement management strategies to address eutrophication of the lake. The next chapter expounds on the various study related literature published by other scholars majorly on land use and eutrophication.

CHAPTER TWO: LITERATURE REVIEW

2.1 Eutrophication

Eutrophication an influx of excess nutrients into waterbodies causes growth of algae by inducing biological, chemical, and physical disturbances in aquatic systems, causing diurnal pH changes, oxygen depletion, temperature changes, odours, fish kills, reduced transparency, and degraded aesthetic values ('Eutrophication in aquatic ecosystems: a scientometric study', 2018). There are many documented cases of eutrophication of Ugandan freshwaters bodies including; Lake Victoria (Krafft, 2006; Sitoki *et al.*, 2010; Kundu *et al.*, 2017; Glaser *et al.*, 2019), Lake George, Edward, and Mbuho (George, 2018; Ganf *et al.*, 1974; Hartwig *et al.*, 2005; Okello and Kurmayer, 2011; Nunan, 2015). The term eutrophication was introduced to describe the slow nutrient enrichment process (Figure 2-1) of change in water bodies, classifying their trophic states; oligotrophic (low nutrients content), mesotrophic (intermediate nutrients content) and eutrophic (high nutrients content) (Sabljić, 2009; McDonald *et al.*, 2014).

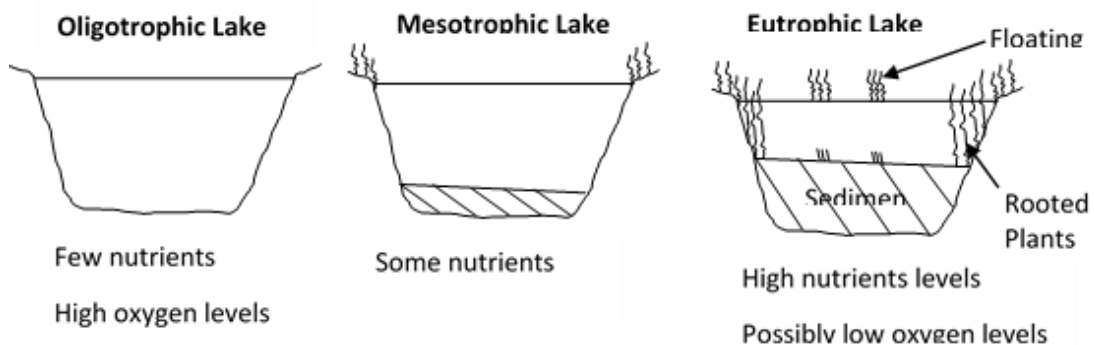


Figure 2-1: The eutrophication process (Sabljić, 2009)

Studies have reported that approximately 54% of the lakes/reservoirs in Asia, 53%, in Europe 48% in North America, 41% in South America, and 28% in Africa are impaired by eutrophication.

Removal of nutrients from water entails basically the removal of nitrogen and phosphorus. Limited nutrient inflow however may increase the productivity of freshwater bodies and perhaps its self-purification capabilities through the presence of algae. The study by Ebenezer on investigating the importance of algae in faecal coliform removal in eutrophic waters, established that faecal coliforms rate of decay increased with increased chlorophyll-a concentration. Chlorophyll a concentration, an indicator of algae abundance of the lake was directly proportional to the rate of decay of E. coli in the lake (Ebenezer, 2013). This was due to the fact that Chlorophyll-a concentration is affected by quality of dissolved organic compounds present in the raw wastewater. Therefore determination of TN, TP and Chlorophyll a were important attributes to this study.

2.2 Nutrients

The most important limiting nutrients in aquatic systems are Total Nitrogen (TN) and Total Phosphorus (TP) and both have major anthropogenic sources, as categorized into two sources: point sources (dry-weather pollutants that are directly discharged nutrient into the receiving environments (catchment) through an identifiable discharge point including industrial and domestic effluent and non-point source/ diffuse sources (nutrients

that area transported to the catchment including urban runoff, acid rain, runoff from agriculture and runoff from pasture land) (Suwarno *et al.*, 2014; Gupta, 2017).

Diffuse nitrogen (N is needed for protein synthesis) and phosphorus (P needed for DNA, RNA, and energy transfer) pollutions are now the main drivers of the new wave of eutrophication which support the growth of algae on lakes (Van Beek *et al.*, 2016). Any increase in P and N loading will also rapidly increase the expansion of algal blooms in the lake water catchment as ascertained from the various studies conducted on tropical inland lakes. For instance, a review study done by Fernando on Mexico's Mesa central Lakes (Lake Cuitzeo and Pátzcuaro) involving the survey of limiting nutrient on algae growth found that both P and N were potentially limiting to algal growth in the lakes (Sánchez Chávez *et al.*, 2016). Luciana Rangel observed that P consistently demonstrated as the primary limiting nutrient in various hydrographic fresh water reservoirs in Brazil (Rangel *et al.*, 2012). On the other hand, Metillo demonstrated that there was severe N depletion in Lake Lanao under review study on its ecology and biodiversity (Metillo and Garcia-Hansel, 2016). This was still confirmed by Viner, who showed a permanent shortage of N and P in Lake George Uganda, with N supply being more critical (Ganf, 2006).

Naturally, light availability and high air temperature during the dry season generally facilitates an increase in phytoplankton biomass (and lake stratification) and the changes in rainfall regimes, run-off, and erosion have an influence on nutrient (P and N) loading from the catchment into the lakes (Mills, 2009). However, a phenomenon often referred

to as cultural eutrophication that defines the causal relationship with human activities through discharge of excessive amounts of nutrients in the form of sewage, detergents, and fertilizers to the surface water also accelerates the process of nutrient enrichment in lakes (Ansari and Gill, 2014).

2.3 Eutrophication threat

The threat of eutrophication reported for numerous freshwater ecosystems (Ansari and Gill, 2014; Harding, 2015; Stachelek *et al.*, 2018), makes the freshwater become unsafe for human consumption, through disruption of homeostasis of lake ecosystems and result an imbalance between the production, consumption, and decomposition of organic matter (Arriaga *et al.*, 2011). The most evident harmful consequence of eutrophication is algal bloom (Commons *et al.*, 2014) where consequential effects may be felt or experienced at ingestion of eutrophic water containing algal blooms (green colored), dialysis treatment and recreational activities while the effect varies from acute to chronic. There was also a direct relationship of primary liver cancer (potent liver toxin and possible carcinogen) and drinking water source established by Oregon State University (Paerl and Otten, 2013).

In January 2015, a 20-month-old child and her family took part in recreational activities at Carrasco and Malvín beaches in Montevideo, Uruguay where they were exposed to an intense harmful algae bloom having swallowed some of the water while swimming, a few hours later, the family suffered gastrointestinal symptoms which were self-limited except in the child's case, who was admitted to hospital in Uruguay with diarrhea, vomiting,

fatigue, and jaundice (Andrinolo *et al.*, 2017). Dialysis, a concern besides algal toxins, was also experienced in a medical facility in Brazil. 116 of 130 patients at the medical facility experienced weakness, anorexia, vomiting, headache, visual disturbance, gastric ache, pallor of mucous membranes, nausea, painful hepatomegaly, urinary bleeding, cold extremities, diarrhea (Carmichael, 2005; Zaccaroni and Scaravelli, 2014).

2.4 Land use

Urbanisation, defined as the population shift from rural areas to urban areas, the gradual increase in the proportion of people living in urban areas, and the ways in which each society adapts to this change, has led to substantial anthropogenic modification of the environment (Bocquier, 2005). Deep lakes, such as Lake Victoria, and Lake Edward; shallow lakes, such as Lake George, and Lake Kyoga; and man-made lakes such as Kabaka's lake all indicated that by far the most important problems concerning nutrients in Uganda are related to urbanization (Nyenje *et al.*, 2010; Robarts *et al.*, 2018) which is a major challenge faced by Kampala wetland systems (Muchelo, 2018). 72% of the pollution loading into Lake Victoria shores is by urbanisation compared to 13% by industries and 15% by fishing villages.

Land use is the total arrangement, activities, inputs, management, and modification that people undertake in a certain land cover type, like; a built environment from a natural environment, production of goods (crops, timber and manufactures) and services (defence,

recreation, biodiversity and natural resources protection) (Pierre *et al.*, 2016; Msofe *et al.*, 2019).

Agricultural land, built-up area, open water are some of the land use classifications in Kampala of which there has been prevailing changes in their footprint between 1984 and 2015. There has been expansion of built-up land (20.58% to 49.59%) and open water bodies (not detected in 1984 to 1.74%), and decreases in; agricultural land (from 43.88% to 26.10%), forestland (from 23.78% to 17.49%), and wetlands (from 11.76% to 5.08%) (Kiggundu *et al.*, 2018).

Various land use activities such as cultivation have resulted in wetlands being drained and new agricultural plants being introduced which has led to soil erosion and flooding. Construction in wetland has also been a pathway to dumping of waste, debris that has led to destruction of the wetland, hence the need to measure land use and its impact on ecosystem (classify land use classification) (Gumm, 2011).

Land use classification is the consolidation of physical land attributes defining a region and what the cultural and socio-economic function that the land serves by providing labels, describing the physical land type to represent how a land area is being used, quantitatively showcasing the changes in habitation, vegetation, water areas over a span of years through delineation of homogeneous groups of catchments (Toth, 2013). Land use maps, employed for analysis of different classes using image classification tools in ArcGIS

software from Linear Imaging Self Scanning Sensor (LISS-III) satellite images and Landsat Enhanced Thematic Mapper Plus (2008 and 2015) and supervised classification techniques, were useful for developing and implementing valuable management strategies for resource protection in arid areas in India (Pande *et al.*, 2018). Also Akyürek et al. (2018) successfully demonstrated the total and annual environmental changes during the construction Istanbul Grand Airport in Turkey by use of Multi–Temporal Satellite Dataset as used by Pande.

Through land use classification, excrement through sewers, industrial effluent, urban and agricultural excess and saline intrusion, poor waste management, soil particles from construction and demolition sites, oil and toxic chemicals from car maintenance and runoff from road surfaces are among the other water pollution sources that have immeasurably increased over the period of the past few years, in turn distressing wetlands water quality hence social, ecological, and economic consequences, eutrophication status of water bodies may be assessed such as for Kabaka's lake (Rashid *et al.*, 2018).

2.5 Quantification of effects of land use activities on surface water quality

Extensive field and process-based modeling research of individual catchments has improved understanding of the source and transport of nutrients from land to water. Effects of such factors that relate land use to water bodies quality have previously been quantified (Soranno *et al.*, 2015).

Statistical models have been used to simulate water quality, predicting future water quality conditions resulting from potential changes in lakes operations and/or environmental conditions by calculating concentrations of key water quality indexes (Trophic State Index), matched well with the measured values, to produce information that is extremely useful to water-quality managers in developing abatement management strategies (Zyfi *et al.*, 2014; Osborne and Waters, 2017; Jangamshetti and Sonoli, 2018). TSI is a numeric index of lake trophic status on a scale of 1 to 100 (Table 2-1), the higher the number indicating greater nutrient enrichment. The Trophic State Index is used by the Water Atlas to provide the public with an estimate of their lake resource quality. A "Good" quality lake is one that meets all lake use criteria such as, swimmable, fishable and supports healthy habitat. A trophic state below 60 indicates lakes in this range and these lakes are given the "Good" descriptor. A trophic state above 60 but below 70 can be considered highly productive and a reasonable lake for fishing and most water sports. This lake is considered "Fair", while a lake in the Hypereutrophic range with a TSI greater than 70 will probably not meet the lake use criteria and these lakes are considered to be poor.

Table 2-1: Trophic State Index (TSI) for lakes and Estuaries

TSI	Chl-a (mg/l)	TP (mg/l)	TN (mg/l)	Status	Range	Trophic State Classification
0	0.3	0.003	0.06	Good	0 - 59	Oligotrophic through Mid-Eutrophic
10	0.6	0.005	0.1			
20	1.3	0.009	0.16			
30	2.5	0.01	0.27			
40	5	0.02	0.45	Fair	60 - 69	Mid-Eutrophic through Eutrophic
50	10	0.04	0.7			
60	20	0.07	1.2			
70	40	0.12	2	Poor	70 - 100	Hypereutrophic
80	80	0.2	3.4			
90	160	0.34	5.6			
100	320	0.58	9.3			

Source: (Zyfi *et al.*, 2014)

For example;

- a) A statistical model was successfully used to simulate thermal stratification and modeling outlet water temperature in the Karkhe Reservoir in which confirmed that thermal stratification occurs once a year (Shojaei, 2017).
- b) The above statistical model was also used to quantify the total maximum input load of Torrão reservoir on Tâmega River in Portugal, and classified it as mesotrophic (Mateus *et al.*, 2014).
- c) The above model was also used on Lake Zorinsky in Omaha, Nebraska to compute temperature, dissolved oxygen, and nutrients using semi-deterministic algorithms so as to obtain the capability to quantifiably assess, with acceptable uncertainty,

the effects that operation of district projects have on its water quality conditions to guide in priority water quality management (McCutcheon, 2006).

- d) The above model was also used to evaluate the trophic status in 29 Portuguese reservoirs based on quantifying the present Chlorophyll-a and Total Phosphorous loads and forecast the nutrient loads in several catchment management scenarios where Chlorophyll was confirmed to be the most adequate indicator to classify the trophic level in the reservoirs, which would be overestimated using the Total Phosphorous due to the role of terrigenous material originated by soil erosion (Technico, 2009).
- e) The above model scenario simulations results by Kim, Donghwan, showed that P reduction in the sewage treatment plant (STP) effluent from 0.9 mg/L to 0.1 mg/L would effectively reduce the chlorophyll a concentration in the Lake Uiam, Korea by 62% hence confirming the major cause of eutrophication (Kim, 2019).

The current instrument used to combat eutrophication is the Baltic Sea Action Plan (BSAP), which relies on the integrated ecosystem approach for setting eutrophication indicator targets to achieve good environmental status and environmental sustainability (Jetoo, 2018).

2.6 Eutrophication Management

Developing countries remain the weakest link in the global chain of sustainable development, since there is often no formal legislation or action to control nutrients going

into water bodies in relation to achievement of SDG-6 (United Nations, 2004). Most of the world's developing countries are located in tropical climates where algal blooms due to eutrophication may occur throughout the year because of constant annual solar input and higher temperatures, and studies conducted about eutrophication and algal blooms are limited (Wells *et al.*, 2015). There is an urgent need to make practical use of studies such as Wells *et al.*, 2015 and others reflected in and developed mitigation options, strategies, techniques and measures (both external and in-lake) to enable both accurate assessment and the effective long-term control of lake eutrophication such as on Kabaka's Lake in Uganda.

External measure reduces excessive nutrient load that will stimulate the excessive growths of aquatic plants in the water body. This approach is the most effective techniques in reducing the pollutant load and provides long-term improvement effect to the water quality to the In-lake measure that is concentrated on treating the cause of eutrophication and algal bloom problems (Qin *et al.*, 2006).

The external and internal eutrophication management measures are briefly present in the following sub sections.

2.6.1 External measures

- a) **Advanced waste water treatment (AWT):** Through chemical treatment, advanced biological treatment or a combination both, wastewater treatment plants

have reduced nutrients (P and N) (Yamashita *et al.*, 2014; Osborne and Waters, 2017; Jangamshetti and Sonoli, 2018). For example, AWT reduced P load in Lake Zurich, by up 54 percent (Zurich, 2017). However the cost of installing and running treatment facilities, has been disadvantageous to developing countries in application of this measure.

- b) **Waste water or runoff water diversion:** Nutrient rich water is rerouted through use of; galleries, canals, trenches, preventing it from entering eutrophic lakes that have uncontrollable external nutrient loads from either point or non-point source pollution (Brown *et al.*, 2000). Diversion method application in 1963 on Lake Washington decreased P load up to 28 percent while nitrate reduced less than 20 percent (Thomas *et al.*, 2016). However, such a measure may initiate poor water quality at downstream water bodies where the diverted water is returned.
- c) **Constructed wetlands:** Constructed wetlands are engineered treatment systems that use natural functions involving vegetation, soils, and their associated microbial to improve water quality through trapping nutrients by microorganism or plant uptake (Eizein *et al.*, 2016). 84.32% phosphate load reductions (0.77 gP.m₂ year₁), was achieved in Brillion Marsh, a 156 ha natural wetland in Wisconsin that previously had a hydraulic loading rate of one centimeter per day carried a load of 12.6 gP.m₂ year₁ (Kadlec, 2016). Nevertheless, effective wetland performance depends on effective maintenance (vegetation management, nuisance pest or insects control and odour control) due to leaks in piping system, clogged low flow orifice, breached berms, and storm water drainage.

- d) Law and regulations:** Nutrient export to water bodies can also be controlled by legislation and regulation. For example it is possible to control or restrict the quantity of phosphates in detergents. Only 23% by mass of P in detergent is permitted in Germany and 4% P by mass in detergent is allowed in Italy (Glennie *et al.*, 2002). However no such regulation is found in developing countries, may be because non-point sources such as urban runoff and agricultural runoff are the main concerns in developing countries.
- e) **Buffer strips:** A vegetative buffer strips which are narrow strips of permanent vegetation may help to reduce pollutant in surface runoff from agricultural land into the surrounding water bodies. A study on the effectiveness of buffer strips in removing the pollutants in runoff showed that buffer strips may reduce the runoff volume by 35–90%, sediment concentration by 42–94%, nitrate concentration by 35–88% and phosphate concentration by 28–95% (Saleh *et al.*, 2017).

2.6.2 In-lake measures

- a) **Chemical control:** This method involves the application of specific chemicals to water bodies as to remove nutrients or kill plants. The method works rapidly well on shallow eutrophic lakes such as Kabaka's Lake. A study case on eutrophic shallow Dianchi Lakes in China, application of copper sulphate reduced total phosphorus (TP) in the water column by 60~85% and 84.87% and 75.07% for the Chl-a concentrations (Wu *et al.*, 2005).

- b) **Plant harvesting;** This method involves hand-pulling or mechanical harvesting, cutting or mowing of nuisance growth of macrophytes and attached algae from the water body which are then collected and safely disposed. In 2014, two harvesting efforts (July and August) were effective at reducing to 53% of the TP inflow load (16.4 kg) on Casey Lake (Pilgrim *et al.*, 2017). In contrast, a similar study conducted in Chemung Lake, Canada, gave an efficiency of 92% of net annual P loading in the harvested lake (Thomas *et al.*, 2016). Continuous harvest during the growing season was needed with a drawback that it is usually energy and labour intensive.
- c) **Dredging / sediment removal;** Dredging or sediment removal works by removing the upper layers of the lake bottom sediments to reduce internal nutrient and algal production by preventing the release of P from the sediment. Successful result also been recorded in shallow tropical lakes such as Meiliang Bay, Taihu Lake (China), dredging had a significant controlling effect on phosphorus release ($p < 0.05$) (Zhong *et al.*, 2018).
- d) **Biomanipulation:** Biomanipulation is the deliberate alteration of an ecosystem by adding or removing species (fish and zooplankton), especially predators as a biological control for lake restoration as influenced by top-down and bottom-up forces (Peretyatko *et al.*, 2012). Lake Væng, Denmark, a 16 ha shallow lake, shifted from a turbid, phytoplankton-dominated state to a clear, water macrophyte-dominated state after being biomanipulated were also TP was reduced from about

0.12 to 0.07 mg.L-1 and TN decreased from 1.0 to 0.4 mg.L-1 (Søndergaard *et al.*, 2017).

Table 2-2: Summary of some of the reviewed Nutrient reduction strategies

Measure	Study/ Application	Country	Nutrient reduction Effectiveness	Citation
External Measures				
Advanced waste water treatment (AWT)	Quality of Life in Lake Zurich	Switzerland	54% TP reduction	(Zurich, 2017)
	Proactive protection of the Baltic Sea	Baltic Sea	50% load reduction	(Uta <i>et al.</i> , 1950)
	Tertiary treatment stage of Wastewater		55% TN and 40% TP reduction	(Boeriu <i>et al.</i> , 2013)
Waste water or runoff water diversion	Lake Washington restoration using the diversion method	USA	28% TP and 20% TN reduction	(Eizein <i>et al.</i> , 2016)
	Management of nutrient losses	Denmark	40% TN reduction	(Aloe <i>et al.</i> , 2014)
	Lake Okeechobee	Florida, USA	73 % TP reduction	
Constructed wetlands	Large Constructed Wetlands for Phosphorus Control	Canada	84.32% TP reductions	(Kadlec, 2016)
	Removal of nutrients in various types of constructed wetlands	USA	40~50% TN and 40~60% TP reduction	(Vymazal, 2018a)
Buffer strips	A Review of the Use of Buffer Strips for the Maintenance and Enhancement of Riparian Ecosystems	Canada	45% to 184% TN reduction	(Hickey and Doran, 2002)
	Effectiveness of buffer strips in removing the pollutants in runoff	Canada	35~88% TN and 28~95% TP reduction	(Saleh <i>et al.</i> , 2017)

Table 2 2: Summary of reviewed Nutrient reduction strategies **continued**

Measure	Study/ Application	Country	Nutrient reduction Effectiveness	Citation
Internal Measures				
Chemical control	Eutrophic of shallow Lakes (Dianchi Lakes)	China	60~85% TP and 75.07%~84.8 7% Chl-a reduction	(Wu et al., 2005)
	Manitoba Prairie Lakes: Eutrophication and In-Lake Remediation Treatments	Canada	40~70% TN and 35~80% TP reduction	(Lewtas, 2015)
Plant harvesting	Aquatic plant harvesting: An economical phosphorus removal tool in an urban shallow lake (Casey Lake)	USA	53% TP	(Pilgrim <i>et al.</i> , 2017)
	Weed harvesting on Chemung Lake	Canada	92% of net annual TP	(Thomas <i>et al.</i> , 2016)
Dredging / sediment removal	Meiliang Bay, Taihu Lake	China	Tp < 0.05	(Zhong <i>et al.</i> , 2018).
	Manitoba Prairie Lakes: Eutrophication and In-Lake Remediation Treatments (Lake Trummen),	Sweden	80% TN and 90% TP reduction	(Lewtas, 2015)
Biomanipulation	Repeated Fish Removal to Restore Lakes: during	Denmark	58.3% TP and 40% TN reduction	(Søndergaard <i>et al.</i> , 2017).
	Reviewed lake restoration projects carried out in Denmark and the Netherlands	Denmark	82 % TP and 69% TN reduction	(Lewtas, 2015)

2.6.3 Decision matrix using simple additive weighting

Multi criteria assessment (MCA) refers to the methodology used to establish exact connection between decision making using simple additive weighting and evaluation criteria by the user in consideration of the goals and objectives to manage eutrophication (Kadlec, 2016). The usage of score and weight is explicitly developed according to the established techniques. According to Nor Zalina Kasim, the following were the steps used in selection of the best mitigation and management strategies for reducing eutrophication in tropical humid regions (Kasim, 2015).

Step 1: Identified the 15 measure options including those reviewed in Table 2-2.

Step 2: Categorized the identified optional measures on five criteria basis; Effectiveness (C1), Longevity (C2), Confidence (C3), Impact (C4) and Cost (C5).

Step 3: Obtained performance score for the decision matrix by using the five previously established criteria, an estimated measurement were given to each measure option and rated by the keywords of “Excellent”, “Good”, “Fair” and “Poor” as an evaluation criteria as elaborated in Table 2-3.

Table 2-3: Rating definition for the measures criteria

Criteria	Excellent	Good	Fair	Poor
Longevity (C2)	$C2 \geq 5$ year	$5 \geq C2 \geq 1$	1 year without reapplication $\geq C2$	1 year with few reapplication $\geq C2$

The keywords such as, excellent, good, fair, and poor were then expressed into fuzzy logic (Table 2-4) since the criteria are always in different units.

Table 2-4: Fuzzy number for score

Linguistic term	Linguistic value
Excellent	1
Good	0.75
Fair	0.5
Poor	0.25

Step 4: Linguistic variables of five linguistic terms (“Very Unimportant”, “Unimportant”, “Fair”, “Important”, and “Very Important”) for the importance of each criterion expressed in fuzzy number as shown in Table 2-5 were used.

Table 2-5: Fuzzy number for criteria

Linguistic	Fuzzy number
Very Important	1
Important	0.8
Fair	0.6
Unimportant	0.4
Very unimportant	0.2

Step 5: Decision matrix ranking was made by multiply the weights representing the relative importance of indicators by the normalized scores and summed up to determine the overall score of the measure options from which the highest scoring option according to the ranking was used as the best option. The evaluation matrix was calculated based on Equation 2-1 which was derived from the general additive value function as used by Roy (1990) and Hobbs et al. (1992) as below;

$$A_i = \sum_{j=1}^m S_{ij} (W_j) \quad \text{Equation 2-1}$$

Where;

A_i = measures alternative;

S_{ij} = performance score of the alternative for criteria j , $i=A_1, n$; and

w_j = weighting factors for the criteria, $j=1, \dots, n$;

2.6.4 Sediments nutrients

The study on Bukit Merah Reservoir, Perak in Malaysia established that there is a significant relationship between sediment phosphorus and Surface water phosphorus - ($r = 0.517, p < 0.003, n = 30$), sediment nitrogen and surface water nitrogen - ($r = 0.448, p < 0.013, n = 30$) because of the high value of determination of correlation (R^2). Both relationships had a trend of decreasing concentration from upstream to downstream (Talib *et al.*, 2016). A liner regression relationship between amounts of phosphorus adsorbed by the sediment and that dissolved in water column exists (Usda-ars, 2007).

2.6.5 Wetland management studies

Constructed wetlands (CWs) are engineered systems that are designed and constructed to make use of natural processes in treating wastewater (Oirschot et al., 2017). Wetlands naturally act as main buffers between pollution sources and adjacent aquatic or terrestrial ecosystems (Luangcharoenrat *et al.*, 2017). Wetlands such as mangroves, saltmarshes and coral reefs play crucial roles in controlling flood peaks and spreading the water table since they act as permeable barriers that slow waves. This also increases their ability to retain nutrients from the inflowing water (Fisher *et al.*, 2004). Numerous studies (including those highlighted in Table 2-6) have testified the possibility of wetlands in meeting wastewater treatment standards basing on various factors including; which determine their effectiveness and performance.

Table 2-6: Citation review for various studies on Constructed wetlands efficiency

Title/ Study	Efficiency	Citation
Removal of Nutrients in various Types of Constructed Wetlands	40%-50% TN load reduction (250 and 630 $\text{gNm}^{-2} \text{yr}^{-1}$) 40%-60% TP load reduction (45 and 75 $\text{gNm}^{-2} \text{yr}^{-1}$)	(Vymazal, 2018b)
Intensification of constructed wetlands for land area reduction	78% TN load reduction and 54% TP load reduction	(Ilyas and Masih, 2017)
Constructed wetlands as urban water constructed wetlands as urban water quality control ponds - studies on reliability and effectiveness	96% TN load reduction and 96% TP load reduction	(Thomas <i>et al.</i> , 2016)

Table 2-6: review for various studies on constructed wetlands efficiency continued

Title/ Study	Efficiency	Citation
Wetlands for wastewater treatment and subsequent recycling of treated effluent in Karachi	49% TN load reduction 52% TP load reduction	(Almuktar <i>et al.</i> , 2018)
Wetlands for wastewater treatment and subsequent recycling of treated effluent: a review assessed the possibility of recycling domestic wastewater treated by vertical-flow constructed wetlands for crop irrigation	49% TN load reduction 52% TP load reduction	(Qing <i>et al.</i> , 2014)
Designed constructed wetlands for maximal nitrogen removal and minimal nitrous oxide (N ₂ O) emission.	90% TN load reduction	(Ward and Jensen, 2014)
Advanced treatment of mixed wastewater	52% TN load reduction 45% TP load reduction	(Martinez <i>et al.</i> , 2018)
A pilot study on municipal wastewater treatment using a constructed wetland in Uganda	58% TN load reduction 37% TP load reduction	(Okurut, 2000)

Source: (Fisher *et al.*, 2004)

Several research studies (Table 2-7) have also been dedicated as other options of reducing constructed wetland footprint besides achieving good quality effluent (Molle, 2012; Zhang *et al.*, 2012; Wu *et al.*, 2014).

Table 2-7: Citation review for constructed wetlands foot print and efficiency studies

Depth (m)	Area (acres)	HLR (m ³ m ⁻² d ⁻¹)	TN %	TP%	Reference
1.4	4.7	0.03	76	97	(Kantawanichkul <i>et al.</i> , 2018)
1.4	2.6	0.06	57	93	
1.4	1.8	0.12	75	55	
0.6	4.2	0.03	79	99	
0.6	1.9	0.06	64	90	
0.6	1.5	0.12	73	63	
1.0	2.3	0.16	82	67	(Ye and Li, 2009)
1.0	1.2	0.32	83	64	
0.6	3.2	0.06	24	49	(Foladori <i>et al.</i> , 2013)
0.6	6.4	0.03	78	98	
0.6	1.3	0.12	40	36	
0.6	2.6	0.06	75	64	
0.8	7.9	0.046	72	80	(Ilyas <i>et al.</i> , 2015)
0.8	3.4	0.046	82	61	
0.8	2.6	0.046	78	44	

Source (Ilyas and Masih, 2017)

2.7 Chapter Summary

This chapter has presented the reviewed literature largely with summarized earlier studies cited that are relevant to study and in line with the study objectives. It further details the key findings and knowledge gaps in literature review as presented below;

Findings

- i. Studies have shown that P primary limiting nutrient factor is more pronounced in fresh water lakes like Lake George,
- ii. The most significant change in land use classification over years has been built-up areas confirming urbanization bloom.

- iii. Developing countries are more prone to eutrophication due to constant annual solar input and higher temperatures characterized in tropical climates throughout the year.

Knowledge gaps

- i. Studies conducted about eutrophication and algal blooms are limited in tropical regions
- ii. Legal framework gap is deterring nutrient regulating composition in products

The next chapter expounds on the adopted methodology used to carry data collection and analysis for the study.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the broad four principles of the research methodology that were adopted for the detailed Kabaka's Lake eutrophication assessment in relation to selection of abatement management strategies. These principles include; Literature review, Baseline data collection and analysis, pollution modelling, selection of management strategies.

3.2 Research design

This research was based on experimental data for numerical modeling following the pattern (Figure 3-1);

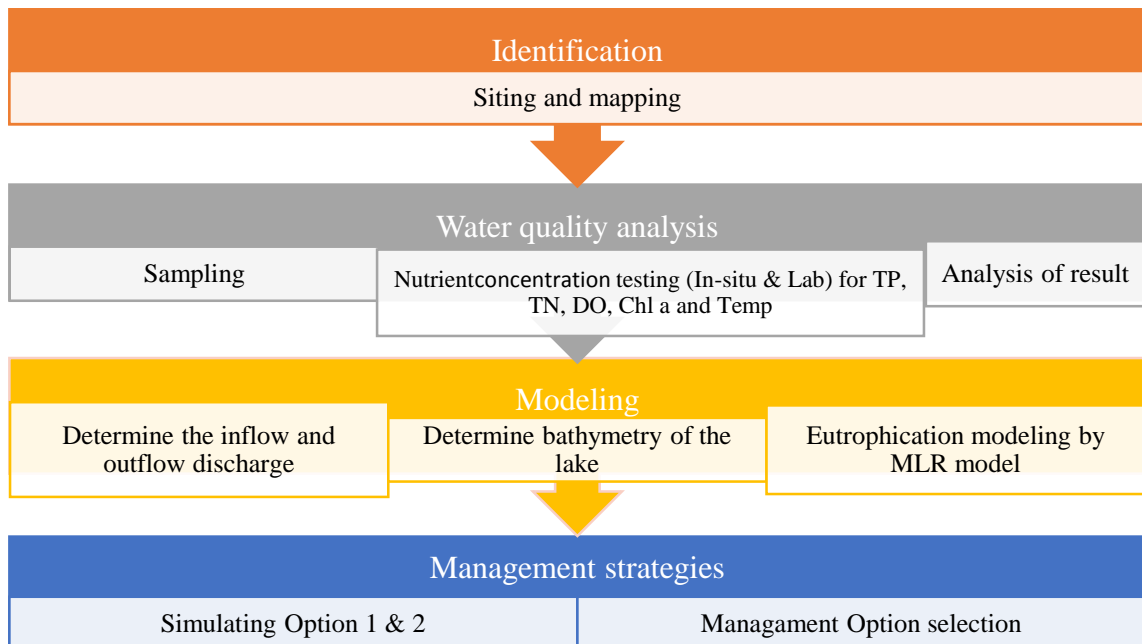


Figure 3-1: Proposed Theoretical and Conceptual methodology pattern

3.3 Research approach

A quantitative research approach was used, basically relating land use activities and nutrient pollution concentration statistical data to enable selection of eutrophication abatement measures for Kabaka's Lake located in Lubaga Division, Kampala District.

3.4 Data collection and analysis

Field data was collected from Kabaka's Lake catchment as primary data, and a review of the available literature (Chapter two) concerning the catchment, eutrophication, Draft Kabaka's Lake Redevelopment Environmental and Social Impact Assessment report and management strategies was undertaken as secondary data.

Step 1: Kabaka's Lake catchment site reconnaissance

A site reconnaissance/ground trothing was conducted as to allow among other things identification and siting of; Land use activities and Water ways leading to the lake (water ways) which were geo-referenced using portable GPS (Garmin Etrex 20x GPS 3D model) and expressed in the WGS 84 system. Biomass Uganda data was used to classify the identified land use activities in the delineated Kabaka's Lake catchment using Arcmap11.

From the site reconnaissance visit, seven sampling points were selected in Kabaka's Lake catchment (Figure 3-2). Sampling point one (SP_1), located approximately 200 meters from the north eastern side of the lake, is a focal point through which all water ways from the North western side (settlements, and more than 0.8 acreage agriculture land) of the

main inlet of the lake flow bearing both nonpoint discharges and point discharges. Whereas discharges from north eastern water ways (University, church, settlements) flowed through SP_2 (approximately 175 meters). Mechanical workshops (garage), heavy vehicle parking lot, washing bay and the church kitchen surrounded SP_3, located approximately 300 meters north east of the lake. SP_4 located approximately 500 meters, was selected due to; mixed farming (majorly banana plantation, beans, gnuts and maize) on a 0.46 acres, dense settlements, restaurants and 2 mechanical workshops.

Last but not least, SP_5 was located in the middle of the lake at the deepest section (determined by the bathymetry) since it would give a representative gab sample from various water levels of the lake. Additionally two more samples were analyzed from the lake; from the Lake Inlet (SP_LI) since it's heavily affected by runoff during the wet season and growing indigenous vegetation cover in its riparian margin and Lake Outlet (SP_LO) due to the washing bay activities in the 1 meter radius of the out let weir.



Figure 3-2: Kabaka's Lake pollution hotspots location map

Step 2: Sampling

Surface water sampling was conducted in consideration of the weather conditions for only dry season; Sunny days (28th/02, 15th/03, and 23rd/03) and rainy days (20th/02, 4th/03, 27th/03) at identified locations (Table 3-1 and Figure 3-2). Prior to sampling, the research team wore protective wear to avoid sample contamination and a tool kit drill was conducted as to be conversant about the excises, equipment usage, sampling procedures and safety measures as per the sampling plan. Six (6) samples were abstracted by a collection container from locations (SP_1, 2, 3, 4, LI, and LO), however from SP_5, a three (3) level sampling depth technique was deployed; surface (, sub surface, and deeper end (near the water bed), all collected by the Vendome (78-300 field master Horizontal bottle-Figure 3-3a) and mixed in the collection container to obtain a composite sample.

At each sampling location (Figure 3-4); three sample replicates were collected and each measured (In-situ-Figure 3-3b) subsequently using the water quality meter to get a worthy representation (Average) of the water quality characteristics such as Temperature, Dissolved Oxygen, pH, colour, and atmospheric pressure. From the samples collected, two replicate samples (one for analysis and the other to act as a control / backup sample) were packed in 1L plastic bottles, labelled, assigned a unique identifier, preserved in a cooler box with ice packs and transported (Figure 3-3c) to Makerere Chemistry laboratory and National Water and Sewerage cooperation for analysis within less than 2 hours.

Table 3-1: Sampling location for water quality

<i>Sampling point ID</i>	Sampling Location		Justification for considering sampling location/ Land use activity
	<i>Easting's</i>	<i>Northings</i>	
SP_1	451091	33261	Agricultural area
SP_2	451144	33277	University/ churches and settlements
SP_3	451213	33408	Kitchen and Garage service area
SP_4	451181	33653	Restaurants, Settlements, Agriculture area
Lake			Eutrophication study case
L1	451198	33110	Main Inflow of the lake
SP_5	451222	32882	Middle section and Deepest end of the lake
LO	451208	32701	Outlet section of the lake



(a) Sampling with a Vendome



(b) In-situ measurements



(c) Sampling, storage and transportation

Figure 3-3: Sampling along Kabaka's lake



Figure 3-4: Kabaka's Lake sampling map (SP_1, SP_2, SP_3, SP_5, LI and LO)

Step 3: Lab analysis

Chlorophyll-a was analyzed at National water and sewerage cooperation (NWSC) laboratory using fluorometric method whereas TP and TN were analysed at Makerere University public health and environmental engineering laboratory (Figure 3-5) by the following procedure;

Nitrates (N) - Cadmium Reduction Method (Using Powder Pillows)

10 ml of sample were poured into 2 test tubes, to which Nitra Ver 5 Nitrate reagent powder pillow was added to one and shook vigorously for 1 min while the other was left as a blank. Placed first the blank into the test-tube holder, read off a zero reading, and then replaced it with the other test tube and read off the calorimeter reading in mg/l.

Phosphorus (P) – Persulphate digestion Method

Poured 50 mls of Distilled water, Stock solution, and Sample into a beaker, added 1 drop of Phenolphthalein Indicator (PPI), 1 ml of sulphuric acid, and 0.5 g of potassium persulphate, then autoclaved for 30 minutes at 121°C. Left them to cool for 20 min, then added 1 drop of PPI and titrated with 5 N of sodium hydroxide to a faint pink colour. Added 50 ml of distilled water to the content, followed by 1 drop of PPI, and 8 ml of combined reagent. Mixed well and let to stand for 20 min, placed first the distilled (read off zero), followed by the stock (read off 0.245), then the sample and took readings.



Figure 3-5: Sample Lab analysis (a- Lab Setup for analysis, b- Sample analysis)

Step 4: Lake's Bathymetry

The lake's total survey area was sub-divided equally into grids of size 30x30 m (segments- Figure 3-8) using Arc map and a hand held depth finder (H22FX Handheld Sonar System with LED Flashlight, Figure 3-6) was used to take the water depth readings (Figure 3-7) of various points along the grid lines which data was input into GIS software for Bathymetric modelling.



Figure 3-6: Hawkeye Hand held depth finder



Figure 3-7: Bathymetry survey

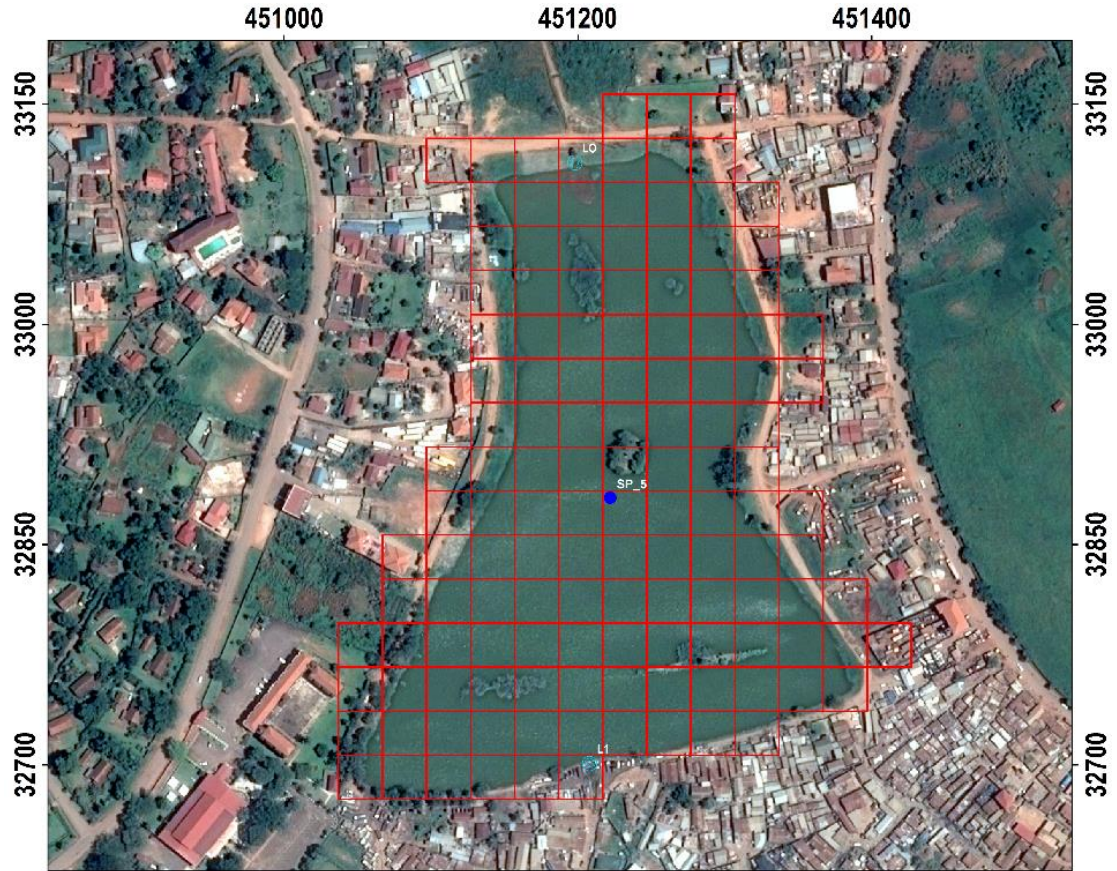


Figure 3-8: A 30 x 30 m grid Index

The findings of the bathymetry study were referenced with secondary data (1st August, 2017) obtained from the draft Kabaka's Lake ESIA report and interpolated to develop bottom surface layer for Kabaka's Lake. Critical factor in determining the amount of dredging required was the depth of the water at which self-purification of water will occur due to thermal stratification to ensure satisfactory water quality. The Average End Method was used to estimate likely dredge volume. Cross-sections across the Lake were taken at a constant interval and the quantity computed based on the volume between the cross-sections.

Step 5: Classification

For the purpose of this study the multispectral Landsat satellite images (LSI) of different epochs, produced by USGS in GeoTIFF format were downloaded from <https://earthexplorer.usgs.gov> and used (Table 3-2). The study area was contained within the Landsat path 173, row 060, georeferenced by the EROS Data Centre (Sioux Falls, South Dakota) to less than ½ pixel root mean square error, registered to UTM coordinates, zone 36N, WGS84 Datum. Using the LIS natural and standard false colour [band 5 (SWIR 1), band 2 (green), band 4 (NIR) and band 1 (blue)], composite images were generated to achieve a general description of LU/LC changes.

Table 3-2: Detail characteristics of the Landsat satellite imageries used in this study

Request ID	WRS:P/R	Acq. Date	SENSOR_ID	Optimum Band Indices	Optimum Band Factors
0701902057935_00071	1:173/060	2019-02-04	OLI_TIRS	B1- B2 - B5	6087.47
0501701250730_06121	2: 173/060	2003-01-31	ETM+	B1- B4 - B5	48.28
0501701098471_17164	3: 173/060	1995-01-17	TM	B1- B4 - B5	49.05

The System for Automated Geoscientific Analyses (SAGA) GIS software (v. 2.0.7) was used for the preliminary data processing through training at least 50 selected areas (using Equation 3-1 to achieve a significant accuracy of more than 75%), extracting clipped Landsat scenes from delineated catchment extent, supervised classification and post classification comparison to produce change detection maps. Areas depicting the various defined land covers were digitized from the aerial photography and topographic maps.

$$N = \frac{Z^2(p)(q)}{E^2} \quad \text{Equation 3-1}$$

Where; P = Expected percent Accuracy, q = 100 – p, E = Allowable error and Z = 2 (from the standard normal deviate of 1.96 for the 95% two-sided confidence interval)

3.4.1 Nutrient concentration prediction

Running a Multiple linear regression (MLR) build model, a forecast was obtained and validated through smoothening (removing seasonality and irregularity component) and deseasonalization at 0.0001 toleranc.

Accuracy assessment of the models to predict water quality values

The standardized residual normal Q-Q plot for each raw water quality parameter of the training dataset were done to assess the normality distribution of the residuals for the two variables (dependent and independent). A comparison of the observed values versus the predicted values of raw water quality was plotted and the line of best fit was determined. Pearson correlation coefficient (r^2) was then used to understand how well the predicted values were related to the observed raw water quality values. Using the Trophic State Index (TSI) developed by Carlson (1977), the TSI index ranges from 0 to 100 was used to assign a trophic state “grade” to a lake basing on the following equations in (Table 3-3).

Table 3-3: TSI Equations

Secchi disk	$\text{Ln}(\text{SD}) = 2.04 - 0.68 \text{Ln}(\text{CHL})$	Equation 3-2	(Carlson, 1977)
	$\text{TSI}(\text{SD}) = 60 - 14.41 \text{Ln}(\text{SD})$	Equation 3-3	
Chlorophyll a	$\text{TSI}(\text{CHL}) = 9.81 \text{Ln}(\text{CHL}) + 30.6$	Equation 3-4	(Paulic, Hand and Lord, 1996)-Page 87
TP	$\text{TSI}(\text{TP}) = 14.42 \text{Ln}(\text{TP}) + 4.15$	Equation 3-5	
TN	$\text{TSI}(\text{TN}) = 10 * [5.96 + 2.15 \text{Ln}(\text{TN} + 0.001)]$	Equation 3-6	
Nitrogen Limited Lakes (TN/TP)<10)	$\text{TSI} = [\text{TSI}(\text{CHL}) + \text{TSI}(\text{TN})] / 2$	Equation 3-7	

In assumption that the current lake status is nitrogen limited, the relationship between total phosphorus and chlorophyll was established by use of Equation 3-10 and 3-11 for prediction modelling (Dillon and Rigler, 1974).

$$\text{Ln Chl} = 1.449 \text{Ln TP} - 2.616 \quad \text{Equation 3-8}$$

$$\text{Ln SD} = 3.876 - 0.98 \text{Ln TP} \quad \text{Equation 3-9}$$

The model was used to predict the lakes TP concentration, TN concentration and TSI for a 5 year range period (5, 10, 15, 20, 25, and 30 years).

3.4.2 Determination of Significance

The study adopted P value, a number between 0 and 1 as a statistical measure for determining whether the subject hypothesis is correct hence significance of results. The null hypothesis (H_0) was a default position that there was no relationship between two measured data sets or phenomena and the alternative hypothesis (H_a) was the one used to believe if the null hypothesis is concluded to be untrue. XLSTAT, a statistical software was used to help calculate the p-value at a pre-defined threshold (α) of 0.05 by

corresponding it from the obtained Z value (Equation 3-12 and z table). To this a small p-value, which is lesser than the level of significance indicated rejection of the null hypothesis and that which was greater indicated that failure to reject the null hypothesis.

$$z = \frac{\hat{p} - p^0}{\sqrt{\frac{p^0(1 - p^0)}{n}}} \quad \text{Equation 3-10}$$

Where \hat{p} is Sample Proportion, p^0 is Assumed Population Proportion in the Null Hypothesis, n is the Sample Size and Z is the test statistic

3.5 Selection of eutrophication management measures

Based on Kasim's (2015) dissertation Scenario 6 which assumed that there is a change in the land use pattern near the water catchment characterized by increased land use for agriculture and human settlement leading to increased pollutant concentration in the catchment. The scenario opted for longevity of the control techniques as the most important criteria for ranking the eutrophication management strategies (Kasim, 2015). Table 3-4 presents the eight identified management options for abatement of eutrophication of the lake.

Table 3-4: Ranked eutrophication Management Strategies

Nor Zalina Kasim's best Management Strategies applicable to this dissertation (Kasim, 2015)			Management options	
Option ID	Identified Option	Scenario Ranking	Option ID	
			Selected	Not Selected
External Measures				
A5	Law and regulations	1		OP-3
A1	Advanced waste water treatment (AWT)	2		OP-4
A4	Constructed wetlands	3	OP-1	
A2	Waste water or runoff water diversion	4		OP-5
Internal Measures				
A12	Dredging / sediment removal	1	OP-2	
A7	Chemical control	2		OP-6
A14	Biomanipulation	3		OP-7
A8	Plant harvesting	4		OP-8

Longevity of each measure reflects the duration of effect for the measures option. The measures option can be categorized as short term if the duration of its effect is only effective for one year or less.

- a) **Option 6, 7, and 8** (Internal measures) are short term measure. Both might be one of the most effective measures in controlling the algal bloom because it rapidly eliminates algae from water column and increase the water clarity immediately during the growing season. However, the duration of effect of may only last for several weeks or for a single growing season. Therefore, to increase the effectiveness and duration of effect, reapplication of chemical control, biomanipulation and plant harvesting might be needed hence triggering continuous management and monitoring (intervention). Based on Kasim rank under longevity criteria **Option 2** are long term measure was selected from the internal measures

for this study. It was also adopted in the sense of the increase in lakes sedimentation benchmarked on the 2017 Bathymetric study (Draft Kabaka's lake ESIA report), both assumed to be attributed to eutrophication concentration of the lake.

- b) **Option 1, 3, 4, and 5** (External measure) are long-term measure, effective for more than a year, hence bearing a lower continuous management and monitoring (intervention).
- **Option 3:** Law and regulations- the options requires review of the current environmental conservation, wetland and product (composed of N and P) legal frameworks including standards. A long term measure that requires a vigorous debt process from both the technical and political wing of administration. Enacting of such a measure comes with backlogs of implementation of such standards benchmarked on the week systems experienced in developing countries like Uganda.
 - **Option 4:** Advanced waste water treatment- adopting such an option for Kabaka's Lake would require more than 1.5 acres of land which is not available. The Cost burden of implementation and maintenance would be too high.
 - **Option 5:** Waste water or runoff water diversion; a trench or channel along the boundaries of the lake, diverting storm water away from the lake would be the cheapest measure, but only effective during storm events (months) since

it will be diverting away storm water runoff. This would not be able to reduce the nutrient concentration of the receiving streams of the lake.

Option (OP) 1 was adopted in the sense of the degrading wetland sited before the lakes inlet and its attribute to effectively reduce the nutrient concentration of the receiving streams of the lake.

3.5.1 Thesis management adoption

1) Option 1 Constructed wetlands

Basing on the Google Earth historical satellite Imagery, a trend of lakes receiving wetland foot print was established for the last 17 years (2002, 2011, and 2019) as presented in Figure 3-9. A bench mark of 2002 was established basing on the resolution of the imagery and the settlement pattern in the catchment.

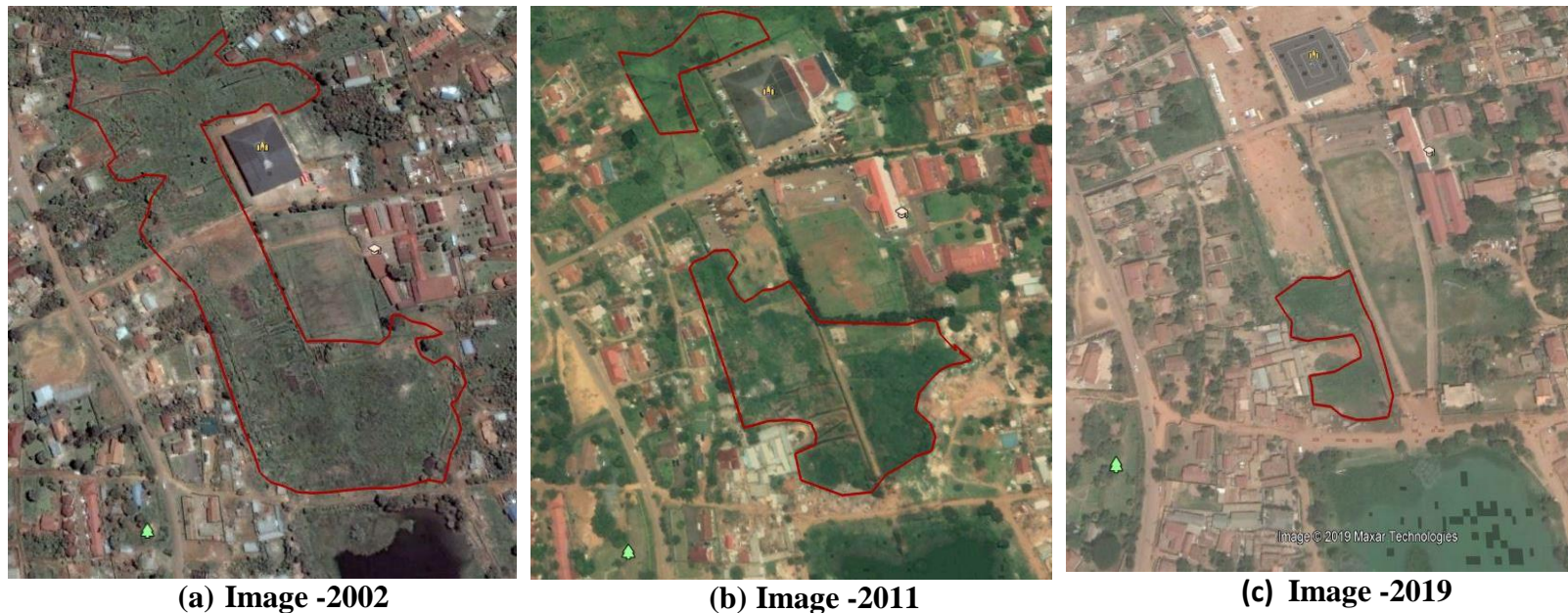


Figure 3-9: Lakes receiving wetland extent (foot print)

Guided by the recommended wetland footprint and nutrient reduction efficiency (Vymazal, 2010, 2018b; Ms *et al.*, 2013; Qing *et al.*, 2014; Ilyas and Masih, 2017; Almuktar *et al.*, 2018; Martinez-guerra *et al.*, 2018), the study adopted a nutrient reduction efficiency range (40% - 60%) for TN and (30% - 40%) for TP. This range was also benchmarked on the 40% TN and 36% TP reduction achieved by the 1.3 acreage vertical flow constructed wetland in Italy (Foladori *et al.*, 2013) and 58% TN and 37% TP reduction 320 m² total surface area wetland under the study of the Jinja Kirinya Sewage anaerobic lagoons (Okurut, 2000).

2) Option 2 Dredging / sediment removal

Critical factor in determining the amount of dredging required at a given depth of the water at which self-purification of water will occur due thermal stratification to ensure satisfactory water quality was understating the; quantities of sediment dredging limits and dredge depths by use of Arc- GIS. Average End Method (Equation 3-11) to estimate the likely dredge volume.

$$V = \sum L \frac{A_1 + A_2}{2} \quad \text{Equation 3-11}$$

Where: V = Volume, A₁ = Area from one end, A₂ = Area of another end and L = perpendicular distance between the two area-faces

Using Vollenweider model Equation 3-12, lake's phosphorous concentrations (P_{lake}) was estimated using a mass balance approach that included phosphorous inflow relating in-lake phosphorus (P_{lake}) inlet concentrations (P_{in}) and hydraulic residence time (tw) (Miller, 2018):

$$P_{lake} = \frac{P_{in}}{1 + \sqrt{tw}} \quad \text{Equation 3-12}$$

Using Brian's (2018) liner regression Equation 3-13, the lakes absorbed phosphorous concentrations (P_{sed}) was estimated from lake's surface water phosphorous concentrations (P_{lake}) (Usda-ars, 2007).

$$P_{sed} = 0.213 \times P_{lake} - 0.007 \quad \text{Equation 3-13}$$

3.6 Chapter Summary

This chapter has presented the methods used to carry data collection and analysis for the study such as site reconnaissance, sampling, lab analysis, lake's bathymetry measurements, land use classification, nutrient concentration prediction, and criteria for selecting best eutrophication management measures of Kabaka's lake. The next chapter expounds on the study findings in line with the study research questions, including catchment land use characterization, watershed nutrient profiling, and effectiveness of selected eutrophication management measures of Kabaka's lake.

CHAPTER FOUR: PRESENTATION OF RESULTS, ANALYSIS, AND DISCUSSION

4.1 Introduction

This chapter explains how land use has changed from 1995 to 2019 and nutrient distribution in Kabaka's lake catchment. It also details the selected eutrophication management measures for the lake.

4.2 Categorization of the anthropogenic activities in Kabaka's lake watershed

From the sited anthropogenic activities in relation to choice of sampling (Chapter 3, Figure 3-2) and the trained satellite Imagery of year 1995, 2003 and 2019 (Figure 4-2), the lakes catchment (1.69 Km²) bears majorly three land use classes; Buildup (Buildings and impervious surface), Vegetated (agricultural, forestry, large green compounds, wetlands and riparian area of the lake), and Water (water ways and lake). Over the last 25 years, there has been a significant redistribution of catchment land use (Appendix 3). Vegetation area was significantly ($p < 0.005$) greater than the built up area. Trends over time have shown that the buildup area increased by 78.5%, vegetated area reduced by 37.2% and water reduced by 1.8%, mainly attributed to increased settlements and paving in the catchment (Figure 4-1). Figure 4-3 expounds more on the various extents of change in land use, including distribution from vegetated to buildup ($P = 0.021$), water to vegetate ($P = 0.0002$) and water to buildup ($P = 0.001$) (see table in appendix 3). Most people in

the area have encroached on the lakes receiving wetland and the lake's banks downstream leading to a decrease in the area covered by the open water bodies.

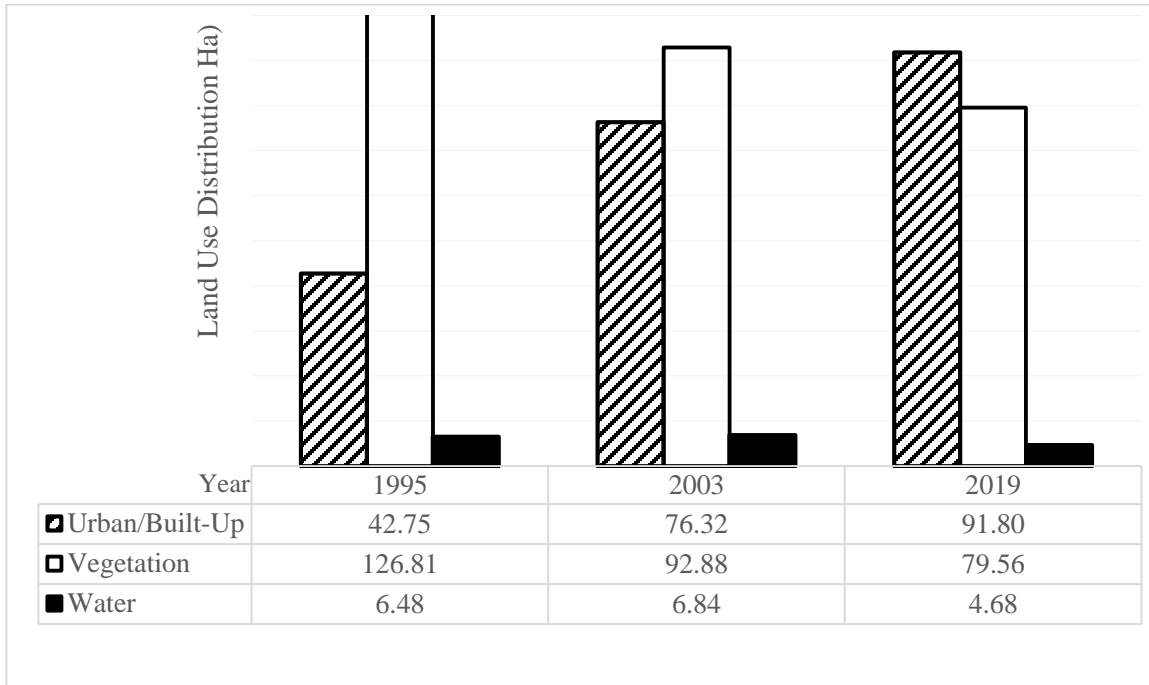


Figure 4-1: Lake Catchment Land Use distribution

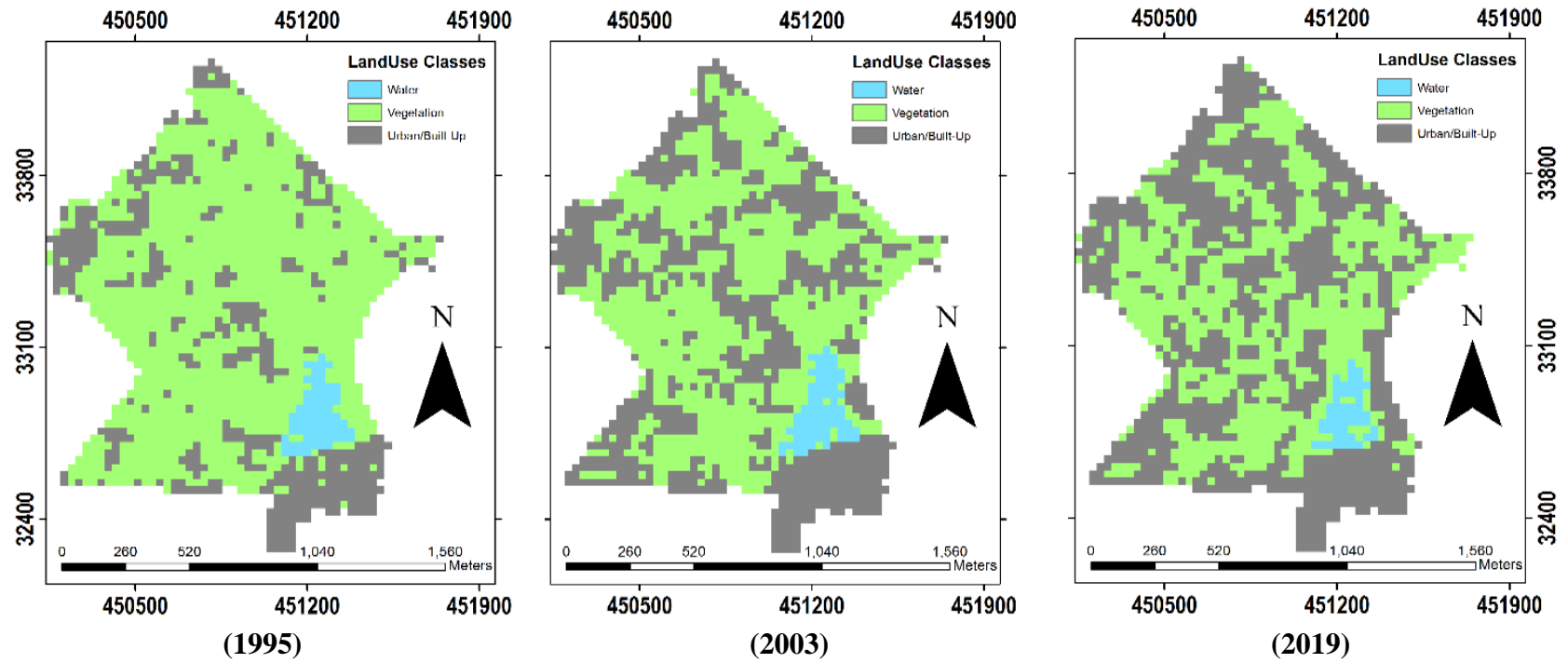


Figure 4-2: Lake Catchment Land Use delineation

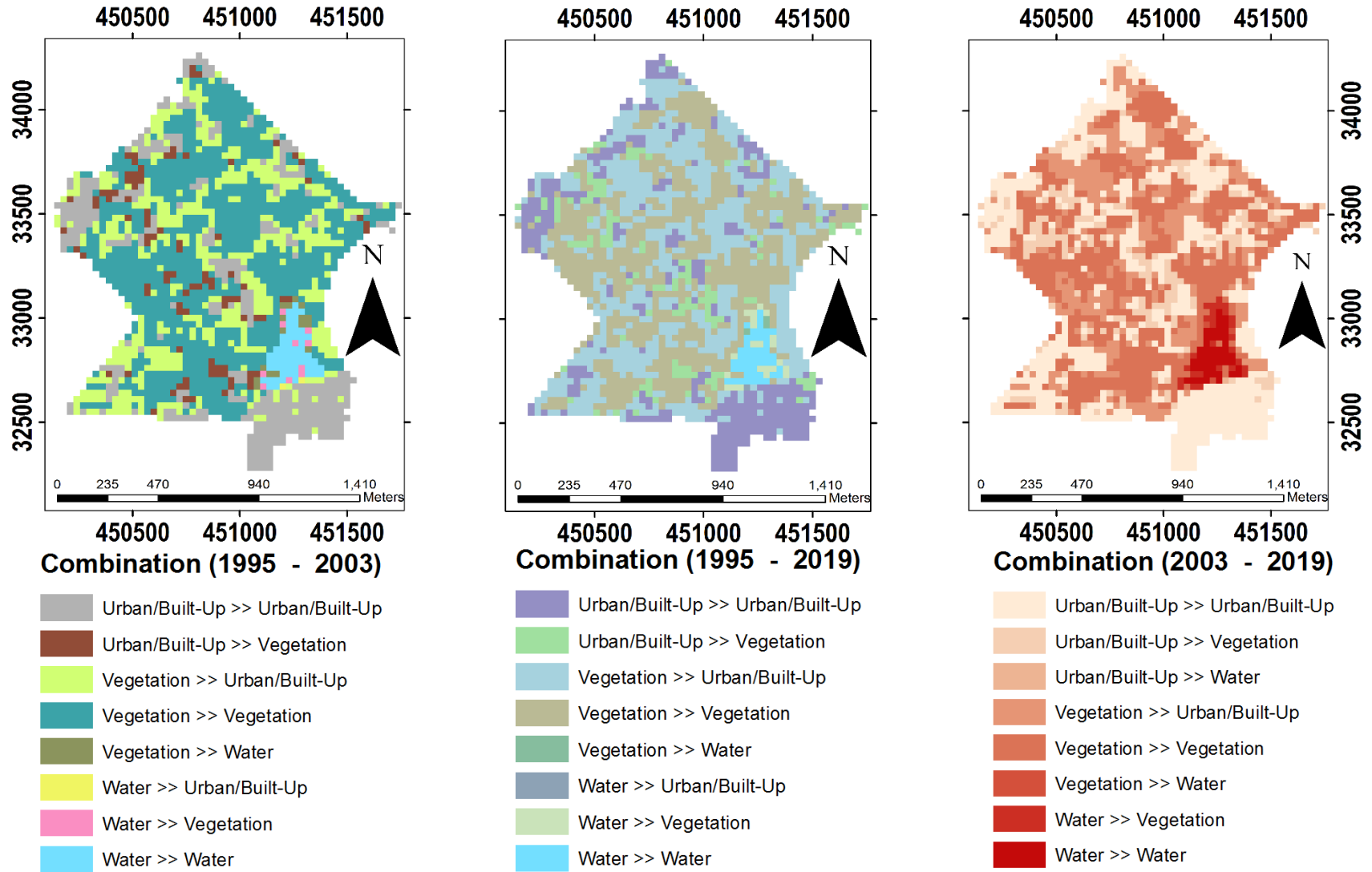


Figure 4-3: Post-Classification for Lake Catchment Land Use distribution

4.3 Mapping the distribution of nutrients in the Kabaka's lakes watershed.

From both Insitu and lab analysis results for TN and TP concentration at points SP_1, 2, 3, and 4 (see chapter 3), the catchment was classified. The water from Kabaka's lake given the various anthropogenic activities in its catchment is a likely recipient of waste and wastewater discharges. The analysed samples from the laboratory displayed 14% variation trend between nitrates and phosphorus concentrations where SP_4 exhibited highest levels of TN and TP, followed by Sp_3 (Figure 4-4). This was mainly attributed by buildup area catchment land use class, including: oil spillages from garages, wastewater from car washing bays, sewerage inflow from hostel and residence, inflow from runoff, direct deposition of solid waste to the lake resulting in to nutrient (eutrophic) enrichment process. However, the study established that nutrient concentration in to the water way reduces downstream (From furthest point in catchment to pour point), which may be attributed to the soils profile in the catchment.

The nutrient ration ($TN/TP=5.89\pm 3$) is low, indicating that the primary eutrophication enrichment especially in the middle of the lake is limited by nitrates. This implies that the ecological turn-over in the lake is significantly affected by inputs of nitrates into the lake. In contrast, the study on Lake Victoria reported that the TN to TP ratios was in the range 8.0 to 42.0, average 15.7, hence showing that phosphates were the limiting factor and the average TN: TP ratios were almost double in inshore than offshore indicating that P is excess relative to N in offshore than inshore (Shahidul *et al.*, 2005).

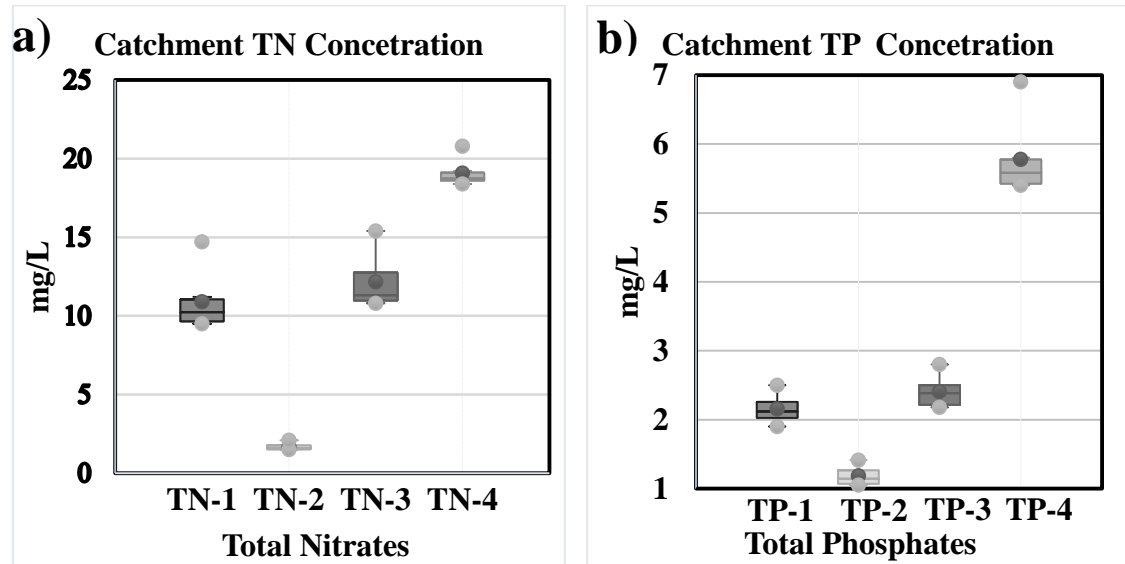


Figure 4-4: Lakes catchment classified land use pollution concentration (a)-Total Nitrites (TN) Concentration, b)-Total Phosphates Concentration)

Box plots (Figure 4-4) represents 50% of the data points, whiskers represent minimum and maximum, line in box represents the median.

4.3.1 Kabaka's lake nutrient concentration profile

The 80,596 m² surface area Kabaka's lake (Figure 4-5) bears a high pH (above 8.5) as indicated by the insitu-measurements supports growth of the green algae which is responsible for the green colour (874±210 P_{tc0}) of water due to enhancement of conversion of nontoxic ammonia to a toxic form of ammonia at temperature ranges of 25-35 °C. These high water temperatures foster green algae by increasing the solubility evidenced by the high dissolved oxygen content (218.73±20.91%) from the lake samples attributed to low salinity (0.13±0.00) and high pressures (880.43±0.62 mbar). Transparency variation is due to the affected lakes water color caused by algal abundance (ascertained by Chl-a concentration variation), mainly experienced in the middle section (presence of small green aquatic plants in the islands riparian area).

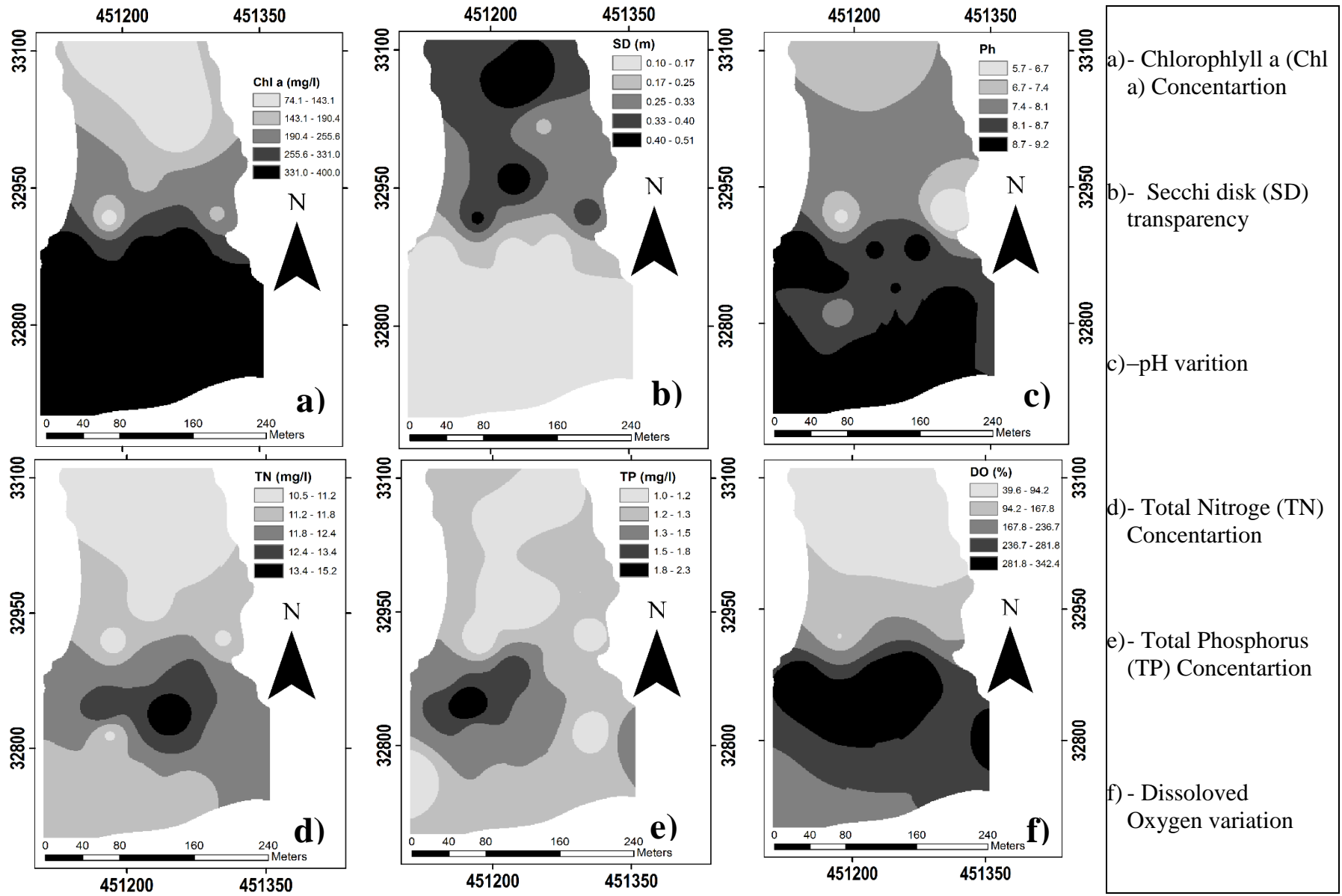


Figure 4-5: Spatial interpolation of Kabaka's lake water quality eutrophication parameters

This matches the dissolved oxygen concentration variation along the lake cross-sectional area, since it is an important factor impacting aquatic organisms and nutrient recycling (P and N) within the lakes aquatic systems for the varying pH range. Increase in pH value in this section indicates a higher degree of eutrophication process.

Mixing occurs at different times and to different degrees in different parts of the lake. The master variable controlling the eutrophication effects in the lake is the mixing depth (Figure 4-5 and Figure 4-12). It appears that typical values in the middle of the lake range from 1.2-2.8 meters bear more nutrient concentration than at the shores and at the inlet section of range 0.8 – 1.0 meters. This may be attributed to photic depth high efficiency in chlorophyll due to light stressed phytoplankton communities as evidenced by ranges of measured secchi depths (transparency). As the depth increases, less light penetration is experienced hence phytoplankton species compete at low average light favouring the growth of photosynthesizing algae.

The extreme fluctuations (19.82 Standard Deviation) in the Trophic State Index value between (SD = 18.66 and Chl-a = 18.65) and (TN=24.88 and TP=20.146) is based on biological parameters in the lake. Presence of such parameters is confirmed by the dominance of algae in light attenuation due to the similarity between the TSI value of Secchi disk and Chlorophyll a [$TSI(Chl-a) = TSI(SD)$] and the nitrogen limiting factor limiting the algal biomass concentered by [$TSI(TP) > TSI(Chl-a) = TSI(SD)$] as argued by Brown and Simpson, (2001). According to Florida Department of Environmental

Protection (FDEP), Kabaka's Lake with a TSI value of 21.57 is classified under oligotrophic class of lakes (TSI<40) due to its low nutrient concentration. However, it bears a potential to support the highest level of biological productivity (e.g., an abundance of algae, aquatic plants, birds, fish, insects, and other wildlife) (Paulic *et al.*, 1996).

4.3.2 Nutrient concentration prediction

The Multiple linear regression build model (Table 4-1), was able to quantify the nature of the relationship between the independent variable (t) and two dependent /explanatory variables (TN and TP) with a 63% Root mean square model fitting the data with goodness fitness of minimal residual sum of squares (3.439) and acceptable P values (TN= 0.005492 and TP= 0.000139). The normality standardized residual plots of the generated model for TN and TP followed a normal distribution (homogenously spread along the line $[y=0]$) validating the reliability of the model. The plots (Figure 4-6 and Figure 4-7) show reasonable correlation model results between the observed and predicted values.

Table 4-1: Regression model of raw water quality over Kabaka's Lake

Water quality parameters	Developed models (t=time period)-MLR	Model remarks	Model Equation
TN	$=11.485+ 0.029*t$	To predict Nitrate concentration (N*) at time (t*)	Equation 4-1
TP	$= 1.574- 0.034*t$	To predict Phosphate concentration (P*) at time (t*)	Equation 4-2

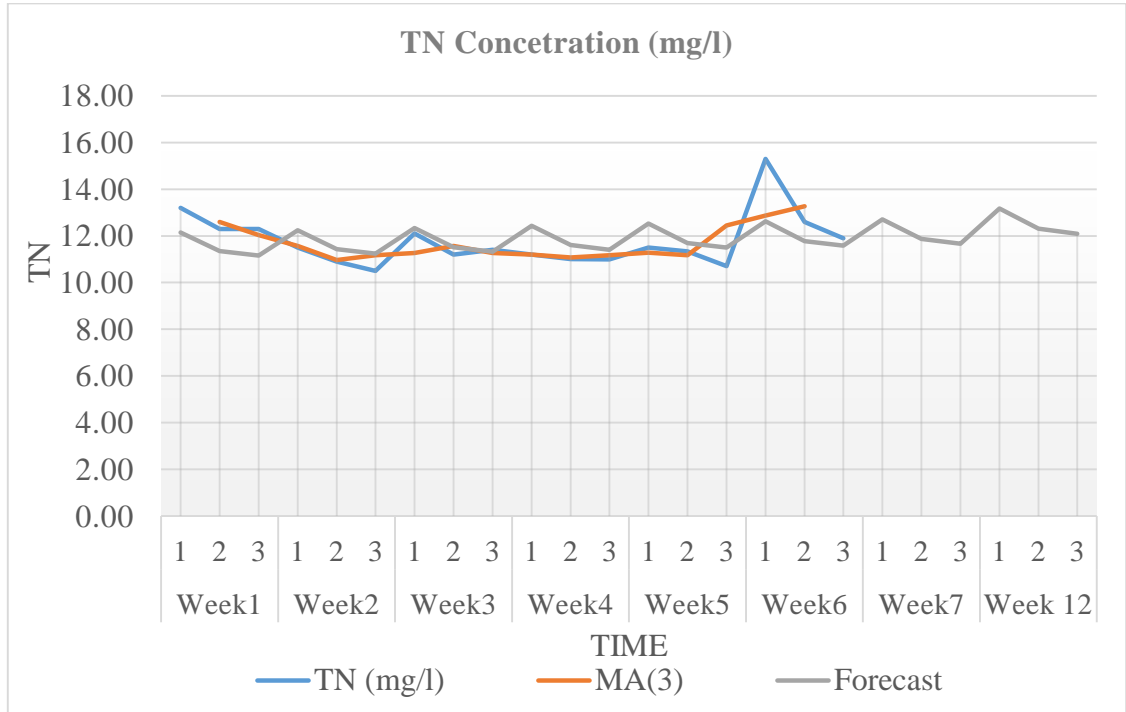


Figure 4-6: Model prediction for Total Nitrates (TN)

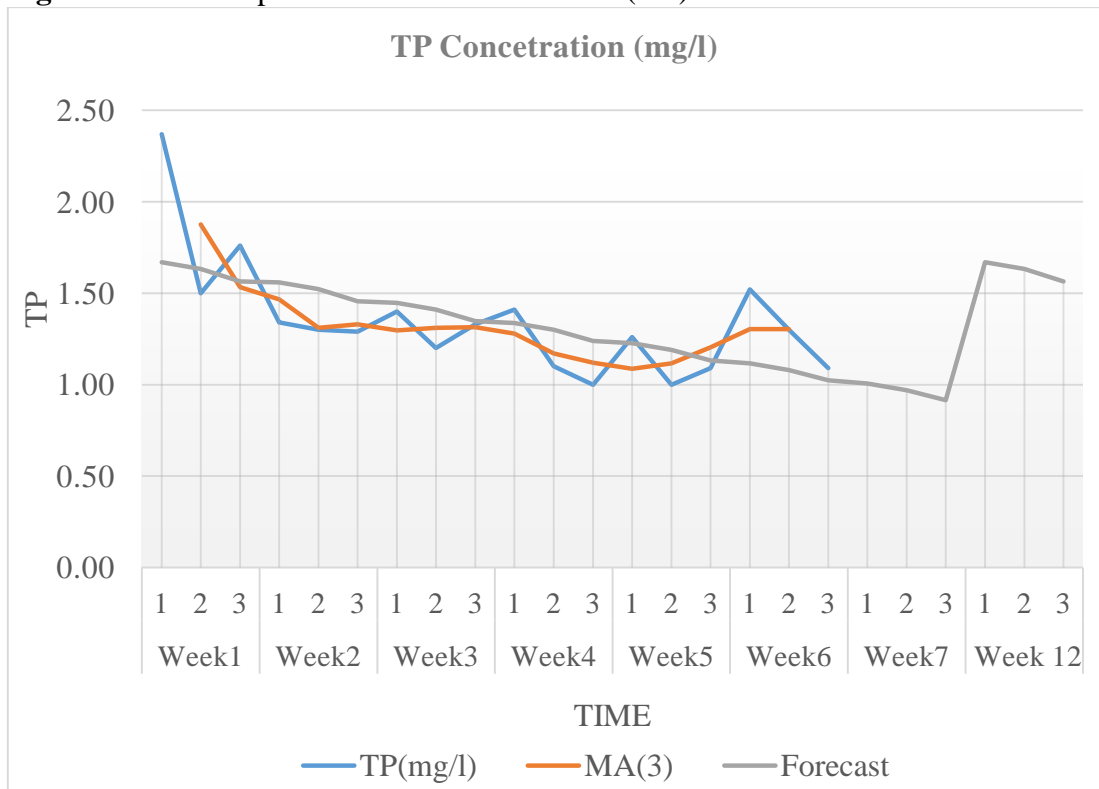


Figure 4-7: Model prediction for Total Phosphates (TP)

The model was able to predict an average of 1.14 (5.2%) nutrient pollution concentration annual increment for the next 30 years and the lake will be eutrophic in an estimate of 25 years (Figure 4-8).

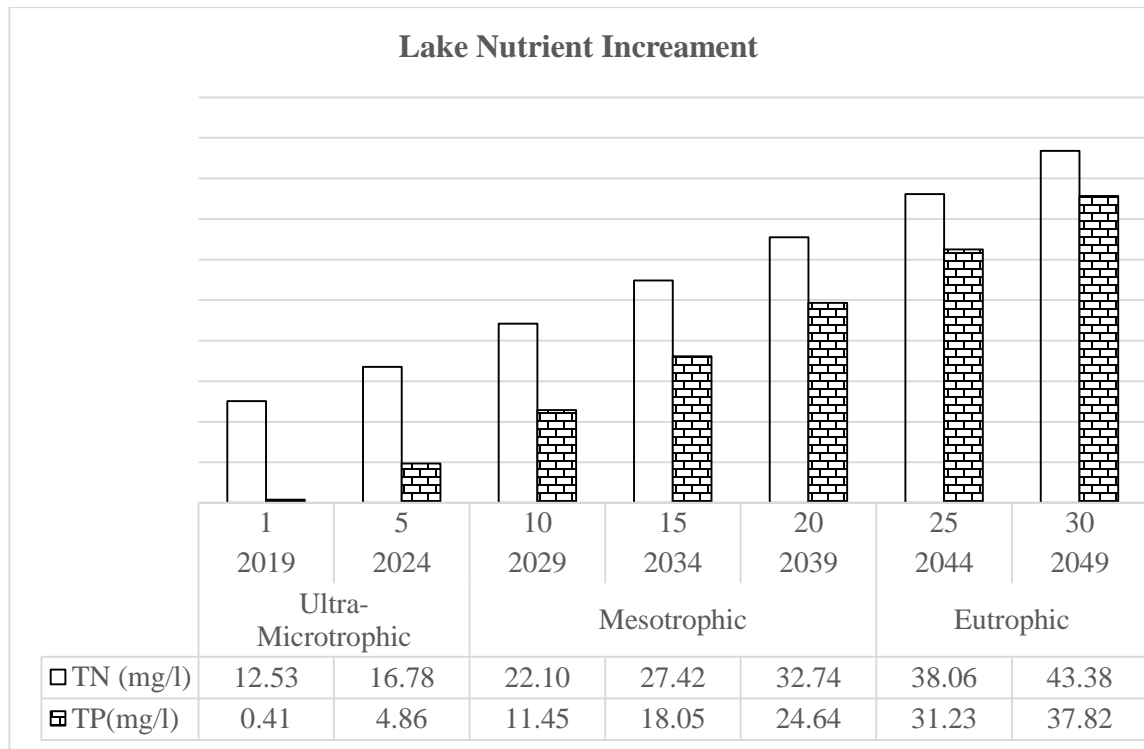


Figure 4-8: Kabaka’s lake Nutrient prediction concentration

4.4 Abatement of Kabaka’s lakes eutrophication

4.4.1 Option 1: Enhancement of the current receiving wetland

There was a significant difference in receiving wetland acreage footprint ($p < 0.00001$) as established in the last 17 years (Figure 4-9). A reduction trend ($R^2 = 0.96$) in the wetland acreage was established bearingEquation 4-3.

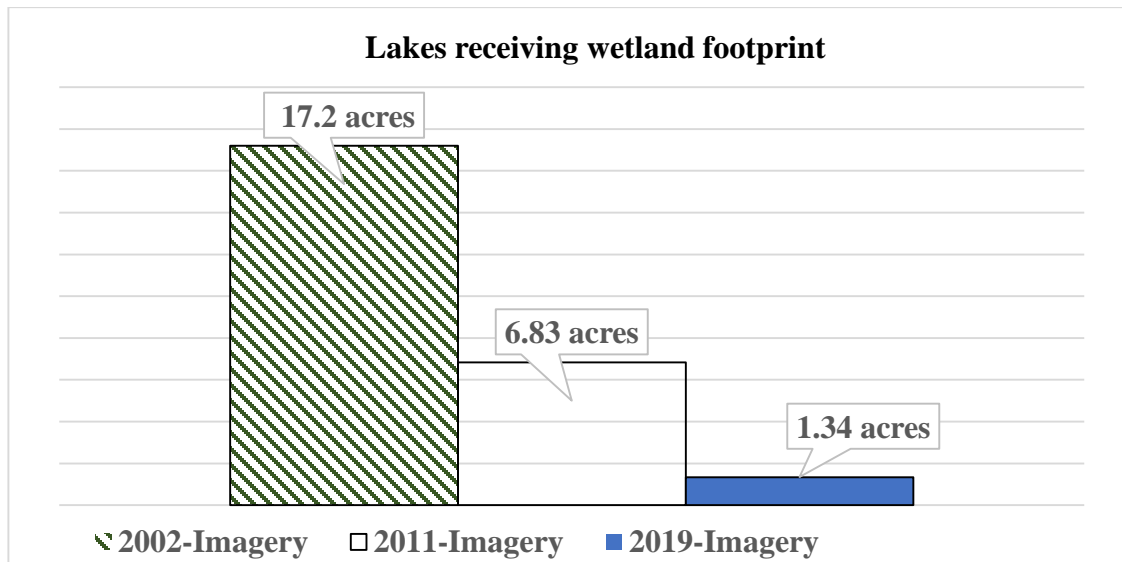


Figure 4-9: Changes in Lakes receiving wetland footprint

$$y = -7.93x + 24.32 \dots \dots \text{Equation 4-3}$$

Where; y - Acreage and x - Year

The increase in wetland encroachment (Chapter 3:- Figure 3-9) has translated into a gradual loss of nutrient reduction efficiency for lakes eutrophication enrichment as ascertained by the (Gumm, 2011; Watson *et al.*, 2016; Kiggundu *et al.*, 2018; Gideon and Bernard, 2018; Guetté *et al.*, 2018; Amritsar, 2019). This study established that the 2019 estimated 1.34 acreage lakes receiving wetland has a significant nutrient reduction ($p=0.0006$) attributed by a 33% TN (0.1 mg/l - 5.6 mg/l) and 68% TP (1.8 mg/l - 2.65 mg/l) reduction.

Construction of a wetland in the remaining 1.34 acres of natural wetland there will be a significant TP reduction ($p = 0.0102$, Figure 4-10) and TN reduction ($p = 0.000083$, Figure 4-11) in the lake (Table 4-2).

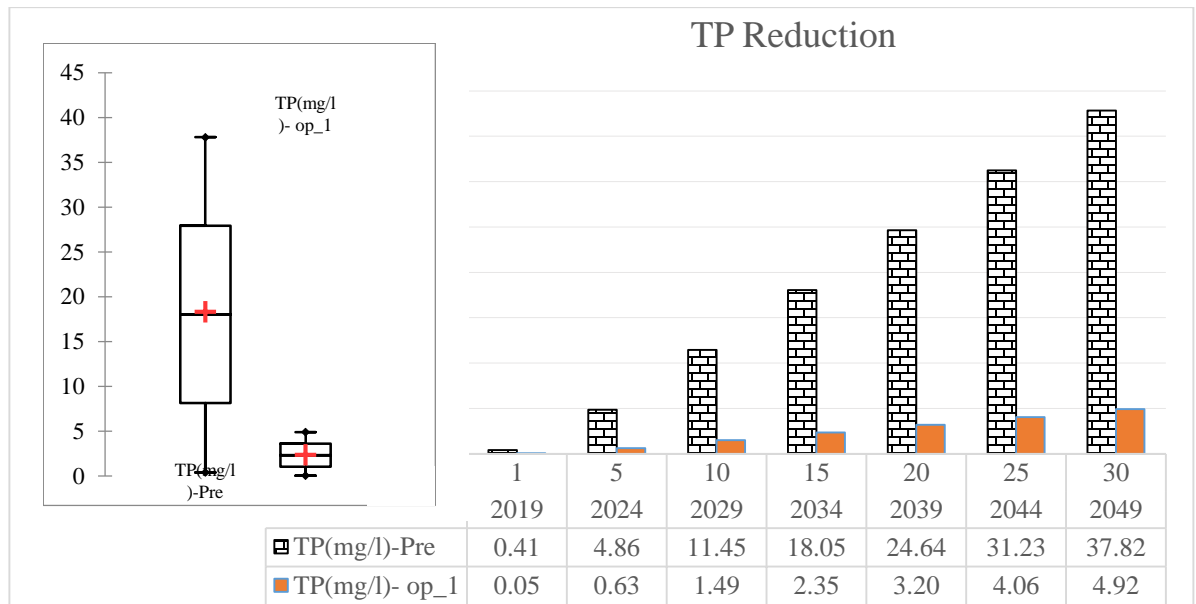


Figure 4-10: Total Phosphates reduction by use of a Constructed wetland option

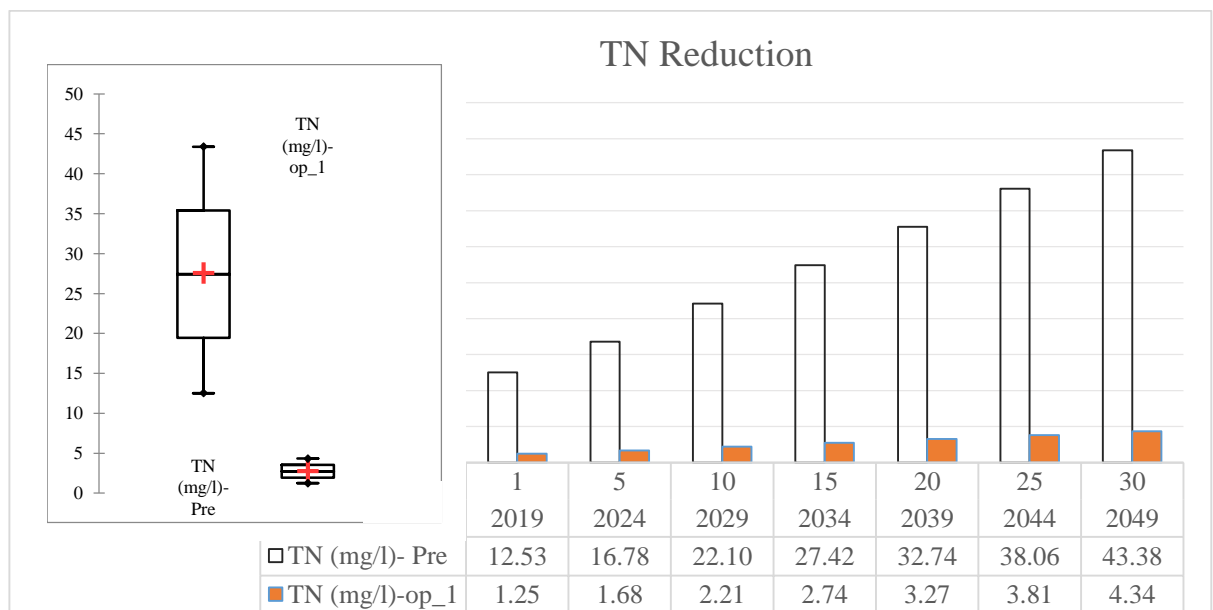


Figure 4-11: Total Nitrates reduction by use of a Constructed wetland option

Table 4-2: Kabaka’s lakes trophic status after constructing a wetland

Year	Predicted	Constructed Wetland option
2019	Ultra-Microtrophic	Ultra-Microtrophic
2024		
2029	Mesotrophic	
2034		
2039		
2044	Eutrophic	Mesotrophic
2049		

4.4.2 Option 2: Dredging of Kabaka’s lake

Kabaka’s Lake was categorised as a shallow lake (128,301.53 m³) with its deepest and shallow water columns being at 2.8 m and 0.8 m respectively as evidenced by the bathymetry survey results, bathymetric zoning (Figure 4-12) and an illustrative depth model (Figure 4-13). The lakes mean depth was 1.325 m varying by 0.251 across the lakes cross sectional depths and there was a significant variation ($P < 0.0001$, $n=103$) in the lake’s horizontal profile for the last 2 years (Figure 4-14, Figure 4-15 and Table 4-3).

Table 4-3: Summary of the baseline bathymetry

Depth (m)	Colour zoning	Comments/ observation
0.8-1.0	Dark Blue	The region is mainly in the upper side of the lake, adjacent to SP_LI, covering over 39% of the lake's surface area.
1.0-1.2	Light Blue	The region transcends round the outer boundaries; lower and part of the middle sides of the lake by over 20% coverage.
1.2-1.5	Light Green	The region transcends round the inner boundaries; lower and part of the middle sides of the lake by over 17% coverage.
1.5-1.8	Orange	The region transcends round the inner boundaries of the lower side (middle section of the lower side) of the lake by over 14% coverage.
1.8-2.8	Red	The region is mainly in the middle lower side of the lake (adjacent to washing bay, and SP_LO), covering over 10% of the lake's surface area.

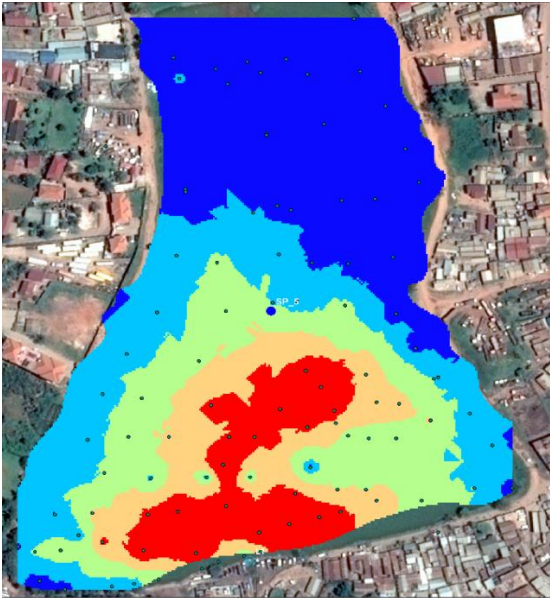


Figure 4-12 Lake Bathymetry zoning

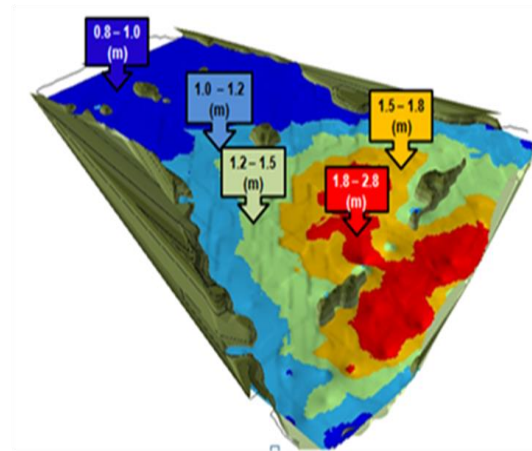


Figure 4-13 Lake Depth modelling

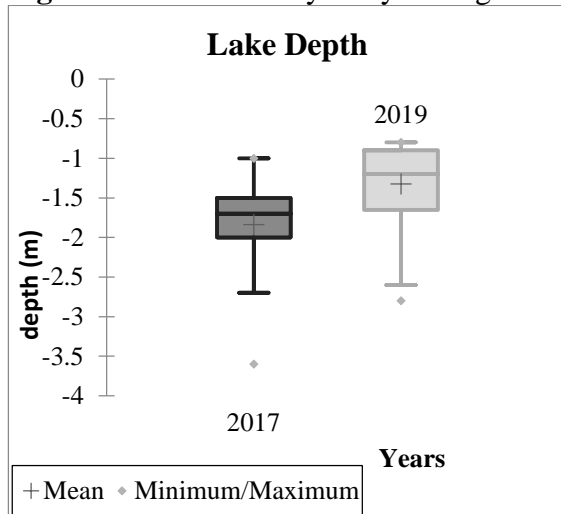


Figure 4-14: Lakes Depth 2 year variation

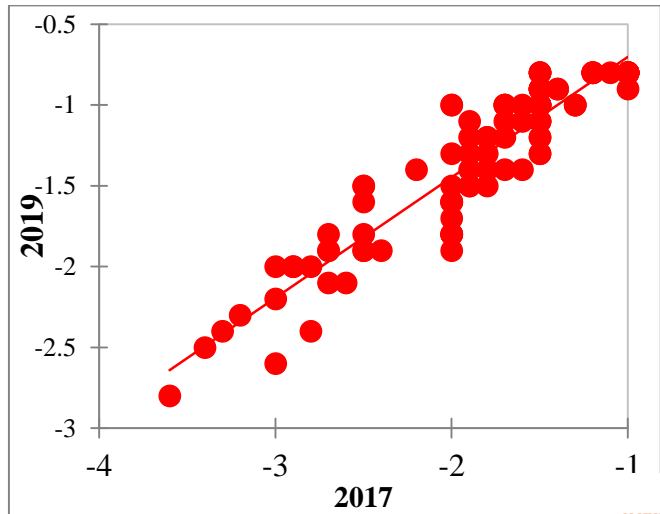


Figure 4-15: Correlation in Lakes depth variation

According to the Kabaka’s Lake ESIA report (secondary data), it was observed from the reservoir routing (Figure 4-16) that the lake has a significant ($p= 0.00003$) ability to attenuate and control flooding in the downstream areas basing on its attenuation effect to the peak flood flows. However this has aided significant ($p<0.0001$) sedimentation load of the lake for the last 2 years (Figure 4-18 and Figure 4-19), hence affecting its storage capacity (Figure 4-17).

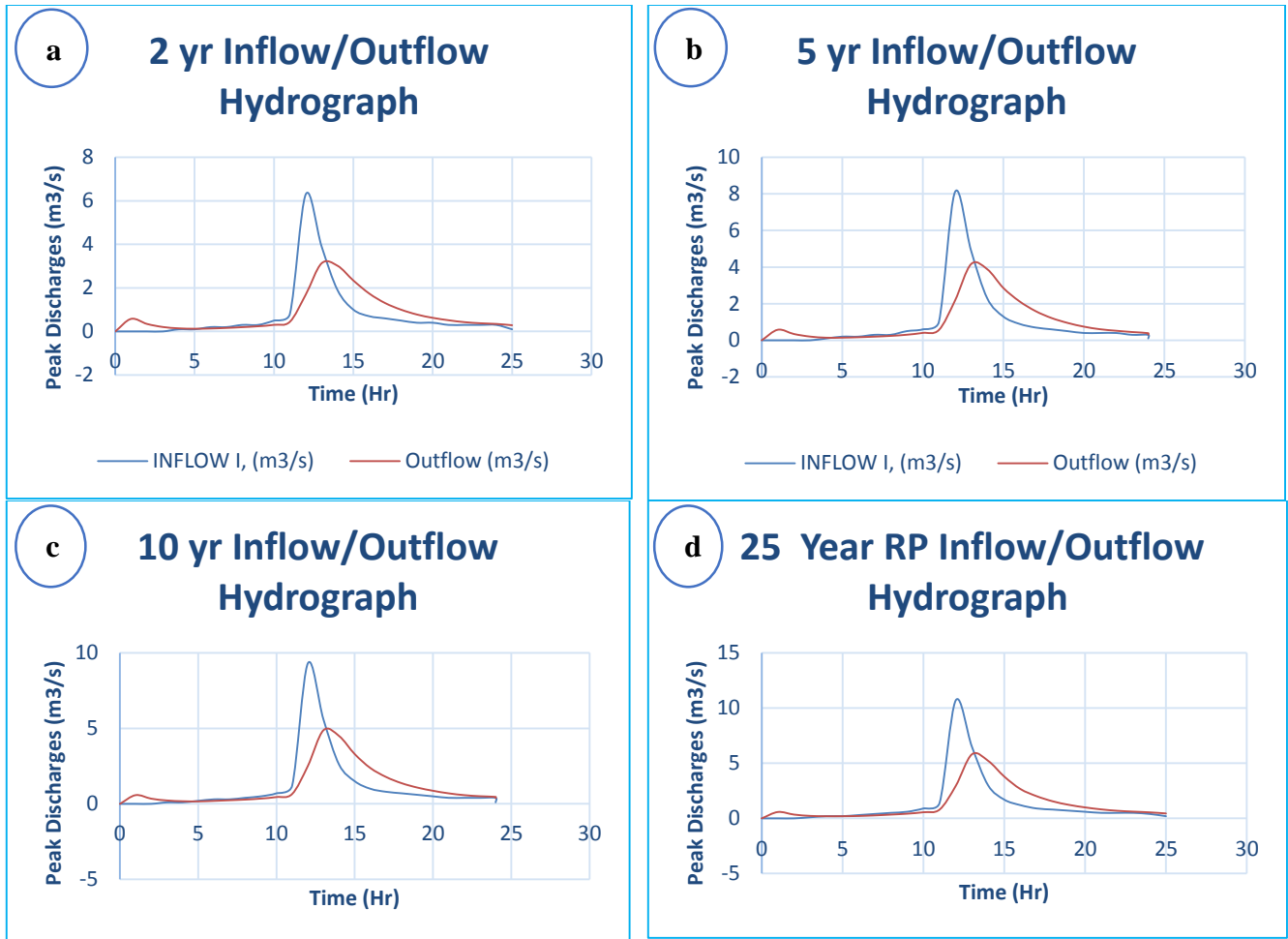


Figure 4-16: Inflow-outflow hydrograph for the Lake (a- for 2yr flood, b- for 5yr flood, c- for 10yr flood, d- for 25yr flood)

Source: Based on the draft Kabaka' lake ESIA report for 2017

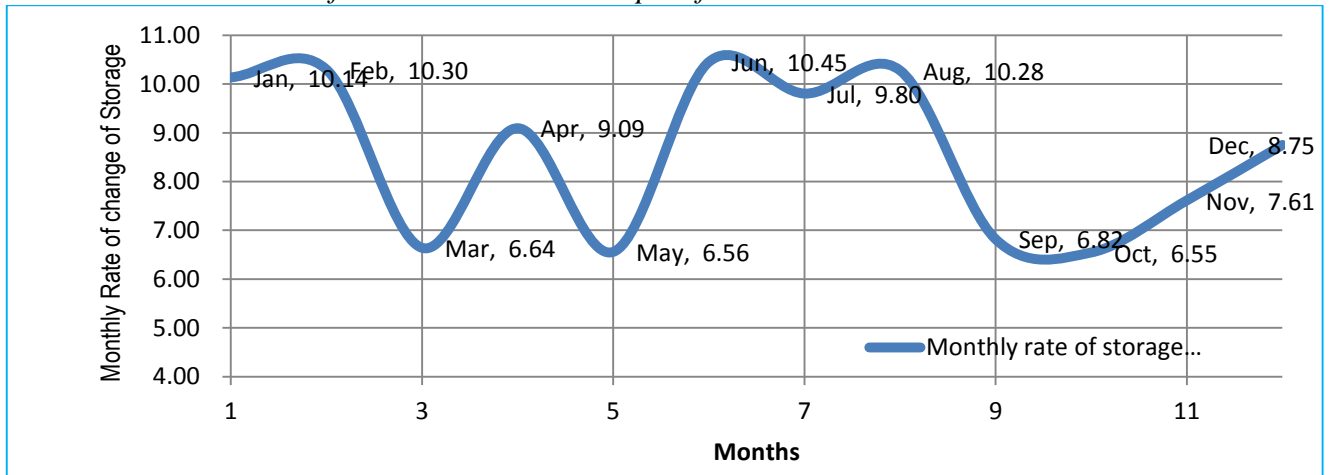


Figure 4-17: Monthly rate of change of lake's storage

Source: Based on the draft Kabaka' lake ESIA report for 2017

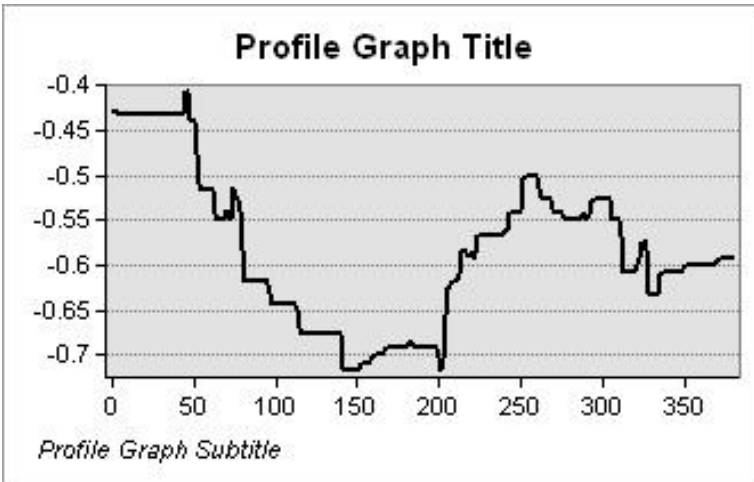


Figure 4-18: Kabaka's lake sedimentation profiling

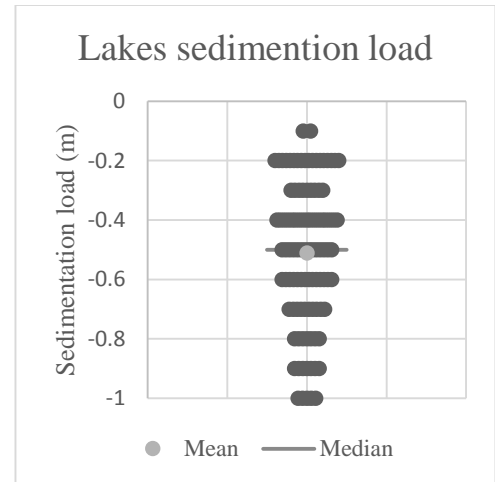


Figure 4-19: Lakes sedimentation load

Generally there is no distinct boundary between water and sediment at the bottom of the Lake with wave action mixing sediment more than a foot deep (0.5 m). This creates conditions where nutrients stored in the sediment significantly ($P < 0.0001$) contributes to those in the water column.

In reference to Brian (2018), this study as well established a significant correlation ($r = 0.98$, $p < 0.0001$, $n = 6$) of the lake's phosphorus composition ($P_{\text{lake}} = 0.517$ mg/l and $P_{\text{sed}} = 0.103$ mg/l) at a hydraulic residence time ($t_w = 4$ hrs) from (Figure 4-16). Therefore the lake's attenuation beneficial effect can be enhanced by dredging to increase the storage capacity (Table 4-4, Figure 4-20 and Figure 4-21) and retention capacity. The approximate dredge volume is approximate $76,493 \text{ m}^3$ for the lake to achieve self-purification.

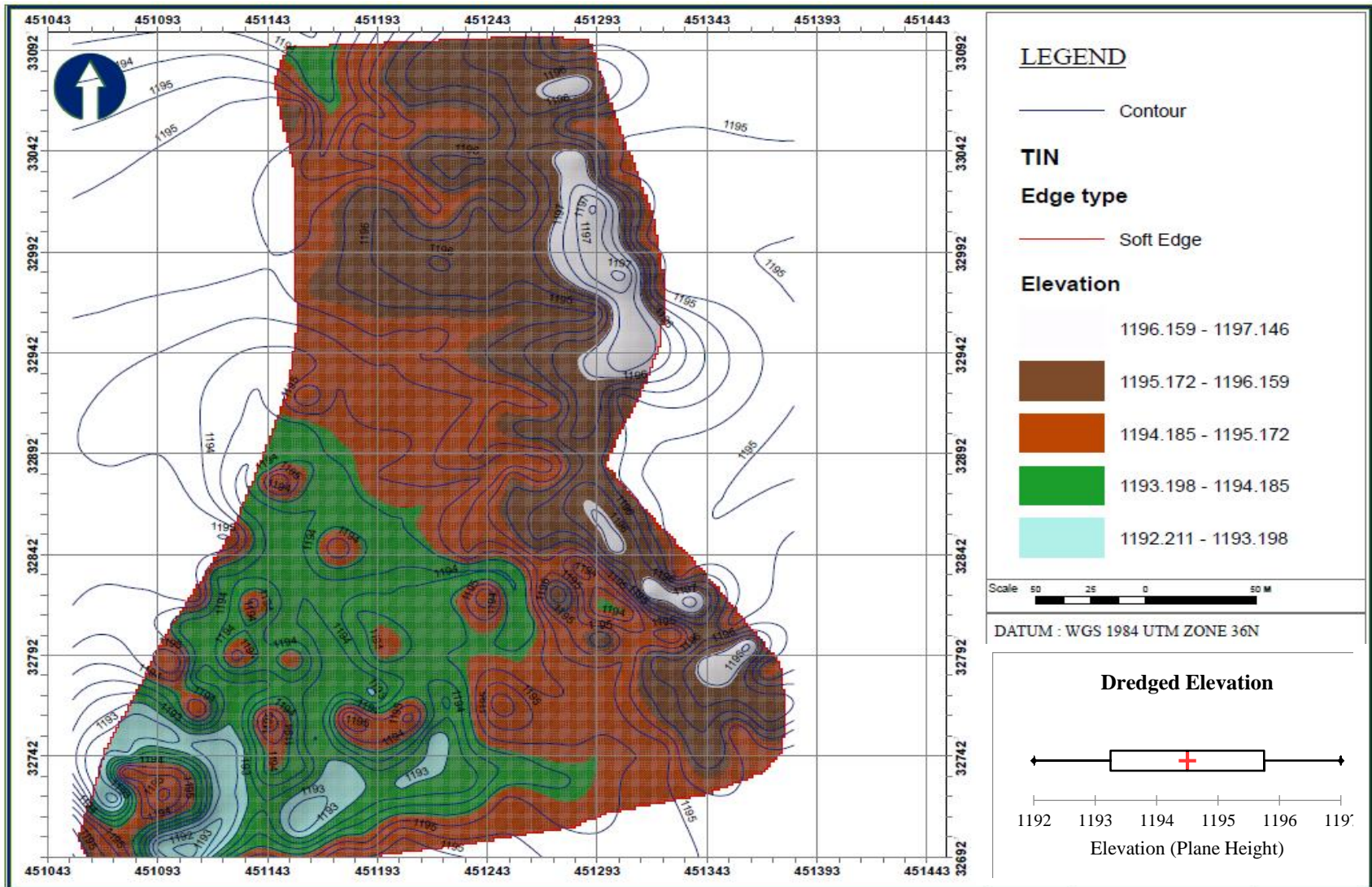
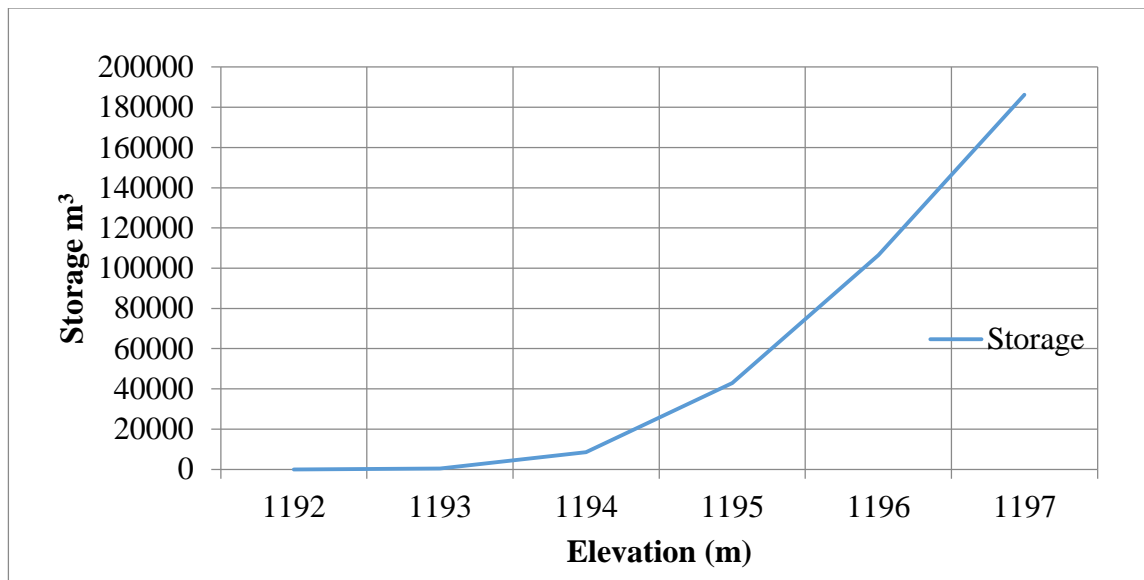


Figure 4-20: Interpolated lake bottom surface based on results of bathymetric surveys

Table 4-4: Elevation-area-storage functions based on bathymetric survey

Elevation (Plane Height)	Surface Area 2D	Surface Area 3D	Storage Volume(m ³)- Below Plane Height
1192	0	0	0
1193	2216.64	2221.81	484.61
1194	18169.04	18212.50	8518.83
1195	49243.57	49335.27	42959.12
1196	75562.74	75692.16	106556.58
1197	81665.87	81806.97	186224.87

**Figure 4-21:** Elevation-storage function for the lake

Dredging the lake will significantly reduce nutrient concentration in the lake by 80%; TP reduction ($p = 0.00017$) in Figure 4-23 and TN reduction ($p = 0.00027$) in Figure 4-24. The lake's self-purification after dredging will cause an Ultra-Microtrophic status for the next 30 years (Table 4-4).

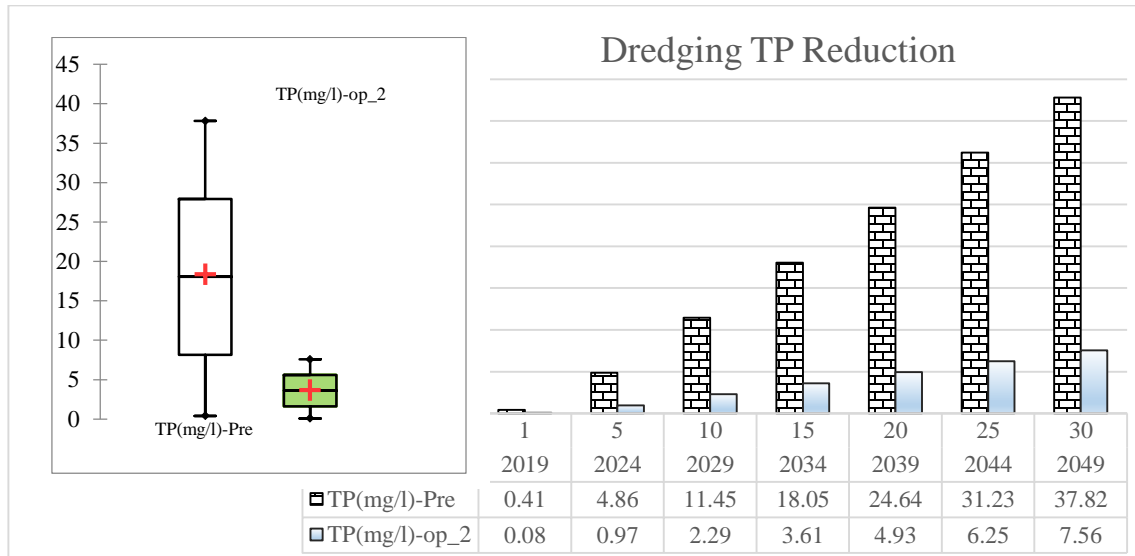


Figure 4-22: Total Phosphates (TP) reduction by dredging

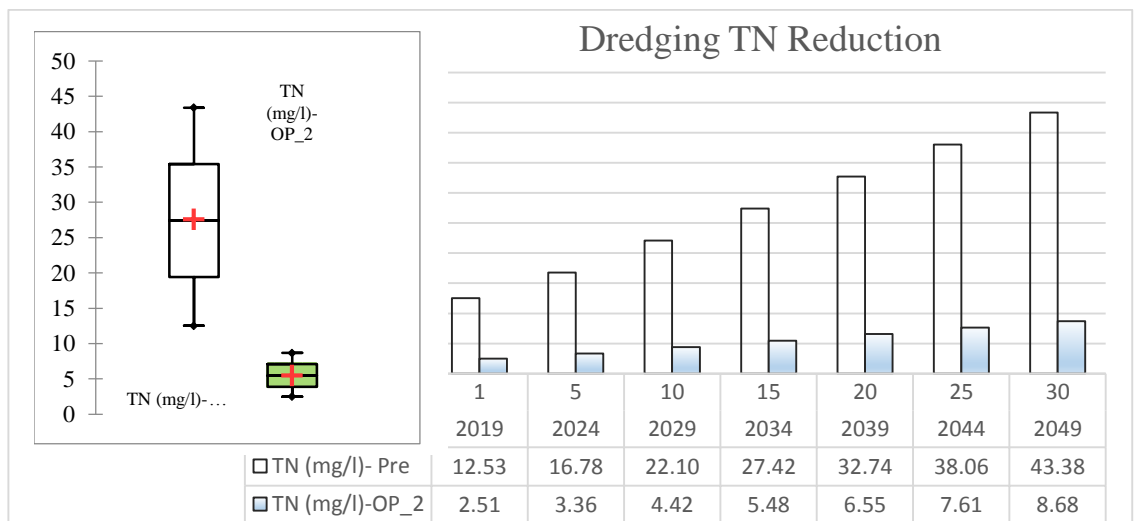


Figure 4-23: Total Nitrates (TN) reduction by dredging option

Table 4-5: Lakes trophic status after dredging

Year	Predicted	Dredging option
2019	Ultra-Microtrophic	Ultra-Microtrophic
2024		
2029	Mesotrophic	
2034		
2039		
2044	Eutrophic	
2049		

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This section presents summary of the findings and recommendations as per the objectives of assessing eutrophication management strategies for abatement of the effects of the different land use activities on natural water quality of Kabaka's lake.

5.2 Conclusions

Eutrophication of tropical lakes in Uganda is highly attributed to the influence of anthropogenic catchment disturbance. Kabaka's lake catchment, categorized with built, agricultural and water land use has been redistributed ($p < 0.005$), with buildup area increasing by 78.5%, vegetated area reducing by 37.2% and water reducing by 1.8% through increased human settlement activities. This has not only reduced the lakes receiving wetland footprint by 92.2% ($p = 0.000003$) but also increased flow of nutrient within the watershed with concentrations of TP and TN ranging from 10.5 – 15.3 mg/L and 1.00 - 2.37 mg/L respectively, mainly from; garage oil spillages, car washing bays wastewater, and sewerage. The 80,596 m² lake's light attenuation is currently algae dominate, limited by nitrogen and classified under oligotrophic class of lakes (TSI < 40) with a threat of eutrophication in an estimate of 25 years. Construction of a wetland in the remaining 1.34 acres of natural wetland will significant reduce Total Phosphorus by 35% and Total Nitrates by 45% ($p = 0.05$), whereas dredging the lake will reduce both by 80% ($p = 0.0005$). Watershed management is the only sustainable solution to control nutrient flow into the lake and

enable self-purification. Therefore, the combination of external and internal nutrient control is recommended to improve water quality. These findings will be critical in lakes redevelopment master plan for Buganda Kingdom, Kampala catchment reclamation for Kampala Capital City Authority (KCCA) and researchers.

5.3 Recommendations

It is important to recognize the limitations of this study and the effect they may have had undermining trophic state estimations. A set of six samples, all collected during the dry season were analyzed, which may obscure the broad limnologic characterization of water quality since the lake is mainly affected by Peak flood flows as evidenced by storm runoff and floating waste on the lake. Second, this study sampled surface waters, but from literature review, the main component of lakes hydrology is ground water recharge from springs, hence further investigations requirement on its nutrient concentration. Also the adopted constructed wetland management option considered only surface area as a design parameter whereas there other critical parameters like depth, wetland type, root-zone system, plants for determination of nutrient reduction efficiency. Lastly due to the unstudied kabaka's lake watershed, there was no water quality data available before 2017 hence limiting nutrient concentration profiling but had to instead consider nutrient concentrations.

Despite these limitations, the results reveal useful findings about the trophic state of the lake in Kampala water shade. These findings will provide a baseline for long-term,

detailed studies on eutrophication in freshwater bodies in Uganda. Currently, there is no national strategy for lake management in Uganda, therefore the study recommends that future studies on Kabaka's watershed be conducted focusing on;

Impact of anthropogenic activities of Lake Victoria catchment on Kabaka's watershed. Since Kabaka's lake watershed is a sub catchment of Lake Victoria's catchment, such findings will simulate a linkage of various anthropogenic activities hence a Knowledge gap benchmark for Kabaka's lake. Strategies on how to manage this impact such as; Proper land use management practices for example, planned settlements and; Sensitization of the communities of Kayanja I & II, Kayanja, Agrey and Spier zones about catchment management could be considered.

Impact of ground water recharge and its effects on nutrients concentration of Kabaka's lake water quantity and quality. Such findings will expound on the lakes hydrology and better understanding why the nutrient concentration in the middle of the lake is higher than other sections.

Impact of constructed wetland and diversion channel on the water quality of Kabaka's lake. Considerations of constructed wetlands parameters besides surface area, lake's hydrology mainly surface water recharge and extensive consideration of conditions in tropical and developing countries for nutrient management among others including regular monitoring in the catchment as to obtain more data such as water quality.

Application of advanced GIS and remote sensing in Kabaka's watershed modelling to address the above cited issues.

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APPENDICES

Appendix 1: Water quality results

	20th/02	28th/02	4th/03	15th/03	23rd/03	27th/03
Sampling period	1	2	3	4	5	6
Sample ID	N (mg/l)	N (mg/l)	N (mg/l)	N (mg/l)	N (mg/l)	N (mg/l)
SP_1	14.7	9.5	10.6	9.6	9.9	11.2
SP_2	2.1	1.5	1.8	1.5	1.6	1.6
SP_3	15.4	10.8	13.2	10.9	11.2	11.4
SP_4	19.2	18.6	20.8	18.8	18.7	18.4
SP_5	12.3	10.9	11.2	11.0	11.3	12.6
SP_LI	13.2	11.5	12.1	11.2	11.5	15.3
SP_LO	12.3	10.5	11.4	11.0	10.7	11.9
	20th/02	28th/02	4th/03	15th/03	23rd/03	27th/03
Sampling period	1	2	3	4	5	6
Sample ID	P (mg/l)	P (mg/l)	P (mg/l)	P (mg/l)	P (mg/l)	P (mg/l)
SP_1	2.30	2.14	2.00	1.90	2.10	2.50
SP_2	1.20	1.05	1.29	1.06	1.09	1.41
SP_3	2.80	2.18	2.50	2.20	2.27	2.50
SP_4	6.90	5.41	5.80	5.46	5.40	5.70
SP_5	1.50	1.30	1.20	1.10	1.00	1.30
SP_LI	2.37	1.34	1.40	1.41	1.26	1.52
SP_LO	1.76	1.29	1.33	1.00	1.09	1.09

Sampling pe	1
Sample ID	chlorophyll-a (yg/l)
Inlet	0.0801
Middle	0.3952
Outlet	0.3631



**NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY - BUGOLOBI**

P.O BOX 7053 KAMPALA Email: waterquality@nWSC.co.ug

CERTIFICATE OF ANALYSIS

CLIENT: Abel Mutyaba

Serial No: ES/RF/2019/1079

Address: Kyambogo University

Sampled by: Client's Staff

Date Sample Received: 02/05/2019

Date of Report: 14/05/2019

Parameters	Units	SP-IL	National Standards for Environmental water
Sample Number	--	K2245/2019/B	
Chlorophyll 'a'	µg/L	0.0801	2000

Remarks

The water sample showed complying physiological characteristics compared to the National Standards for Environmental water.

ANALYSED BY: Araa Kennedy

AUTHORISED BY: Manager Central Laboratory Services :

APPROVED BY: Senior Manager - Water Quality Management Department :

The NWSC certificate of analysis by no means constitutes a permit to any person or company undertaking to conduct business





**NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY - BUGOLOBI**

P.O BOX 7053 KAMPALA Email: waterquality@nwscc.co.ug

CERTIFICATE OF ANALYSIS

CLIENT: Abel Mutyaba

Serial No: ES/RF/2019/1079

Address: Kyambogo University

Sampled by: Client's Staff

Date Sample Received: 02/05/2019

Date of Report: 14/05/2019

Parameters	Units	SP-OL	National Standards for Environmental water
Sample Number	--	K2246/2019/B	
Chlorophyll 'a'	µg/L	0.3631	2000

Remarks

The water sample showed complying physiological characteristics compared to the National Standards for Environmental water.

ANALYSED BY: Araa Kennedy

AUTHORISED BY: Manager Central Laboratory Services :

APPROVED BY: Senior Manager - Water Quality Management Department :

The NWSC certificate of analysis by no means constitutes a permit to any person or company undertaking to conduct business





**NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY - BUGOLOBI**

P.O BOX 7053 KAMPALA Email: waterquality@nWSC.co.ug

CERTIFICATE OF ANALYSIS

CLIENT: Abel Mutyaba

Serial No: ES/RF/2019/1079

Address: Kyambogo University

Sampled by: Client's Staff

Date Sample Received: 02/05/2019

Date of Report: 14/05/2019

Parameters	Units	SP-OS	National Standards for Environmental water
Sample Number	--	K2247/2019/B	
Chlorophyll 'a'	µg/L	0.3952	2000

Remarks

The water sample showed complying physiological characteristics compared to the National Standards for Environmental water.

ANALYSED BY: Araa Kennedy

AUTHORISED BY: Manager Central Laboratory Services :

APPROVED BY: Senior Manager - Water Quality Management Department :

The NWSC certificate of analysis by no means constitutes a permit to any person or company undertaking to conduct business



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PUBLIC HEALTH AND ENVIRONMENTAL ENGINEERING LABORATORY
 Tel: 041 -4543152 E-mail: rkulaba@cedat.mak.ac.ug

CERTIFICATE OF ANALYSIS-WATER QUALITY

CLIENT: Mr. Abel Mutyaba

PROJECT: Kabaka Lake Research Study

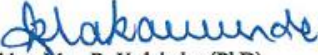
Sampling date: 20th Feb 2019 **Delivery:** 20th Feb 2019 **Analysis dates:** 20th Feb – 24th Feb 2019

Sample ID	Parameter/	Nitrates (mg/l)	Total Phosphorus (mg/l)
1. SP_1		14.7	2.30
2. SP_2		2.1	1.20
3. SP_3		15.4	2.80
4. SP_4		19.2	6.90
5. SP_5		12.3	1.50
6. SP_LI		13.2	2.37
7. SP_LO		12.3	1.76
NEMA Effluent Discharge Stds*		50	10

*National effluent discharge standards (NEMA, 1999)

Commentary

The water from Kabaka's lake given the various anthropogenic activities in its catchment is a likely recipient of waste and wastewater discharges. Hence to ascertain the extent of the possibility of contamination of this source, national effluent discharge standards are used here. The water from the lake complies with the national effluent discharge standards with regard to nitrates and total phosphorus. The samples water at the various locations, exhibits variable levels of nitrates and total phosphorus with the highest at the SP_4 followed by Sp_3. This observation points to the need to ascertain the sources of these nutrients at the SP_4 and SP_3 given the likelihood of the discharges from these areas negatively impacting the quality of the lake waters, specifically resulting in eutrophication.


 Checked by: Mrs. R. Kulabako (PhD)
 In-charge PHEE lab



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CLIENT: Mr. Abel Mutyaba

PROJECT: Kabaka Lake Research Study


Sampling date: 28th Feb 2019 **Delivery:** 28th Feb 2019 **Analysis dates:** 28th Feb – 1st March 2019

Sample ID	Parameter/ (mg/l)	Nitrates (mg/l)	Total Phosphorus (mg/l)
1. SP_1		9.5	2.14
2. SP_2		1.5	1.05
3. SP_3		10.8	2.18
4. SP_4		18.6	5.41
5. SP_5		10.9	1.01
6. SP_LI		11.5	1.34
7. SP_LO		10.5	1.29
NEMA Effluent Discharge Stds*		50	10

*National effluent discharge standards (NEMA, 1999)

Commentary

The water from Kabaka's lake given the various anthropogenic activities in its catchment is a likely recipient of waste and wastewater discharges. Hence to ascertain the extent of the possibility of contamination of this source, national effluent discharge standards are used here. The water from the lake complies with the national effluent discharge standards with regard to nitrates and total phosphorus. The samples water at the various locations, exhibits variable levels of nitrates and total phosphorus with the highest at the SP_4 followed by Sp_3. This observation points to the need to ascertain the sources of these nutrients at the SP_4 and SP_3 given the likelihood of the discharges from these areas negatively impacting the quality of the lake waters, specifically resulting in eutrophication.


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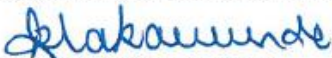
Sampling date: 4th March 2019 **Delivery:** 4th March 2019 **Analysis dates:** 4th March – 7th March 2019

Sample ID	Parameter/ Nitrates (mg/l)	Total Phosphorus (mg/l)
1. SP_1	10.6	2.00
2. SP_2	1.8	1.29
3. SP_3	13.2	2.50
4. SP_4	20.8	5.80
5. SP_5	11.2	1.20
6. SP_LI	12.1	1.40
7. SP_LO	11.4	1.33
NEMA Effluent Discharge Stds*	50	10

*National effluent discharge standards (NEMA, 1999)

Commentary

The water from Kabaka's lake given the various anthropogenic activities in its catchment is a likely recipient of waste and wastewater discharges. Hence to ascertain the extent of the possibility of contamination of this source, national effluent discharge standards are used here. The water from the lake complies with the national effluent discharge standards with regard to nitrates and total phosphorus. The samples water at the various locations, exhibits variable levels of nitrates and total phosphorus with the highest at the SP_4 followed by Sp_3. This observation points to the need to ascertain the sources of these nutrients at the SP_4 and SP_3 given the likelihood of the discharges from these areas negatively impacting the quality of the lake waters, specifically resulting in eutrophication.


 Checked by: Mrs. R. Kulabako (PhD)
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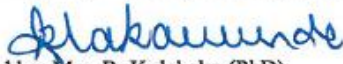
Sampling date: 15th March 2019 **Delivery:** 15th March 2019 **Analysis dates:** 17th March–20th March 2019

Sample ID	Parameter/ (mg/l)	Nitrates (mg/l)	Total Phosphorus (mg/l)
1. SP_1		9.6	1.90
2. SP_2		1.5	1.06
3. SP_3		10.9	2.20
4. SP_4		18.8	5.46
5. SP_5		11.0	1.10
6. SP_LI		11.2	1.41
7. SP_LO		11.0	1.00
NEMA Effluent Discharge Stds*		50	10

*National effluent discharge standards (NEMA, 1999)

Commentary

The water from Kabaka's lake given the various anthropogenic activities in its catchment is a likely recipient of waste and wastewater discharges. Hence to ascertain the extent of the possibility of contamination of this source, national effluent discharge standards are used here. The water from the lake complies with the national effluent discharge standards with regard to nitrates and total phosphorus. The samples water at the various locations, exhibits variable levels of nitrates and total phosphorus with the highest at the SP_4 followed by Sp_3. This observation points to the need to ascertain the sources of these nutrients at the SP_4 and SP_3 given the likelihood of the discharges from these areas negatively impacting the quality of the lake waters, specifically resulting in eutrophication.


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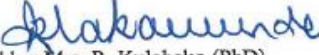
Sampling date: 23rd March 2019 **Delivery:** 24th March 2019 **Analysis dates:** 24th March–27th March 2019

Sample ID	Parameter/ (mg/l)	Nitrates (mg/l)	Total Phosphorus (mg/l)
1. SP_1		9.9	2.10
2. SP_2		1.6	1.09
3. SP_3		11.2	2.27
4. SP_4		18.7	5.40
5. SP_5		11.3	1.00
6. SP_LI		11.5	1.26
7. SP_LO		10.7	1.09
NEMA Effluent Discharge Stds*		50	10

*National effluent discharge standards (NEMA, 1999)

Commentary

The water from Kabaka's lake given the various anthropogenic activities in its catchment is a likely recipient of waste and wastewater discharges. Hence to ascertain the extent of the possibility of contamination of this source, national effluent discharge standards are used here. The water from the lake complies with the national effluent discharge standards with regard to nitrates and total phosphorus. The samples water at the various locations, exhibits variable levels of nitrates and total phosphorus with the highest at the SP_4 followed by Sp_3. This observation points to the need to ascertain the sources of these nutrients at the SP_4, SP_3 and SP_1 given the likelihood of the discharges from these areas negatively impacting the quality of the lake waters, specifically resulting in eutrophication.


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CERTIFICATE OF ANALYSIS-WATER QUALITY

CLIENT: Mr. Abel Mutyaba

PROJECT: Kabaka Lake Research Study

Sampling date: 27th March 2019 **Delivery:** 27th March 2019 **Analysis dates:** 27th March–29th March 2019

Sample ID	Parameter/ (mg/l)	Nitrates (mg/l)	Total Phosphorus (mg/l)
1. SP_1		11.2	2.50
2. SP_2		1.6	1.41
3. SP_3		11.4	2.50
4. SP_4		18.4	5.70
5. SP_5		12.6	1.30
6. SP_LI		15.3	1.52
7. SP_LO		11.9	1.09
NEMA Effluent Discharge Stds*		50	10

*National effluent discharge standards (NEMA, 1999)

Commentary

The water from Kabaka's lake given the various anthropogenic activities in its catchment is a likely recipient of waste and wastewater discharges. Hence to ascertain the extent of the possibility of contamination of this source, national effluent discharge standards are used here. The water from the lake complies with the national effluent discharge standards with regard to nitrates and total phosphorus. The samples water at the various locations, exhibits variable levels of nitrates and total phosphorus with the highest at the SP_4 followed by Sp_3. This observation points to the need to ascertain the sources of these nutrients at the SP_4, SP_3 and SP_1 given the likelihood of the discharges from these areas negatively impacting the quality of the lake waters, specifically resulting in eutrophication.


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 In-charge PHEE lab



Appendix 2: Catchment characteristics/ HECHMS model inputs for Reservoir routing

Catchment Name	Catchment/Sub-basin ID	Catchment area, A (sq.km)	Stream length, L (km)	Catchment Average Slope	Slope, %	Time of Concentration, Tc (Hour)	Curve Number, CN	Potential Maximum Retention, S (mm)	Initial Abstraction, Ia (mm)	Tlag (min)
Kabaka's Lake Catchment	1	0.1101	0.925	0.0097	0.967	0.70	97.00	7.86	1.57	25.3
	2	0.1513	0.879	0.0110	1.100	0.63	97.00	7.86	1.57	22.7
	3	0.1742	1.064	0.0086	0.865	0.79	97.00	7.86	1.57	28.4
	4	0.0001	0.938	0.1925	19.250	0.81	97.00	7.86	1.57	29.2
	5	0.0462	0.013	0.0500	5.000	0.01	97.00	7.86	1.57	0.3
	6	0.0857	0.967	0.0270	2.700	0.61	97.00	7.86	1.57	22.1
	7	0.0629	0.383	0.0260	2.600	0.25	97.00	7.86	1.57	9.1
	8	0.0116	0.793	0.0380	3.800	0.57	97.00	7.86	1.57	20.6
	9	0.1191	0.968	0.0098	0.980	0.73	97.00	7.86	1.57	26.2
	10	0.2442	0.949	0.0160	1.600	0.60	97.00	7.86	1.57	21.7
	11	0.1648	0.872	0.0170	1.700	0.57	97.00	7.86	1.57	20.4
	12	0.1233	1.707	0.0240	2.400	1.07	97.00	7.86	1.57	38.5
	13	0.0098	0.855	0.1400	14.000	0.48	97.00	7.86	1.57	17.5
	14	0.0082	0.606	0.1400	14.000	0.35	97.00	7.86	1.57	12.6
	15	0.0585	1.027	0.0370	3.700	0.64	97.00	7.86	1.57	22.9
	16	0.0861	1.044	0.0340	3.400	0.63	97.00	7.86	1.57	22.7
	17	0.0801	1.033	0.0100	1.000	0.80	97.00	7.86	1.57	29.0
	18	0.0025	0.619	0.0590	5.900	0.48	97.00	7.86	1.57	17.2
	19	0.0535	0.166	0.0140	1.400	0.13	97.00	7.86	1.57	4.5
	20	0.0006	0.166	0.1000	10.000	0.13	97.00	7.86	1.57	4.8

Source: Draft Kabaka's Lake ESIA report- 2017

Appendix 3: Catchment Land Use Redistribution

Land Use/Land Cover	Categories	Units	W>>W	W>> V	W>>BU	V>>W	V>>V	V>>BP	BP >>V	BP >> BP	Total	Kappa Statistics	Overall Accuracy
1995-2003	Area change	(ha)	5.4	0.9	0.18	1.44	83.16	42.21	8.82	33.93	176.04	0.82	0.93
		%	3.07	0.51	0.10	0.82	47.24	23.98	5.01	19.27	100		
2003-2019	Area change	(ha)	4.32	2.52	0.27	57.96	34.65	0.09	19.08	57.15	176.04	0.8	0.93
		%	2.45	1.43	0.15	32.92	19.68	0.05	10.84	32.46	100		
1995-2019	Area change	(ha)	4.41	1.98	0.09	0.27	65.79	60.75	11.79	30.96	176.04	0.74	0.89
		%	2.51	1.12	0.05	0.15	37.37	34.51	6.70	17.59	100		
P and R² values			R ² = 0.6048	P= 0.0026	P= 0.0114	P= 0.0026	R ² = 0.9404	P= 0.218	P= 0.218	R ² = 0.9566			

Note W - Water; V - Vegetation; BP Urban/Built-

