HEAVY METAL CONTAMINATION IN WATER, SEDIMENTS AND FISH FROM SELECTED WETLANDS IN THE LAKE VICTORIA BASIN OF UGANDA

BY

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AUGUST 2023

DECLARATION

I hereby declare that this research report is my original work and has not been previously submitted for a degree or any other qualification at any university.

……………………………………… ……………………………………….

Signature **Date**

DUSABE DAPHINE **18/U/GMSM/19516/PD**

APPROVAL

We confirm that the work in this dissertation was done by the candidate under our supervision

……………………………………………… ……………………………………………..

Signature **Date**

Prof. Charles Twesigye. Department of Biological sciences, Kyambogo University

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Signature **Date**

Dr. Ssanyu Grace Asiyo, Department of Biological Sciences, Kyambogo University

DEDICATION

I dedicate this work to my husband, children and parents who have encouraged and prayed for me continuously throughout my studies.

ACKNOWLEDGEMENTS

Great thanks to Lord God almighty for his providence and protection throughout the research period.

I would also like to extend my deep and sincere gratitude to my research supervisors, Professor Twesigye Charles and Dr. Ssanyu Grace for their tireless effort and guidance throughout this research.

Great thanks go to my husband Mr Tendo Ivan Okumu for the moral and financial support accorded to me during my study time. Lots of love to my parents Mr and Mrs Bahane for their unconditional love and support. I also heartfully thank my children for their patience during the time I was studying, special thanks to Mr and Mrs Posian Tumusiime for the encouragement especially at the time I was almost giving up.

Iam extremely grateful to the water quality fraternity for enabling me to successfully carry out my research.

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OPERATIONAL DEFINITION OF ACRONYMS

ANOVA	Analysis of Variance
APHA	American Public Health Association
BOD	Biological Oxygen Demand
COD	Chemical Oxgyen Demand
CL	Chlorides
^{O}C	Degrees Celicious
EC	Electrical Conductivity
FAO	Food and Agricultural Organisation
ICP OES	Inductively Coupled Plasma -Optical Emission Spectrometer
L	Litres
M	Metres
Mm	Millimetre
Na_2SO_4	Sodium Sulphate
NEMA	National Environment Management Authority
NH_4	Ammonia
TN	Total Nitrogen
TP	Total Phosphate
TSS	Total Suspended Solids
TDS	Total Dissolved Solids
QC	Quality control
WHO	World Health Organisation

ABSTRACT

In Uganda, there is increased industrial and municipal waste disposal into wetlands around Lake Victoria which pose a great threat to different wetland components. A number of studies have been carried out to ascertain the impact of heavy metals in wetlands. Due to the increase in population near the wetlands, there is a higher possibility of receiving more pollutants and effluents hence the necessity of this study. This study assessed the physicochemical parameters and heavy metal concentration in water, sediments and fish from Gabba, Nabugabo, Nakivubo and Lwera wetlands. This study undertook a quantitative research approach with data collected from twelve random sample sites over a period of six months from August 2021 to January 2022. Some parameters were measured in-situ whereas others were analysed at the National Water Quality Laboratory in Entebbe. All water quality analysis was performed according to Standards methods for the Examination of waters and Wastewaters. Heavy metals analysis was done using the inductively Coupled Plasma–Optical Emission Spectroscopy (ICP-OES) following the American Public Health Association – 23rd Edition. The physicochemical parameters and heavy metals of water analysed were within the recommended limits of the East African Standards (2018) except for Nakivubo wetland which had a higher Chemical Oxygen Demand result of 60mg/L. In all the sediment samples, there were considerable concentrations of Chromium (22.97 mg/Kg - 39.34 mg/Kg), Lead (9.34 mg/Kg-19.32 mg/Kg), Cobalt (2.68 mg/Kg- 3.87 mg/Kg) and Nickel (7.67 mg/Kg-11.43 mg/Kg). In particular, Nakivubo and Gabba wetlands had the highest levels of heavy metal concentrations compared to Lwera and Nabugabo wetlands in as much as there was no significant difference in concentrations across the wetlands. The fish species analysed; Clarias Galiepinus, Clarius Liocephalus and Protopterus are mainly consumed by the local population. Chromium and Nickel concentrations in the fish muscles were observed to exceed the WHO maximum permissible limits in all the wetlands. Gabba and Nakivubo wetlands had cadmium results of 0.189 mg/Kg and 0.116 mg/Kg respectively which is beyond the recommended WHO limits. It is therefore recommended that collaborative engagement with the respective stakeholders be pursued to create awareness in communities on the apparent health risks from consuming this fish but also improve the regulatory framework of catchment-based water quality goals that would aim at reducing heavy metal loads. Continuation of regular monitoring by relevant authorities' guidance for proper wetland management, conservation policies implementation and further research on the pollutant retention ability of these wetlands to be urgently undertaken.

CHAPTER ONE: INTRODUCTION

1.1 Background

Wetlands are not only useful for purification of water but are also a source of food, water, firewood, sand, raw materials for making mats, baskets and pots (Kellner and Hubbart, 2019). Wetlands are also a habitat for a variety of aquatic organisms and it is here where their evolution occurs hence a range of aquatic biodiversity (Miyazono and Taylor, 2015). Wetlands conserve the aquatic ecosystem through "moderation of extreme flows, erosion prevention, sediment traps, climate modification, sediments formation, maintenance of water tables in surrounding lands, and as centres of biodiversity and wildlife habitat" (Griffin and Ali, 2014). Wetlands have also been reportedly used as grounds for performing spiritual rituals and recreation purposes in Uganda (Uganda Wetland Atlas, 2016). The sustained increase of human activities for extraction these goods and services from wetlands beyond their carrying capacity increases their degradation and raises pollution levels in both wetland water, sediments and fish. To cope with the increasing food insecurity in urban and per urban areas, farmers have extended their bounds of cultivation to virgin and fragile areas, especially wetlands (Turyahabwe, 2013).

The threat of food insecurity still remains a challenge to especially to developing countries (FAO, 2018). However, fish has been reported to contribute to household nutrition and food security systems against malnutrition and hunger (FAO, 2021). This is so because fish is a rich source of polyunsaturated fatty acids such as eicosapentaenoic acid and essential amino acids including docosahexaenoic acid, among other minerals and vitamin nutrients (Golden et al., 2016). There is an increasing trend in fish consumption worldwide versus the global population growth due to increased urbanization and increased awareness about the health benefits of fish consumption (Anderson et al., 2017). In Uganda, the fish per capita consumption is estimated at 12.5 kg (FAO, 2018). In addition, fisheries is a source income through the sale of farmed and wild fishes (Cai et al., 2019).

Regardless of all benefits associated with fish, these aquatic habitats are increasingly challenged with heavy metals from geological and anthropogenic sources (Briffa et al., 2020). Wetlands have been thought to be sinks of heavy metals in their sediments (Guo Y, 2016) and therefore tend to accumulate these pollutants in fish habitats. The excessive concentration of these pollutants in aquatic habitats adversely affects the growth, reproduction and population density of fisheries but also transfer the pollutants through bioaccumulation. As benthic feeding fish species feed, heavy metals from the polluted sediment is ingested into their tissue which sequentially poisons man who tertiary consumer along the food chain (Zhao et al., 2012; Castro-Gonzalez & Mendez-Armenta, 2008).

This cascading effect of heavy metals' pollution in the water, sediments and fish tissue as such compromises the nutritional benefits accrued from fisheries. Previous research in similar fields have indicated the potential of heavy metal health risks in surface, ground and bottled waters (Sekabira et al. 2010, Bamuwamye et al. 2017), in vegetables (Mbabazi et al. 2010) and in meat (Ogwok et al. 2014). The studies done on water resources also indicate increasing trends of heavy metal content in these ecosystems (Sekabira et al. 2010). Therefore, the focus of this study determined the effects of heavy metals (Cadmium, Chromium, Lead, Cobalt and Nickel) contamination in water, sediments on fish from the selected wetlands along L. Victoria.

1.2 Statement of the Problem

Wetlands as natural resources play a pivotal role in provision of numerous ecosystem services by virtue of being an intermediary between the mainland and aquatic ecosystems. The provision of fisheries from wetlands offers opportunities for enhancing food security and financial sustainability from the nutritional value of fish but also trading in them. Other ecosystem services provided by the wetlands attract significant populations for settlement in an amiable micro- climate, industrialization, tourism, transportation and treatment of semi-treated wastewater among others. The wetlands surrounding Lake Victoria continue to face similar challenges in increasing measure which has the impact of reducing the wetland's ability to provide these services. Fish being inhabitants of these ecosystems face a significant incidence of these impacts. Encroachment on the acreage of wetlands is reduces their size of their habitats, wastewater containing high loads of pollutants deprives them of oxygen but also a poor water quality contaminated with heavy metals causes ingestion and bioaccumulation of the pollutants in the fish tissue. Once consumed on the market, there is transfer of these pollutants to humans causing nutritional challenges and reduced financial sustainability from both high costs of treating related diseases and reduced fish catches from smaller wetlands – having been encroached on. Therefore, this study assessed the effects of heavy metals contamination in water and sediments on fish from the selected wetlands surrounding L. Victoria.

1.3 Objectives of the study

1.3.1 General objective

The aim of the study was to investigate the effects of heavy contamination in water and sediments on fish from wetlands along L. Victoria basin.

1.3.2 Specific objectives

The specific objectives of the study were to;

1. Assess the concentration of heavy metal - cadmium, chromium, lead, cobalt, and nickel in the water of Gabba, Nakivubo, Lwera and Nabugabo wetlands.
2. Analyze the concentration of heavy metals - cadmium, chromium, lead, cobalt, and nickel in the sediments in Gabba, Nakivubo, Lwera and Nabugabo wetlands.
3. Determine the concentration of heavy metals in different fish species *Clarias galiepinus*, *Clarius liocephalus* and *Protopterus sp* inhabiting Gabba, Nakivubo, Lwera and Nabugabo wetlands.

1.4 Hypothesis

It was Hypothesised that;

1. There are the variations in heavy metal concentrations of water from Gabba, Nakivubo, Lwera and Nabugabo wetlands.
2. There are the variations of heavy metals (chromium, cadmium, lead, cobalt and nickel) in sediments of Gabba, Nakivubo, Lwera and Nabugabo wetlands.
3. There are the variations in heavy metal concentrations in the different fish species *Clarias galiepinus*, *Clarius liocephalus* and *Protopterus sp* inhabiting Gabba, Nakivubo, Lwera and Nabugabo wetlands.

1.5 Significance of the study

This research aimed at assessing the health risks associated with the consumption of fish contaminated with heavy metals and inconsistency in wetland and water pollution resulting from anthropogenic activities along selected wetlands of Lake Victoria with an overall objective of developing a methodological framework for the establishment of conservation and management policies at the local level.

This study provides an exciting opportunity to advance our knowledge on the safety of fishes farmed from wetlands regardless of their nutritional value.

This research will help decision-makers, planners and other relevant stakeholders in the proper management of the wetland ecosystems that serves as a source for water resource utilization and habitat for various species. This will avail information for the proper management of green spaces and an opening for further research studies.

1.6. Scope of the study

Geographically, the study covered three wetlands that is Gabba, Nakivubo, Lwera and Nabugabo. Within the Lake Victoria Basin. Nakivubo and Gabba wetlands are close to highly urbanised and industrialised neighbourhoods that dispose a significant amount of waste in these wetlands whereas Lwera and Nabugabo are a distant from such settings and more in the remote rural neighbourhoods of Lake Victoria basin in Masaka and Kalungu Districts respectively. These were selected so as to have a comparison of the site's status dependant on geographical neighbourhood and surrounding land uses.

The study included collection of water samples from key fish inhabited wetlands around Lake Victoria basin. They were tested for physicochemical parameters such as the EC, pH, Turbidity, BOD, COD, TN, TP, Phosphates, chlorides and ammonium. In addition, the water was analysed for heavy metal concentration so as to be able to relate the quality of this water to the heavy metal components in fish to conclude where exactly the heavy metals in fish come from before being consumed by people around the lake. Secondly, the study included analysing the concentration of heavy metals in sediments from selected wetlands where these fish live. It's believed that these fish sometime consume these sediments and thus could be a connection to the accumulation of heavy metals in fish consumed by humans around the lake. Lastly, there was an assessment of the heavy metal concentrations in fish inhabiting the wetlands and to evaluate if they had a connection with what was in water and in sediments. The samples were analysed from the National Water Quality laboratory in Entebbe within 24hrs after collection from the field.

The whole study took six (6) months. Among which three months that is August, September and October 2021were for sample collection as other months were spent for laboratory analysis and the other months spent on data analysis and preparation of results outputs.

1.7 Limitation of the study

The study was greatly affected by the limited financial resources available at the individual level since it was privately funded. In addition, accessibility to key points more so inner points within the wetland was hard due to expensiveness and unavailability of boats for transport whenever needed, thus it so hard and impossible to collect samples (Fish and water samples) from the most intended key points in the wetland. On the hand, some fish species of interest were relatively scarce from some wetlands. This caused delay in getting the intended number of fish data required. Also, the fisher men in the wetlands of interest were so skeptical about the intension of the study and most of declined to take part in the study. Furthermore, the uncertain changes in season also greatly impacted my work in that heavy rains could abruptly dilute the water sample before being collected and most times make fish species unavailable and scarce and fisher men most times declined to work on rainy days.

1.8 Conceptual Framework

It was hypothesized in this study that the disposal of municipal and industrial waste such as wastewater into surrounding wetlands greatly pollutes such ecosystems and their inhabitants such as sediments, plants and different fauna like fish. Such wastes are either point source pollutants like domestic sewers, pesticides, herbicides and insecticides. On the other hand, non-point source pollutants include agriculture, livestock farming, road construction and development, industrialization and upstream water runoff. These greatly influence the levels physiochemical properties and heavy metal concentrations in water, sediments and fish. As these are alerted, the impacts are ought to affect different wetland dependant components such as humans and birds mainly through bioaccumulation, fish consumption and water consumption (Figure 1-1).

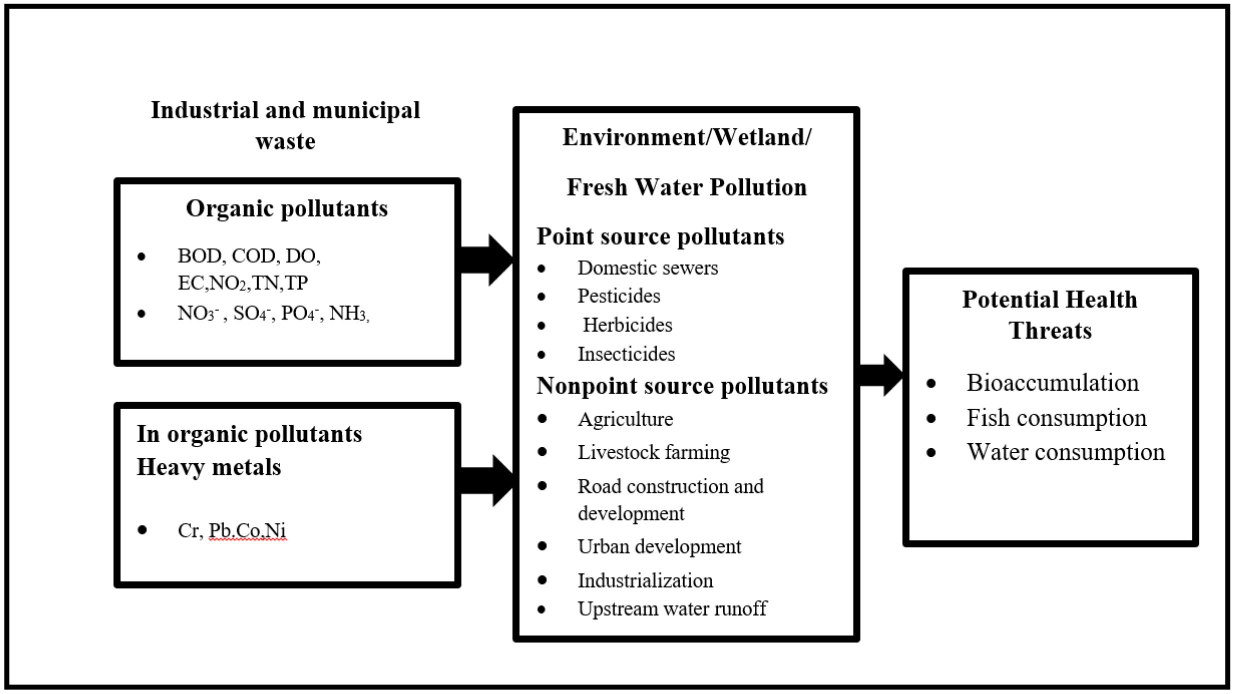

Figure 1. 1: *The interrelationship between the different activities in the wetlands*

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Here, special aspects of the study in relation to existing research that is significant to the study are explored in depth. It presents an overview of key components of the study. It includes an overview of ecosystem service of the wetlands, wetland pressures, water quality in wetlands, heavy metal concentrations in wetlands- emerging pollutants. Wetland and bioaccumulation in fish, and health implication of Heavy metal pollution.

2.2 Ecosystem services of wetlands

Wetlands occupy about 6% of the world's land surface (Hedman, 2019), world over studies including consultative meetings such as Ramsar Convention of 1971 are spotlights presenting earlier initiatives that were undertaken in acknowledging the value and importance of wetland resources (Gardner and Davidson, 2011). The report categorizes wetlands as areas of "both land ecosystems that are strongly influenced by water and aquatic ecosystems with special characteristics due to shallowness and proximity to land" (Max Finlayson et al., 2011). Although various classifications of wetlands exist, a useful approach is one provided by the Ramsar Convention on Wetlands. It divides wetlands into three main categories of wetland habitats: marine or coastal wetlands; inland wetlands and man-made wetlands (Darrah et al., 2019).

Wetlands are not only ecologically important for filtration of effluents and carbon retention but also a source of resources such as fish, yams, sand clay, forage, water and firewood (Kellner and Hubbart, 2019). Wetlands are also home to a number of aquatic organisms and it is here where their evolution occurs hence a range of aquatic biodiversity (Miyazono and Taylor, 2015). Wetlands conserve our ecosystem through "moderation of extreme flows, erosion prevention, sediment traps, climate modification, sediments formation, maintenance of water tables in surrounding lands, and as centres of biodiversity and wildlife habitat" (Griffin and Ali, 2014). Wetlands have also been reportedly used as grounds for performing spiritual rituals and recreation purposes in Uganda (Uganda Wetland Atlas, 2016).

It is also important to note that a number of wetlands in Uganda have been encroached on for subsistence and commercial farming due to their sediment deposition which enhances their sediments fertility on top of the constant water supply, while others are used for commercial purposes such as brick laying, fishing and harvesting of papyrus for craft making including mats by about 10% of the Ugandan population (Uganda Wetland Atlas, 2016; Turyahabwe et al., 2013; Gumm, 2011). Wetlands regulate water table levels and offer protection against storms (NEMA, 2017).. They are also used for eco-conservation by environmentalists such as National Water and Sewage Corporation in Uganda for sewage treatment before the water is channelled back to the lakes and rivers (Uganda Wetland Atlas, 2016).

2.3 Pressures on wetlands

There was a decrease in the global wetlands at a rate of 35% from 1970 - 2015 whereas there was an increase in the number of manmade wetlands at a rate of 233% from 1970 – 2014 suggesting that more efforts are needed to conserve the naturally occurring wetland areas globally (Darrah et al., 2019).

The increasing urbanization and the rapidly growing Ugandan population at 3.2 % per year is putting pressure on the wetlands to give way for infrastructure development and natural resources to sustain livelihoods (UBOS, 2014).

Government policies such as licensing business investments within wetland areas has significantly contributed to wetland degradation either directly by destruction of wetlands or indirectly through the discharge of untreated pollutants from industrial wastes directly into the wetlands (Businge, 2017).

2.4 Wetlands and Water quality

Wetlands are ecosystems intermediate between aquatic and terrestrial systems, which are permanently or seasonally covered with shallow water (Dar et al., 2020). Generally, riparian wetlands are known for water filtration which in turn ends up accumulating heavy metals which have adverse health effects (Zhang et al., 2010).

Over the years, there has been incremental destruction of wetlands over the past century due to human activities regardless of the selfless efforts to preserve wetlands (Hong et al., 2020). Ever since the industrial revolution, there has been increasing pollution of the atmosphere with heavy metals among other pollutants (Nriagu, 1979). "Heavy metals are metals with specific gravity greater than 5 g/cm^{3}" (Taylor & Rai, 2012).

2.5 Heavy metal pollution in wetlands

Extreme levels of heavy metals in water sources poses a health threat to humanity and this calls for sustainable eco-technological innovations that would regulate the release of heavy metals from industrial activities (Taylor & Rai, 2012). Potentially harmful elements (PHE) including copper (Cu), chromium (Cr), cadmium (Cd), and lead (Pb) naturally occur in water, sediments and living organisms with their concentrations depending on local geological activities and pollution from other geogenic and anthropogenic sources (Ngure and Obwanga, 2017). According to (Zhang and Ma, 2011), wetlands are at high risk both lethal and sub-lethal effects due to rising effects of heavy metal pollution, It is costly and time-consuming to examine the environmental quality and concentration levels of heavy metals in wetlands and freshwater ecosystems, thus indicator species and indicator tissues must be selected, the further added that biological monitoring is thought to be satisfactory way to quantify heavy metal abundance and bio-availability.

2.6 Heavy metal pollution in sediments of wetlands

Wetlands occur in the downstream reaches of aquatic ecosystems and therefore receive materials and nutrients from upstream areas of the catchment (Guo and Yang 2016). The structural make up of their macrophytes and sediment profile enables them to intercept pollutant material through adsorption in the root mat structure, and precipitation – eventually settling of this pollutant material in the sediment zones (Komal Arshad, 2022). For this reason, wetland have been thought to act as sinks of pollutants including heavy metals. At favorable physiochemical conditions in the wetlands, such as pH, and the oxidation-reduction potential of the wetlands, the heavy metals in the sediments may be re-suspended in the water column as secondary pollutants (Guo and Yang 2016; Lee et al. 2010).

2.7 Heavy metals and bio accumulation in fish

Heavy metals find their way into the aquatic ecosystem via human activities such as industrialization which releases untreated waste into the atmosphere and water bodies, and by deposition of domestic effluents into water sources. Heavy metals are associated with health risks not only to the aquatic ecosystem but also to the tertiary consumers in the ecosystem such as wildlife and humans. Much as macronutrients such as manganese are essential for normal physiological processes in the body, other minerals such as lead, mercury, arsenic, nickel among others are associated with toxic effects on aquatic organisms leading to bio-magnification in the food chain (Kumar et al., 2011). Alhashemi et al., (2012) reported the prevalence of heavy metals such as cobalt, copper, cadmium in sediments and fish muscles of the commonly farmed fish species farmed in Shadegan wetland in Iran.

Eagles-Smith and Ackerman, (2014) reported the prevalence of mercury in fish's samples farmed from wetlands while a study on the presence of mercury in fish farmed from open bay sites in San Francisco Bay Estuary (2005 and 2008) reported that 26% of the fish flesh was contaminated with mercury at levels beyond the lowest safe limits of 0.20 mg/g wet weight and 0.30 mg/g wet weight for fish and piscivorous bird, respectively. This therefore indicates that more effects are still needed even with the managed wetlands to regulate heavy mental contamination in aquatic ecosystems to the safest levels possible. This could be achieved by treatment of waste water with either poly-aluminum chloride or ferric sulfate since these have been reported to decrease heavy metal contamination in wetlands by precipitation of mercury and allowing the settlement of precipitates as surface water passes by (Ackerman et al., 2015).

2.8 Health implication of heavy metal pollution

According to Taylor and Rai, (2013), exposure to heavy metal beyond recommended levels has been reported to cause kidney damages, cancers, neurological disorders and in extreme cases death. An estimated 6 million people in Cambodia, India and Vietnam were reported at risk of arsenic poisoning from drinking water (Schwarzenbach et al., 2010).

Ngure and Obwanga, (2017), reported lead poisoning among children in West Africa which is associated with detrimental health effects such as interference with normal formation of the blood stream affecting oxygen transportation in humans among other health risks. Elsewhere, gold mining activities in Migori Gold Belt have also been reported to lead to heavy metal contamination in the mining communities as a result of sediments erosion and leaching into the surrounding rivers (Bhupander and Mukherjee, 2011). This consequently affects the water quality and may lead to growth of algae which reduces the amounts of dissolved oxygen in water as well as heavy metal poising to the aquatic live negatively affecting the survival of aquatic organisms, particularly fish which is food needed for human survival (Ochuka et al., 2019).

2.9 Research in relation to the study

Heavy metals are released into the environment from a wide range of natural and anthropogenic sources. The rate of influx of these heavy metals into the environment exceeds their removal by natural processes. In the past decades, therefore research efforts have been directed towards wetlands as an alternative low cost means of removing metals from domestic, commercial, mining and industrial discharge of waste water. Recent studies on water quality in wetlands have entirely concentrated on exploring the heavy metal retention ability of different wetlands, for instance, Fuhrimann et al., (2015) assessed the microbial and chemical contamination of water, sediment and sediments in the Nakivubo wetland area. The efficiency of the wetland as a filter from heavy metal pollutants was also assessed by Mbabazi et al., (2020). In addition, Sekabira et al, (2011), also assessed heavy metal contaminants in the Nakivubo stream water by assessing water samples from Nakivubo channelized stream, tributaries and industrial effluents that drain into the stream. A closer look at most of the studies is that all of them are along Nakivubo wetlands and mostly concentrate on heavy metals in water samples and some in sediments and plants. This leaves the fauna components like fish in the wetland neglected. On the other hand, other wetlands like Nabugabo and Lwera are entirely neglected and knowledge on their component quality status is entirely limited and totally unknown.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This section explores the methods and procedures that were used in conducting this study. This chaptergives a description of Nakivubo, Gabba, Lwera and Nabugabo wetlands as the study areas, their locations, climates and key vegetation covers. It further discusses the research design used, field sampling and data collection methods, Laboratory data analysis procedures and data a nalysis tools used.

3.2 Study area

The study was carried out in wetlands around Lake Victoria, which is the largest freshwater lake in the world covering 68,800 km^2 of surface area (Polder et al., 2014). In Uganda, Lake Victoria has a catchment area of 38,899 km^2. The lake is a shared resource among the riparian countries with Kenya having 6%, Uganda 45% and Tanzania 49% (Bay et al., 2010).

The study sites included Nakivubo, Gabba, Lwera and Nabugabo wetlands. Gabba and Nakivubo wetlands receive high loads of wastewater from a consortium of sources including sewerage fro m households, industrial effluent, and surface runoff from the paved city. Both wetlands are wetl ands are of subsurface flow in nature with papyrus as the most dominant macrophyte. The free fl ow of water in the wetlands has been interrupted through channelization by the Gabba stream an d Nakivubo channel respectively thus reducing the residence time of wastewater in the wetlands. Because of the increasing human pressures on these wetlands in form of increased industrialisati on and population growth in the city, their capacity to treat effluent may be continually undermin ed. In general, both wetlands play a critical role in intercepting wastewater that would otherwise pollute the lake downstream. On the other hand, Nabugabo wetland is located on the shoreline ar eas of Lake Nabugabo which is a satellite lake to Lake Victoria catchment. The wetland has relat ively minimal human pressures compared to the Nakivubo and Gabba wetlands. The major activi ties in this wetland include small scale fisheries, and harvesting of papyrus for making crafts. Th e Nabugabo wetland was used as a control comparison for wastewater remediation in contrast wi th the heavily impacted Nakivubo and Gabba wetlands. Previously, Lwera wetland was a kind of a stable wetland ecosystem, however the current introduction of intensive rice growing activities and extensive sand mining has greatly interrupted the ecological functionality of the wetland.

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Wetlands occur in the downstream reaches of aquatic ecosystems and therefore receive materials and nutrients from upstream areas of the catchment (Guo and Yang 2016). The structural make up of their macrophytes and sediment profile enables them to intercept pollutant material through adsorption in the root mat structure, and precipitation – eventually settling of this pollutant material in the sediment zones (Komal Arshad, 2022). For this reason, wetland have been thought to act as sinks of pollutants including heavy metals. At favorable physiochemical conditions in the wetlands, such as pH, and the oxidation-reduction potential of the wetlands, the heavy metals in the sediments may be re-suspended in the water column as secondary pollutants (Guo and Yang 2016; Lee et al. 2010).

2.7 Heavy metals and bio accumulation in fish

Heavy metals find their way into the aquatic ecosystem via human activities such as industrialization which releases untreated waste into the atmosphere and water bodies, and by deposition of domestic effluents into water sources. Heavy metals are associated with health risks not only to the aquatic ecosystem but also to the tertiary consumers in the ecosystem such as wildlife and humans. Much as macronutrients such as manganese are essential for normal physiological processes in the body, other minerals such as lead, mercury, arsenic, nickel among others are associated with toxic effects on aquatic organisms leading to bio-magnification in the food chain (Kumar et al., 2011). Alhashemi et al., (2012) reported the prevalence of heavy metals such as cobalt, copper, cadmium in sediments and fish muscles of the commonly farmed fish species farmed in Shadegan wetland in Iran.

Eagles-Smith and Ackerman, (2014) reported the prevalence of mercury in fishes samples farmed from wetlands while a study on the presence of mercury in fish farmed from open bay sites in San Francisco Bay Estuary (2005 and 2008) reported that 26% of the fish flesh was contaminated with mercury at levels beyond the lowest safe limits of 0.20 mg/g wet weight and 0.30 mg/g wet weight for fish and piscivorous bird, respectively. This therefore indicates that more effects are still needed even with the managed wetlands to regulate heavy mental contamination in aquatic ecosystems to the safest levels possible. This could be achieved by treatment of waste water with either poly-aluminum chloride or ferric sulfate since these have been reported to decrease heavy metal contamination in wetlands by precipitation of mercury and allowing the settlement of precipitates as surface water passes by (Ackerman et al., 2015).

2.8 Health implication of heavy metal pollution

According to Taylor and Rai, (2013), exposure to heavy metal beyond recommended levels has been reported to cause kidney damages, cancers, neurological disorders and in extreme cases death. An estimated 6 million people in Cambodia, India and Vietnam were reported at risk of arsenic poisoning from drinking water (Schwarzenbach et al., 2010).

Ngure and Obwanga, (2017), reported lead poisoning among children in West Africa which is associated with detrimental health effects such as interference with normal formation of the blood stream affecting oxygen transportation in humans among other health risks. Elsewhere, gold mining activities in Migori Gold Belt have also been reported to lead to heavy metal contamination in the mining communities as a result of sediments erosion and leaching into the surrounding rivers (Bhupander and Mukherjee, 2011). This consequently affects the water quality and may lead to growth of algae which reduces the amounts of dissolved oxygen in water as well as heavy metal poising to the aquatic live negatively affecting the survival of aquatic organisms, particularly fish which is food needed for human survival (Ochuka et al., 2019).

2.9 Research in relation to the study

Heavy metals are released into the environment from a wide range of natural and anthropogenic sources. The rate of influx of these heavy metals into the environment exceeds their removal by natural processes. In the past decades, therefore research efforts have been directed towards wetlands as an alternative low cost means of removing metals from domestic, commercial, mining and industrial discharge of waste water. Recent studies on water quality in wetlands have entirely concentrated on exploring the heavy metal retention ability of different wetlands, for instance, Fuhrimann et al., (2015) assessed the microbial and chemical contamination of water, sediment and sediments in the Nakivubo wetland area. The efficiency of the wetland as a filter from heavy metal pollutants was also assessed by Mbabazi et al., (2020). In addition, Sekabira et al, (2011), also assessed heavy metal contaminants in the Nakivubo stream water by assessing water samples from Nakivubo channelized stream, tributaries and industrial effluents that drain into the stream. A closer look at most of the studies is that all of them are along Nakivubo wetlands and mostly concentrate on heavy metals in water samples and some in sediments and plants. This leaves the fauna components like fish in the wetland neglected. On the other hand, other wetlands like Nabugabo and Lwera are entirely neglected and knowledge on their component quality status is entirely limited and totally unknown.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This section explores the methods and procedures that were used in conducting this study. This chapter gives a description of Nakivubo, Gabba, Lwera and Nabugabo wetlands as the study areas, their locations, climates and key vegetation covers. It further discusses the research design used, field sampling and data collection methods, Laboratory data analysis procedures and data analysis tools used.

3.2 Study area

The study was carried out in wetlands around Lake Victoria, which is the largest freshwater lake in the world covering 68,800 km^2 of surface area (Polder et al., 2014). In Uganda, Lake Victoria has a catchment area of 38,899 km^2. The lake is a shared resource among the riparian countries with Kenya having 6%, Uganda 45% and Tanzania 49% (Bay et al., 2010).

The study sites included Nakivubo, Gabba, Lwera and Nabugabo wetlands. Gabba and Nakivubo wetlands receive high loads of wastewater from a consortium of sources including sewerage from households, industrial effluent, and surface runoff from the paved city. Both wetlands are wetlands are of subsurface flow in nature with papyrus as the most dominant macrophyte. The free flow of water in the wetlands has been interrupted through channelization by the Gabba stream and Nakivubo channel respectively thus reducing the residence time of wastewater in the wetlands. Because of the increasing human pressures on these wetlands in form of increased industrialisation and population growth in the city, their capacity to treat effluent may be continually undermined. In general, both wetlands play a critical role in intercepting wastewater that would otherwise pollute the lake downstream. On the other hand, Nabugabo wetland is located on the shoreline areas of Lake Nabugabo which is a satellite lake to Lake Victoria catchment. The wetland has relatively minimal human pressures compared to the Nakivubo and Gabba wetlands. The major activities in this wetland include small scale fisheries, and harvesting of papyrus for making crafts. The Nabugabo wetland was used as a control comparison for wastewater remediation in contrast with the heavily impacted Nakivubo and Gabba wetlands. Previously, Lwera wetland was a kind of a stable wetland ecosystem, however the current introduction of intensive rice growing activities and extensive sand mining has greatly interrupted the ecological functionality of the wetland. Figure 3-1 below shows the location of the wetlands and the respective sampling sites in the wetlands.

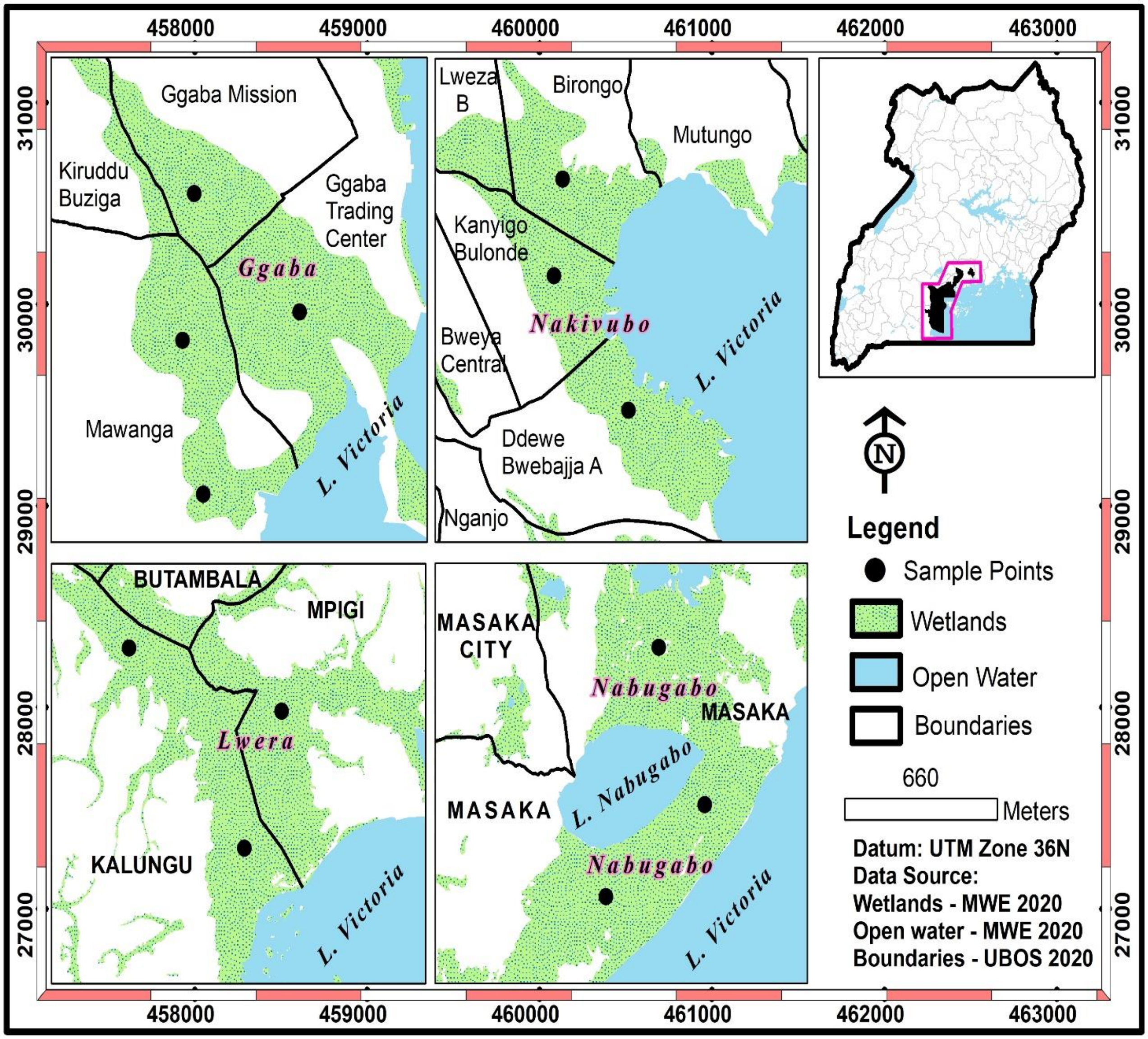


Figure 3. 1**:** *Study areas and sampling sites in Lwera , Nabugabo, Nakivubo and Gabba Wetlands*

3.3 Research Design

The research undertook a quantitative research approach. Specifically, this involved assessing the connection between the physicochemical parameters and heavy metal concentrations of water in the different wetlands (Nakivubo, Gabba, Lwera and Nabugabo) and what was actually concentrated in the fish living in these wetlands. The research involved collection of water, sediments and fish samples species for over three months. This aided to fully understand how the said increase in the deposition of industrial and agricultural waste from highly urbanised wetland surroundings have affected the quality of wetland waters and sediments that might have eventually impacted on the quality and safety of fish consumed by humans. The results from this assessment were compared to those of control wetland in a less industrialised, agricultural and urbanised site miles away from active areas.

3.4 Data collection methods

3.4.1 Water Analysis

Field water sample collection

In order to assess the physicochemical parameters and heavy metal concentrations of water that enters the selected wetlands. Twelve selected sampling sites (3 per wetland) were monitored over a period of three months. The water quality variables considered include pH, EC, TN, TP, NH_3, NO_3, SO_4, PO_4, COD, BOD and heavy metals such as; Chromium, Cadmuim, lead, Cobalt and Nickel.

Plate 3. 1: *Water sampling at the different selected spots in the different wetlands*

At the sampling site, some in-situ measurement for water quality factors including Electrical Conductivity, pH, temperature and turbidity were undertaken using an integrated Multi-parameter Horiba (Model U-52G, Japan) mounted with five probes. Before use, the Horiba was pre-calibrated and measurements were taken based on procedures outlined by the manufacturer's manual.

Plate 3. 2: *In-situ water quality testing of collected samples*

Water samples for physicochemical parameters determination were collected directly from the wetlands using clean plastic beakers of 250 ml that were first rinsed with distilled water in between samples and then put in a 1 litre plastic jerrican. All collected water samples were kept in an ice box at 5 ± 3°C and transported to the Water Quality Reference laboratory in Entebbe for analysis within 24 hours. All samples were stored and handled according to standard protocols of the Standards method of Examination of Water and wastewater.

Plate 3. 3: *Water sampling from the wetland.*

Laboratory water sample analysis

All water quality analysis was performed according to Standards Methods for the Examination of waters and Wastewaters 23rd Edition (Baird, et al, 2017). All laboratory glassware was acid cleaned using 20% HCL for nutrient measurements, and HNO_3 (2%) for trace metals measurements. The parameters to be analyzed included BOD, COD, TN, TP, NH_4, NO_3, SO_4, PO_4, and heavy metals such as; chromium, lead, cobalt and Nickel as elaborated below;

a) Biochemical Oxygen Demand (BOD_5) determination

The method used was 4500-O G. Membrane-Electrode Method in standard methods for the examination of waters and Wastewaters 23rd Edition (Baird, et al, 2017). This uses the Oxygen-sensitive polarography membrane electrodes composed of two solid metal electrodes in contact with supporting electrolyte separated from the test solution by a selective membrane. Under steady-state conditions, the current is directly proportional to the DO concentration in mg/L.

The biochemical oxygen demand is defined as the mass of dissolved oxygen required by a specified volume of liquid for the process of biochemical oxidation under prescribed conditions over a period of 5 days at 20 ^{o}C in the incubator. The result is expressed as milligrams of oxygen per litre of sample

The BOD test was performed by incubating a sealed water sample after addition of dilution water for a period of five days in a BOD incubator at 20^{o}C. BOD in mg/L was obtained subtracting the final DO after incubation from the Initial DO before incubation.

The results were calculated as BOD mg/L according to standard methods for Examination of Water and Wastewater 23rd Edition using the formula.

$$BOD\ [mg/l] = n\ (d_1 - d_2 - B) + B$$

Where;

n – Dilution

d_l – initial DO concentration (mg/L) ,

d_2 – final D.O concentration (mg/L)

B – Concentration of blank water (mg/L)

Plate 3. 4: *Laboratory analysis of Biological Oxygen Demand from water samples in wetlands*

b) Chemical Oxygen Demand determination

This was determined using the closed reflux calorimetry method. Here potassium dichromate reagent mixed with sulfuric acid and mercuric sulfate was used to mask chloride which consumes the dichromate ions hence giving high false values. The excess dichromate which remains unreacted after a 2 hours of reaction process was titrated using was measured spectrophotometrically.

In this method, 2 mLs of each water sample was pipetted and put into a digestion tube. The tubes were caped tightly and gently mixed. They were then placed in a digestion block maintained at 150 ^{o}C for 2hours. After the tubes were removed, swirled to mix and then cooled at room temperature. The results were measured spectrophotometrically on a DR 6000(Hach USA) at a wavelength of 620nm.

c) Determination of Ammonium, Chlorides, Phosphates, Nitrates and Sulphates

The above nutrients were analyzed using a discrete analyzer, Gallery Plus, manufactured by Thermo Fisher Scientific, U.S.A. It performs a discrete photometric test on each required analyte; hence it is optimized for the specific concentration range of each individual analyte. The instrument offers barcoded sample and reagent identification, automated dilutions and re-analyses, several blanking methods, automated reagent consumption monitoring, and minimal waste generation. The water samples were automatically dispensed into 5ml cuvettes, into which method-specific reagents were also automatically dispensed using wavelength by the discrete analyzer and converted to a concentration with the aid of a blank and a calibration standard. Quality control was achieved by means of an independent standard measured like the sample. The instrument has the capability to automatically dilute and re-analyze a sample that exceeds the measuring range. The final reading of Ammonium, Chlorides, Phosphates, Nitrates and Sulphates were then reported in mg/L.

d) Total Nitrogen

This followed the Standard method of Analysis water and wastewater 23rd Edition for Total Nitrogen. 10mls of a sample was transferred into the digestion vial, and then one micro spoon of ammonium persulphate and six drops of sodium hydroxide was added and shaken for uniformity. The sample was later digested in an auto clave for two hours at 121^{o}C. After that the samples were run on o the Gallery Plus discrete analyzer which gives the value of Total Nitrogen in mg/L.

e) Total Phosphorus

Total phosphorus was measured on the Gallery Plus Discrete analyzer. Prior to this,10mls of sample was transferred into a digestion vial, then one micro spoon of ammonium persulphate was added then digested in an autoclave for 2 hours at 121 ^{0}C. The samples were run on the Gallery plus analyzer which gives phosphate results in mg/L.

f) `Determination of heavy metals in water samples

Heavy metals from collected waste water samples were determined in the laboratory using the inductively Coupled Plasma –Optical Emission Spectroscopy (ICP-OES) using the APHA 23rd Edition: Method 3120; Determination of Metals by Plasma Emission Spectroscopy Inductively Coupled Plasma (ICP

Here a sample containing the metals was aspirated in high temperature plasma of up to 7700^0C. At this temperature, the metals were converted to atoms, become excited and ionized. The excited atom emitted a radiation(s) when it goes back to ground state. The emitted characteristic radiations were then measured optically by detectors where the intensity of emitted radiation corresponds to the number of toms emitting the radiation. The detector readings were converted to concentration values on a calibration curve according to the Beer-Lambert's law.

g) Determination of Total Suspended Solids

The Total Suspended Solids was determined Gravimetrically. Empty Filter papers were washed, dried in an oven, there weights taken and recorded. A well-mixed sample was then strained and the residue on the filter paper was dried in an oven at 105^0C for one hour. After its weight was taken and recorded. The difference in Weight between the empty filter paper and the Filter paper containing the residue was calculated and recorded as TSS in mg/L.

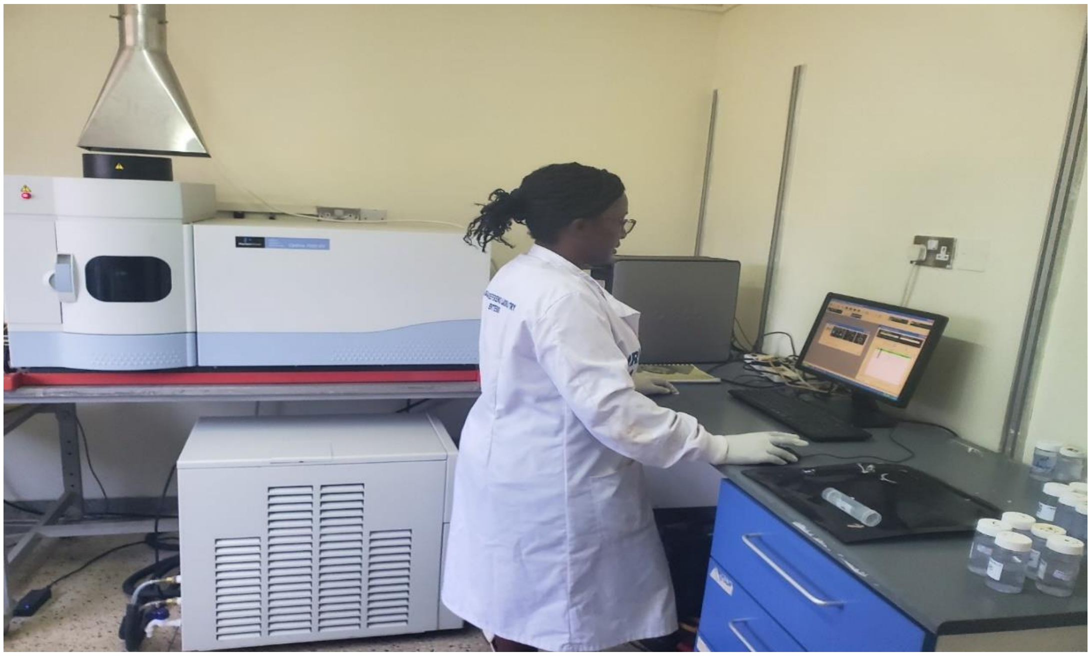


Plate 3. 5: *Analysis of Heavy metals on the ICP OES at National Water Quality Reference Laboratory, Entebbe*

3.4.2 Sediment analysis

Sampling

Sediment samples were collected from three sites in each selected wetland depending on the exposure to wastes at that given part of the wetland. Sediments samples were collected at a depth of six (6) inches using a hand metallic sediments scoop. In total, 6 scoops were collected from each site put in clean container and mixed together. All large debris like rocks, foreign objects and plant parts were removed from the samples. The samples were packaged into brown paper bags and labelled before being transported to the National Water Quality Reference Laboratory for analysis. The sediments scoops were always cleaned after every scooping was done.

Laboratory sediment sample analysis

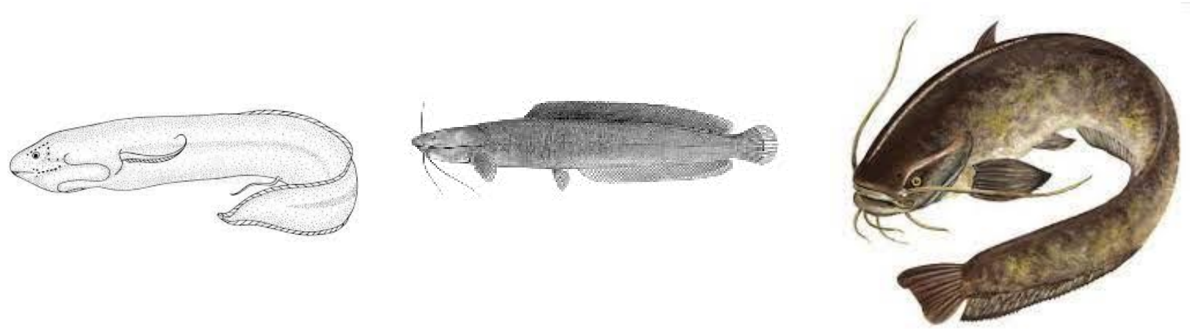
The wet sediments samples were spread and sundried on papers at the laboratory. The dried samples were then ground and sieved. Approximately 1g sample was weighed and then transferred to the polymeric vessel of the microwave. 9 mLs concentrated Nitric acid and 3 mLs of concentrated Hydrochloric acid were added to the sample in the vessel using a fume Hood then digested for 30 minutes. After that, cooled to allow the vessel content to settle, decant, diluted to 100 ml mark volumetric flask then taken to ICP (Inductively Coupled Plasma) for heavy metal analysis

Briefly, the digest solution was nebulized and sample aerosols transferred to argon plasma. The high temperature plasma produced ions that were introduced into the mass spectrometer, which sorted them out according to their mass-to-charge ration. The ions were quantified with an electron multiplier detector.

3.4.3 Fish analysis

Sampling

The fish samples that were considered for this study included: *Clarias galiepinus, Clarius liocephalus and Protopterus sp* locally known as Mamba Nsonzi, and Male respectively. For each fish species, a total of twelve (12) samples were collected from each of the selected study wetlands depending on the availability as informed by the fisher men in the area. The fish samples were obtained with help from local fishermen using hooks at each sampling wetland and these were stored in labelled plastic bags and put in an ice-box before transferred to the laboratory for storage at $4^{\circ}C$ prior digestion (Raja et al., 2009).



Protopterus sp *Clarius liocephalus* *Clarias galiepinus*

Plate 3. 6: *Pictures of the fish species used in the study*

Fish Samples analysis for heavy metals

The fish samples were dissected in the Laboratory, taking a sample from the skin and muscle. The sample was then dried in an oven at a temperature of 105^{o}C and weighed approx.2g and then transferred to the polymeric vessel of the microwave. 9 mls concentrated Nitric acid and 3 mls of concentrated Hydrochloric acid was added to the sample in the vessel using a fume wood then digested for 30 minutes. After that, cooled to allow the vessel content to settle, decant, diluted to 100 ml mark volumetric flask then transferred for ICP (Inductively Coupled Plasma) analysis (Adebayo, 2017).

Plate 3. 7: *Fish sample dissection in the Laboratory for Analysis*

Sample solutions are introduced into the ICP as an aerosol that is carried into the centre of the plasma (superheated inert gas). The plasma desolates the aerosol into a solid, vaporizes the solid into a gas, and then dissociates the individual molecules into atoms. This high temperature source (plasma) excites the atoms and ions to emit light at particular wavelengths, which correspond to different elements in the sample solution**.** Fish samples were analysed in duplicate.

The detection limit for Chromium, Cobalt, Nickel and Lead were considered following the WHO standards respectively.

3.5 Data analysis

Data was recorded and stored using MS Excel spread sheet 2010. Then data was transferred into R-studio where it was summarised using R-software version 4.2.1. Since samples were picked from four sites that is; Gabba, Lwera, Nabugabo and Nakivubo wetlands, it was important to determine whether there were any mean differences across the four sites using Analysis of Variances (ANOVA). Given that it was only one factor variable that's wetlands, a one-way-ANOVA was appropriate to determine the mean differences across the different sites. To check for significant differences between treatments, Tukey's Honestly Significant Difference (HSD) tests were performed for each wetland (Sokal & Rohlf, 2012). The p-values of less than 0.05 were considered to indicate statistical significance. Pearson Correlation was used to analyse the extent and the nature of relationships between different variables. Correlation coefficient 'r' is calculated through the following formula:

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{\left(n\sum x^2 - (\sum x)^2\right)\left(n\sum y^2 - (\sum y)^2\right)}}$$

Where, *x* and *y* are values of variables, and *n* is size of the sample.

The value of correlation coefficient can be interpreted in the following manner:

If 'r' is equal to 1, then there is perfect positive correlation between two values;

If 'r' is equal to -1, then there is perfect negative correlation between two values;

If 'r' is equal to zero, then there is no correlation between the two values.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Introduction

This section presents well organized data summaries and results in form of tables, and figures. It further explains the data by drawing relative interpretations and conclusions. The results are presented on the basis of the specific objectives and the research questions. In addition, the results presented are related to those of other authors in the same field and deductions made as to why they appear different or similar in different instances

4.2 Physicochemical parameters and heavy metal concentration of water in selected fish Habitat wetlands

4.2.1 Physicochemical parameters

The water samples from Lwera and Nabugabo had lower values for Electrical Conductivity in as much as these were not significantly different from other wetlands (Table 4-1). The pH at Gabba and Nabugabo had no significant difference but significantly differed with the pH at Lwera and Nakivubo. Significantly higher concentrations were observed in Ggaba, Lwera and Nabugabo wetlands for BOD, TSS, TN and TP (Table 4-1). Water sample analysis revealed that water from different selected fish habitat wetlands significantly varied in quality in terms of particular physicochemical parameters at the 0.05 significant levels. Of the chemical parameters analysed, it was only turbidity, EC, nitrates and sulphates concentrations that showed no significant differences across the wetlands.

Table 4. 1: *Physicochemical parameters of water from selected fish Habitats*

Variable	Gabba mean±se	Lwera mean±se	Nabugabo mean±se	Nakivubo mean±se	*F-value*	*p-value*
Turbidity	$2.27±0.63^{ab}$	$1.17±0.15^{b}$	$2.63±0.43^{a}$	$1.99±0.41^{ab}$	1.043	0.425
pH	$6.97±0.18^{a}$	$6.33±0.07^{b}$	$6.5±0.12^{a}$	$7.13±0.15^{b}$	8.169	0.00809**
Electrical Conductivity	$590 ±345.2^{a}$	$203.3 ±39.83^{a}$	$23.67±3.18^{b}$	$563.3 ±108^{a}$	2.326	0.151
Total Dissolved Solids	$413 ± 241^{a}$	$142.6 ± 27.8^{a}$	$16.67±2.03^{b}$	$426±44.7^{a}$	18.48	0.00059**
Biological Oxygen Demand	$4.47±1.44^{b}$	$0.45±0.0^{b}$	$1.98±0.98^{b}$	$25.67±5.21^{a}$	3.285	0.0793
Chemical Oxygen Demand	$20±9.1^{b}$	$38.33±11.35^{b}$	$28.33±7.13^{b}$	$60.67±10.7^{a}$	3.285	0.0793
Total Suspended Solids	$76.33±51.9^{b}$	$48.67±9.82^{b}$	$34±7.02^{b}$	$162±29^{a}$	3.562	0.067

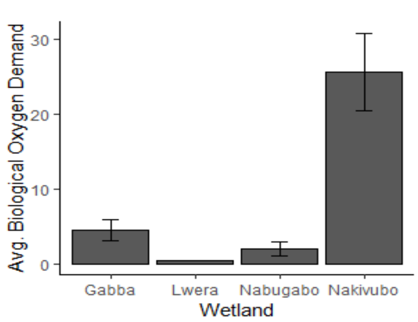
Total Nitrogen (TN)	4.91±2.64[a]	0.62±0.5[b]	0.15±0.08[b]	9.37±3.65[a]	3.627	0.0644
Total Phosphate.TP	0.25±0.05[c]	0.08±0.07[b]	0.05±0.0[b]	3.17±0.89[a]	11.67	0.00272**
Reactive Phosphorus.PO_4	0.2±0.04[c]	0.06±0.05[b]	0.01±0.0[b]	2.53±0.71[a]	11.69	0.00271**
Nitrates ($N0_3$)	0.88±0.43[a]	0.48±0.4[a]	0.08±0.05[b]	0.06±0.04[b]	1.722	0.239
Ammonium (NH_4)	3.11±1.79[a]	0.03±0.0[b]	0.05±0.02[b]	7.56±2.93[a]	4.294	0.0441**
Sulphates	5.7±3.86[a]	1.77±1.08[b]	0.17±0.09[b]	8±1.9[a]	2.618	0.123
Chloride	21.07±11.02[a]	17.53±1.54[a]	1.6±0.32[b]	40±7.02[a]	5.739	0.0215**

*Note: Different letters imply significantly different; "**": significant at 5%,*

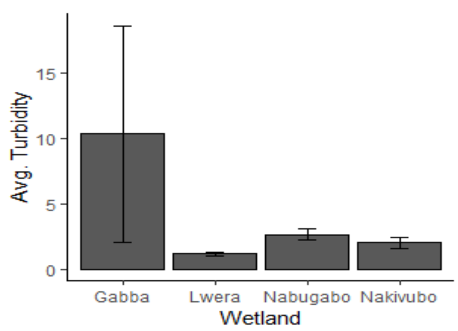
A closer look at the summary results, the following parameters which had $p < 0.05$ showed there was a significant difference. pH (p = 0.00809), TDS (p = 0.00059), TP (p = 0.00272), PO_4 (p = 0.00271), NH_4 (p = 0.0441) and Chloride (p = 0.0215).

The parameters which had p>0.05 showed there was no significant difference. These were Turbidity (p = 0.425), Electrical conductivity (p = 0.151), BOD (p = 0.0793), COD (p = 0.0793), TSS (p = 0.067), TN (p = 0.0644), Nitrates (p = 0.239) and sulphates (p = 0.123).

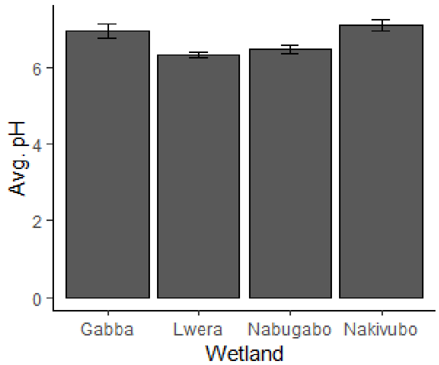
The samples from Nakivubo, and Gabba had a high value for Electrical Conductivity, Total dissolved solids, BOD, TSS, Ammonia and chloride compared to Lwera and Nabugabo. Nakivubo wetland had highest concentrations of all the tested parameters except Turbidity and Nitrates. Such results show a high level of contamination of the wetland compared to other studied sites. Lwera and Nabugabo wetlands had less concentration of all tested physicochemical parameters. (Figure 4-1)



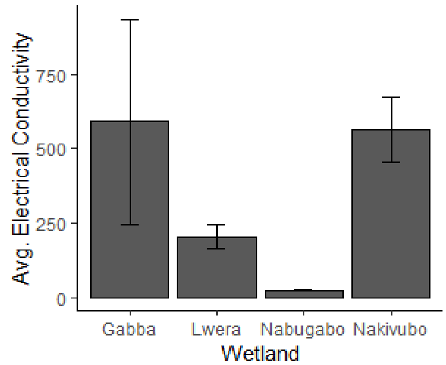
A



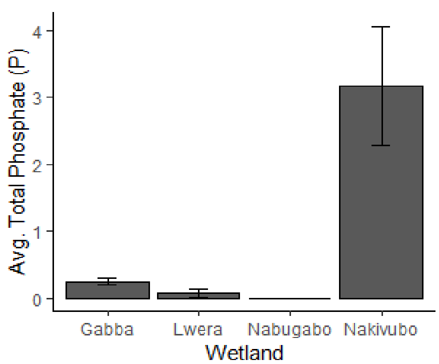
B


Avg. pH
0
2
4
6
Gabba
Lwera
Nabugabo
Nakivubo
Wetland

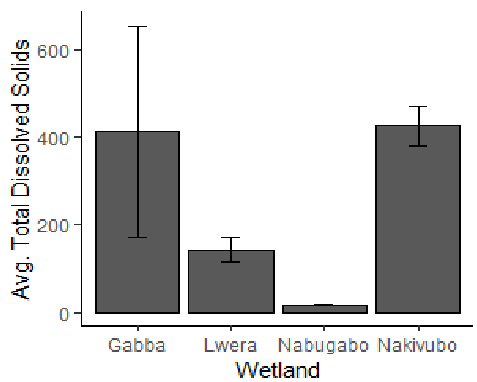
C


Avg. Electrical Conductivity
0
250
500
750
Gabba
Lwera
Nabugabo
Nakivubo
Wetland

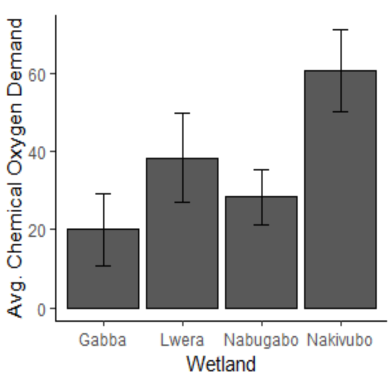
D


Avg. Total Phosphate (P)
0
1
2
3
4
Gabba
Lwera
Nabugabo
Nakivubo
Wetland

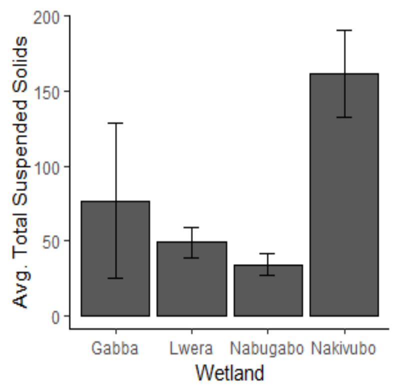
E


Avg. Total Dissolved Solids
0
200
400
600
Gabba
Lwera
Nabugabo
Nakivubo
Wetland

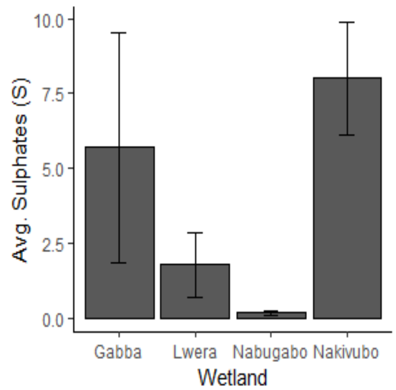
F


Avg. Chemical Oxygen Demand
0
20
40
60
Gabba
Lwera
Nabugabo
Nakivubo
Wetland

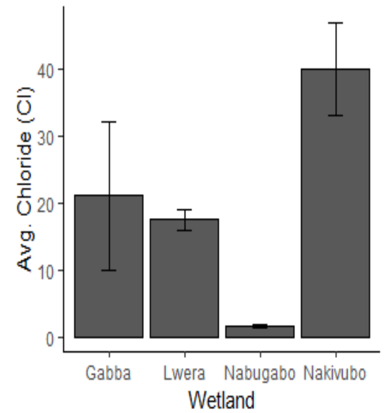
G


Avg. Total Suspended Solids
0
50
100
150
200
Gabba
Lwera
Nabugabo
Nakivubo
Wetland

H



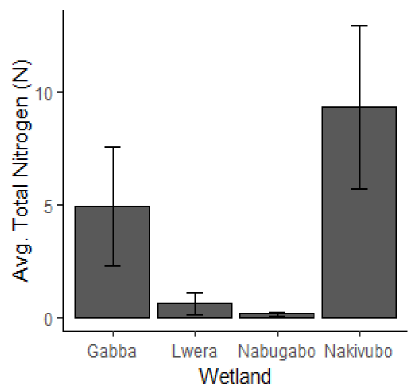
Avg. Sulphates (S)
10.0
7.5
5.0
2.5
0.0
Gabba
Lwera
Nabugabo
Nakivubo
Wetland



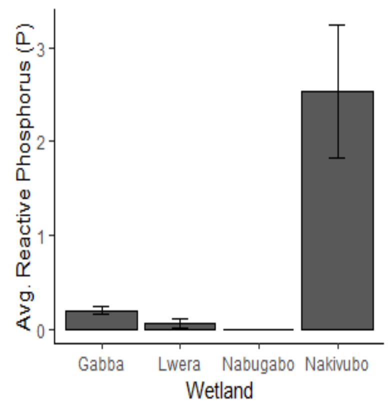
Avg. Chloride (Cl)
40
30
20
10
0
Gabba
Lwera
Nabugabo
Nakivubo
Wetland

I

J



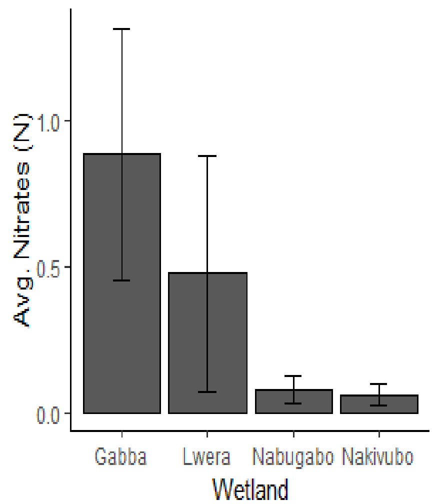
Avg. Total Nitrogen (N)
10
5
0
Gabba
Lwera
Nabugabo
Nakivubo
Wetland

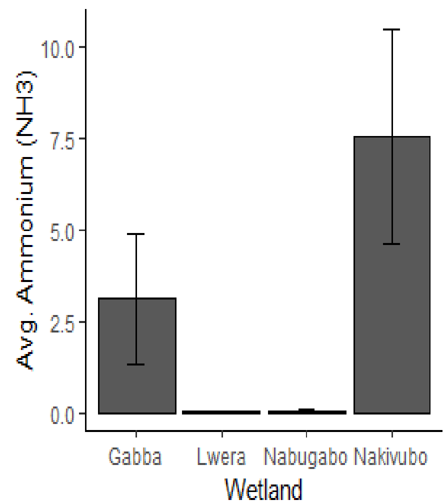


Avg. Reactive Phosphorus (P)
3
2
1
0
Gabba
Lwera
Nabugabo
Nakivubo
Wetland

K

L





M **N**

Figure 4. 1: *Physicochemical parameters of water in selected fish Habitat wetlands along Gabba, Lwera, Nabugabbo and Nakivubo as shown from A to N*

Correlations were made among different physicochemical parameters of water assessed from different wetlands showed that the pH, TSS, BOD, COD, TN, TP and Reactive phosphate are significantly correlated with each of the other physicochemical properties examined (Table 4-3). However, the Turbidity of water in the different wetlands is only significantly correlated to only TSS, Nitrates, Ammonia, Sulphates and chloride at 0.05 significance level or the reverse is also true. On the other hand, Electrical conductivity is also significantly correlated to all the other properties apart from Chemical oxygen demand at either 0.1 or 0.05 significant level. The respective ***r*** values are as summarised in Table 4-3 Below.

Table 4. 2: *Correlational analysis among different physicochemical properties of water samples*

	Turbidity	pH	Electrical Conductivity	Total Dissolved Solids	Biological Oxygen Demand	Chemical Oxygen Demand	Total Suspended Solids	Total Nitrogen-N	Total Phosphate-P	Reactive Phosphorus-P	Nitrates-N	Ammonium-N	Sulphates	Chloride
Turbidity	1													
pH	0.02(0.961)	1												
Electrical Conductivity	-0.05(0.883)	0.76(**0.001)****	1											
TDS	-0.05(0.883)	0.79(**0.001)****	0.99(<**0.001)****	1										
Biological Oxygen Demand	-0.03(0.871)	0.69(**0.002)****	0.36(**0.031)***	0.44(**0.046)*****	1									
Chemical Oxygen Demand	-0.04(0.909)	0.08(0.981)	0.15(0.951)	0.18(0.082)	0.51(**0.021)***	1								
Total Suspended Solids	0.45(**0.034**)**	0.51(**0.002)****	0.21(0.061)*	0.25(**0.048)***	0.75(**0.003)****	0.51(0.012)*	1							
Total Nitrogen-N	-0.16(0.883)	0.62(**0.003)****	0.72(**0.003)*****	0.74(**0.003)*****	0.53(**0.012***)	0.49(**0.014)***	0.24(**0.048)***	1						
Total Phosphate-P	-0.12(0.621)	0.67(**0.002)****	0.32(**0.004)***	0.40(**0.049)***	0.97(**<0.001)****	0.45(**0.034)****	0.75(**0.001)****	0.41(**0.009)****	1					
Reactive Phosphorus-P	-0.12(0.621)	0.67(**0.002)****	0.32(**0.004)***	0.40(**0.049)***	0.97(<**0.001**)**	0.45(**0.034)****	0.75**0.001)****	0.41(**0.009**)**	1	1				
Nitrates-N	0.17(0.092)	0.20(0.08)	0.58(**0.003**)**	0.56(**0.012)*****	-0.25(0.081)*	-0.31(0.008)*	-0.28(**0.041***)	0.20(0.071)	-0.29(**0.048**)*	-0.29(**0.049)***	1			
Ammonium-N	-0.19(0.083)	0.61(**0.003)****	0.66(**0.002)*****	0.68(**0.001)*****	0.57(**0.003)****	0.54(**0.006)****	0.29(**0.041***)	0.99(<**0.001)****	0.45(**0.004**)**	0.45(**0.032)***	0.07(0.981)	1		
Sulphates	-0.23(**0.045**)*	0.76(**0.001)****	0.92**(<0.001**)**	0.92(<**0.001**)**	0.46(**0.034)***	0.22(0.071)	0.25(0.051)	0.81(<**0.001)****	0.44(**0.003**)**	0.44(**0.034)***	0.30(0.056)	0.78(**0.002)****	1	
Chloride	-0.22(**0.045**)*	0.64(**0.003)****	0.83(**<0.001)****	0.84(<**0.001)****	0.59(**0.003)****	0.55(**0.002)****	0.36(**0.031**)*	0.91(<**0.001)****	0.53(**0.002**)**	0.53(**0.012)***	0.26(0.078)	0.89(**<0.001)****	0.87(**<0.001)****	1

*"**" significant at 1%; "*" significant at 5%;*

Values in the brackets are p-values, Bolded figures imply significant

The turbidity of water samples in the wetlands were 2.6 ± 18 NTU in Nabugabo, 1.17 ± 0.15 NTU in Lwera, 1.99 ± 0.41 NTU in Nakivubo, 2.27 ± 0.63 NTU and in Gabba. The findings of Shadrack *et al.* (2015) showed higher levels of turbidity in the Lake Victoria basin wetlands in Kenya. This can be attributed to limited turbulence of water and higher settling rates in wetlands and as such it can be hypothesised that the water in the wetlands is of good quality.

The pH across the wetlands was similar for Gabba and Nabugabo through varied significantly with Lwera and Nakivubo ($p = 0.00809$, Gaba: 6.97 ±0.18, Nabugabo: 6.5 ± 0.12, Lwera 6.33 ± 0.07 Nakivubo 7.13 ± 0.15). pH is a fundamental property that describes the acidity and alkalinity of water resources (Adimalla et al., 2020) and an indicator of water pollution. Such pH is also reported fit for the survival of different fish and other aquatic life species in the different wetlands studied. The high acidity of water can affect gastrointestinal mucous membranes, provide a bitter taste and cause corrosion of discharge pipes (Nayebare et al., 2020). The acidity of the water could be attributed to organic acid pouring with wastewater and effluents from both settlements and surrounding industries which indicated possible water pollution (Marmontelet al., 2018).

The Electrical conductivity of water samples had an average of 23.67 ± 3.18 µS/cm in Nabugabo, 203.3 ± 39.83 µS/cm in Lwera, 563.33 ± 108 µS/cm in Nakivubo, and 590 ± 345.2 µS/cm in Gabba. In relation to the ecosystem provision service of natural waters for drinking water, the results indicate that the water in wetlands is not polluted and fit for human consumptions. The higher EC in both Nakivubo and Gabba could be attributed to effluent from the metropolitan areas and industrial effluent discharge. This resonated with a study in Adama Town, Ethiopia (Karuppannan et al., 2019) that linked high EC values to wastewater discharged from industries and cities. EC is a measure of a material's ability to conduct an electric current and higher EC values indicate enrichment of salts in the groundwater. This may be high salinity and high mineral percentage in groundwater samples, which are generally due to geochemical process like ion exchange, evaporation, and silicate weathering and solubilization process taking place within the aquifers (Amalraj et al., 2018). More so, variation in EC values can be attributed to the different land uses, and the state of conservation of the vegetation (Dagharaet al., 2019).

Water is a good solvent hence easily dissolves many of the surrounding impurities that come in contact with it including dissolved and suspended solids which affects the acceptability of water for human consumption (Dutta, 2010). The total dissolved solids of water samples had mean concentrations of 16.67 ± 2.03 mg/L in Nabugabo, 142.67 ± 27.8 mg/L in Lwera, 426 ± 44.7 mg/L in Nakivubo, and 413.33 ± 241 mg/L in Gabba. In comparison with the East African Standards (2018) of 1500 mg/L max, the study total dissolved solids values are significantly lower. TDS signifies presence of various types of dissolved minerals that include carbonates, bicarbonates, chlorides, nitrates sulfates, phosphates, silica, calcium, magnesium, sodium and potassium (Adimalla et al., 2020). Results of TDS from the study are within the set limits set by both East African Standards (2018) for Natural water and National Environment regulation (2020) for effluent; and they are in agreement with results obtained by (Okot-Okumu et al., 2015). The total suspended solids of water samples ranged from 34 ± 7.02 mg/L in Nabugabo, 48.7± 9.82 mg/L in Lwera, 162 ± 29 mg/L in Nakivubo, and 76.3 ± 51.9 mg/L in Gabba. In comparison with the East African Standards (2018) requirements of no detectable, the study total suspended solids were detectable. This can help us suggests presence of plankton and organic materials as well as reduced runoff into the wetlands.

Oxygen demand is a measure of the amount of oxidizable substances in a water sample that can lower DO concentrations. The study findings of both Chemical Oxygen Demand and Biological Oxygen Demand were lower than National Environment regulation (2020) of 50mg/L except for Nakivubo which had mean BOD values 0f 60mg/L. This differs from the findings of Jang & An, (2016) who found high levels of BOD and COD. This suggest that Lwera, Gabba and Nabugabo wetlands are in critical position to maintain the aquatic life and aesthetic quality of wetlands.

The chloride contamination in water sources could be explained by human activities such as industrialisation. The mean concentration of chloride in the water samples was 1.6 ± 1.54 mg/L in Nabugabo, 17.53 ± 3.2 mg/L in Lwera, 40 ± 7.02 mg/L in Nakivubo, and 21.07± 11 mg/L in Gabba. In comparison with the East African Standards 2018 of 250 mg/L, in the study Chlorides were much lower. This study has not been able to demonstrate Sonowal & Baruah (2017) findings of high chloride in the wetlands in India. The low levels of chloride in this study imply that the study wetlands are free from pollution.

Nitrate serve as nutrients for phytoplankton and algae growth. The nitrate of water samples ranged from 0.08 ± 0.05 mg/L in Nabugabo, 0.48 ± 0.43 mg/L in Lwera, 0.06 ± 0.04 mg/L in Nakivubo, and 0.88 ± 0.4 mg/L in Gabba. In comparison with the East African Standards of 0.9 mg/L max, all the wetland nitrate values were much lower. This differs with the findings of Sonowal & Baruah (2017) who found high levels of nitrate. This shows that the wetlands were naturally purifying the water.

The mean concentrations of reactive phosphorus of water samples were from 0 mg/L in Nabugabo, 0.06 ± 0.01 mg/L in Lwera, 2.53± 0.71 mg/L in Nakivubo, and 0.2 ± 0.03 mg/L in Gabba. In comparison with the East African Standard requirements (2018) of 2.2 mg/L max, the study phosphorus values were much lower in other wetlands apart from Nakivubo. This supports the findings of Martin et al. (2018) who found low levels of Phosphates in most wetlands. The possible explanation for this consistence is the availability of aquatic vegetation that utilize phosphate as nutrients thereby lowering their concentrations in the wetlands. However, such aquatic vegetation is highly degraded in Nakivubo hence leaving the phosphate underutilised thus becoming more in the wetland.

The sulphates of water samples ranged from 0.17± 0.09 mg/L in Nabugabo, 1.77±1.08 mg/L in Lwera, 8 ± 1.9 mg/L in Nakivubo, and 5.7 ± 3.86 mg/L in Gabba. In comparison with the East African Standard requirements (2018) of 400 mg/L, the study sulphate values were much lower. This differs from the study findings of Kipchirchir (2011) who found high concentrations of sulphates in both dry and wet seasons in the Kenan wetlands. This implies that the water quality of wetlands is safe for human consumption and plant growth.

4.2.2 Heavy metal concentration of water

Statistical analysis revealed that all heavy metals concentrations tested were not significantly different ($P > 0.05$) in the different wetlands studied at 0.05 significance level (Table 4-4). For most of the water samples tested, heavy metals were below the detection limit of the equipment and method used apart from those for chromium (0.003mg/L) in Nakivubo wetland.

Table 4. 3: *Heavy metal concentration of water in selected fish habitats in mg/L*

	Gabba	Lwera	Nabugabo	Nakivubo		
Variable	mean±se	mean±se	mean±se	mean±se	F-value	*P* value
Cadmium	0.001±0.000[a]	0.001±0.000[a]	0.001±0.000[a]	0.001±0.000[a]	1	0.441
Chromium	0.001±0.000[b]	0.001±0.000[b]	0.001±0.000[b]	0.003±0.003[b]	1	0.441
Lead	0.002±0.000[c]	0.002±0.001[c]	0.002±0.000[c]	0.002±0.000[c]	1	0.441
Cobalt	0.001±0.000[d]	0.001±0.000[d]	0.001±0.000[d]	0.001±0.000[d]	1	0.441
Nickel	0.005±0.000[e]	0.005±0.000[e]	0.005±0.000[e]	0.005±0.000[e]	1	0.441

Note: Different letters imply significantly different

Heavy metals mostly exist in traces, which do not biodegrade in the habitats such as wetlands where released, and hence get biomagnified in the exposed organisms. Habitats like wetlands are frequently used by several species including migratory shorebirds as refugial sites and fish as breeding grounds. These habitats are not exceptions which also get contaminated by heavy metals from various sources. This study reveals that the wetlands around the Lake Victoria basin might be in a vulnerable state due to contamination of its waters by heavy metal deposition from effluents and waste water from surrounding industries and heavily mushrooming settlements.

Although this study only observed concentrations of chromium at Nakivubo wetland in the water, different heavy metals including Cadmium, Chromium, Lead, Cobalt and Nickel were screened. Concentrations of all heavy metals studied were below those reported by Fuhrimann et al 2015 and Mbabazi et al., (2020) in Nakivubo wetlands. Notably, the chromium concentrations in the wetland were also below the threshold of 0.05 mg/L as per the East African Standards (2018).

Hong et al. (2020) observed high heavy metal concentrations in the wetlands along the Yellow River in Henan Province and found significant correlations with dissolved oxygen, chemical oxygen demand. Similarly, though the concentrations of heavy metals in the water of the studied wetlands were below the detection limits of the methos, with time, this statistic could change with increasing pollutant loads in the wetlands.

The concentration of Chromium in the wetland water from Nakivubo wetland could be explained by the interactions between air and water as observed by Pandiyan et al., 2020. He stressed that chromium cannot easily be removed once it has settled in any aquatic environments. Similar results were obtained by Youssef et al., 2017, and Kumar et al., 2012. Higher levels of chromium may also be attributed to huge amounts of contaminated water and effluents from various sources including agricultural practices, tanneries, industries etc received by the wetlands in question (Pandiyan et al., 2020).

However, the findings of this study are contrary to those of Zhang et al., 2010 who reported Zn and Pb as the major heavy metals in water of riparian wetlands whose concentrations were even slightly higher than those of other riparian wetlands. They attributed such heavy Zn and Pb concentrations to heavy discharge of domestic wastewater. In the same study, Cu exceeded its ranges in uncontaminated fresh waters as such was attributed to the enrichment of Cu in the suspended matter that released considerable amounts of dissolved Cu into river water

4.3 Heavy metal concentration in sediments from fish habitat wetlands along Lake Victoria basin

All heavy metal concentrations in sediments of the wetlands were not significantly different at 95% confidence level ($P>0.05$) (Table 4-5) except for cadmium in Lwera wetland. In the Lwera wetland, cadmium had a significantly lower concentration of 0.11 ± 0.01 mg/kg as compared to all other wetlands. The concentration of chromium, lead and cobalt in sediments from Gabba and Nakivubo wetlands was relatively higher than that from other wetlands. Nakivubo, and Gabba wetlands had relatively higher concentrations of all heavy metals analysed compared to sediments from other wetlands expect for Nickel for which highest concentrations were observed in Lwera wetlands.

In wetland systems, heavy metals are concentrated in sediments via adsorption and precipitation, and are transported and enriched in the food chain through biological absorption. This does not only cause harm to the aquatic organism but to human too who feed on them and other components of the food chain (Table 4-5).

Table 4. 4: Mean variation Heavy metal concentration in sediments from different fish habitats in mg/kg

	Gabba	Lwera	Nabugabo	Nakivubo		
Variable	Mean	Mean	Mean	Mean	F-value	P-value
Cadmium	0.001±0.00[b]	0.11±0.10[a]	0.001±0.00[b]	0.001±0.00[b]	3.461	0.0712
Chromium	34.37±18.26[a]	23.85±11.30[a]	22.97±10.23[a]	39.34±27.47[a]	0.586	0.641
Lead	13.59±1.61[a]	10.70±10.43[a]	9.34±3.47[a]	19.32±3.74[a]	1.71	0.242
Cobalt	3.15±2.42[a]	2.68±2.98[a]	3.85±1.18[a]	3.87±3.41[a]	0.144	0.93
Nickel	9.62±1.30[a]	11.43±6.03[a]	7.67±2.06[a]	9.89±4.14[a]	0.48	0.705

The inter-correlational analysis among heavy metals assessed from sediments of different wetlands showed that the Cd is not correlated to Cr, Pb, and Co but significantly correlated to Nickel (r = 0.67, p = 0.07). On the other hand, the Cr, Pb, Ni and Co were significantly correlated. Pb was also correlated with Co (r = 0.48, p = 0.046) and Ni (r = 0.70, p = 0.011) at 0.05 level of significance (Table 4-6)

Table 4. 5: *Correlational analysis among heavy metals concentration in sediments from different wetlands*

	Cadmium	Chromium	Lead	Cobalt	Nickel
Cadmium	1				
Chromium	-0.01(0.980)	1			
Lead	0.19(0.547)	0.71(**0.009**)**	1		
Cobalt	0.10(0.757)	0.26(**0.049**)*	0.48(**0.046**)**	1	
Nickel	0.67(**0.07**)**	0.58(**0.038**)*	0.70(**0.011**)**	0.50(**0.042**)*	1

*"**" significant at 1%; "*" significant at 5%;*

Values in the brackets are p-values, Bolded figures imply significant

The mean concentration in the analysed metals were in the following order, Cr > Pb > Ni> Co>Cd. The findings are similar to Zhang et al., 2010 who also found cadmium concentration the lowest concentration in their ecosystem well as Zinc had the highest concentration though wasn't considered in the scope of this assessment. Das & Choudhury (2016) also found high metal concentrations of Mn, Fe, Mg, Ca, Cu, Zn, Cd, Cr, Pb, Ni in the sediments in India wetlands. A contrast of the heavy metal elements observed the sediment with those of the water column suggest that the elements are being leached into the sediments of the wetlands rather than remaining in suspension of the water column. As observed by other authors, key sources of these pollutants into the environment include surrounding industries such as paint, alloys. When released into the environment, these elements adsorb on suspended matter or form colloids before settling down to the sediments due to their relative mass. It's argued that cadmium is easily absorbed by plants and then released and enriched to the sediments through plant recycling.

The findings of Chromium, Lead, Cobalt and Nickel concentrations for this study indicate lower values compared to those reported elsewhere. Such results might be attributed to spatial variation of our sampling points from key industrial and municipal centres and establishments. This supported by observance of lowest concentrations of such heavy metals in Nabugabo and Lwera that are basically located in far distant rural areas where there are neither industrial nor densely populated municipal establishments.

In comparison with the World Health Organisation standards for inorganic contaminants in natural water resources, all the concentrations of the identified heavy metals were within the respective thresholds (WHO 1996). Though the concentrations of heavy metals have not yet exceeded the WHO standards, there is a possibility of them exceeding the standards with continued degradation of the wetlands and effluent discharge. Furthermore, the sediment could act as a source of these pollutants into the food chain through filter feeding fish species and respiration through the gills (Malik, N et al. 2010)

4.4 Heavy metal concentration in fish from different wetlands along Lake Victoria Basin

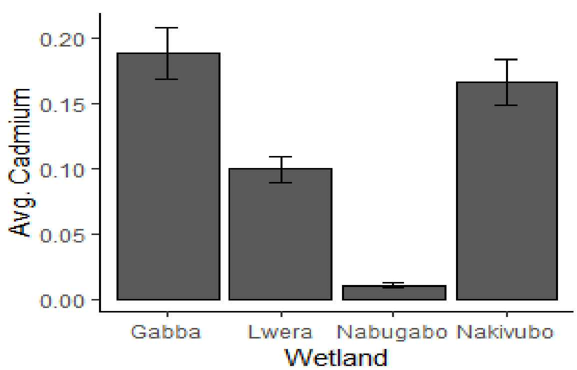
This section presents heavy metal concentrations in different fish species from different wetlands along Lake Victoria Basin. The analysis revealed significant variations of for cadmium and lead elements in the fish tissue across the wetland at 5% significance level (Cd; $p = 0.0001$, Pb; $p = 0.0113$). All other elements analysed had no significant variations across the wetlands for fish tissue.

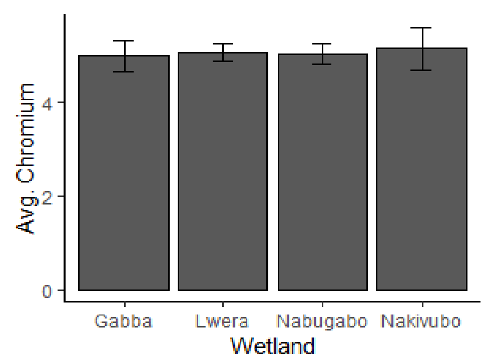
Table 4. 6: Mean variation Heavy metal concentration in fish from different wetlands in mg/kg

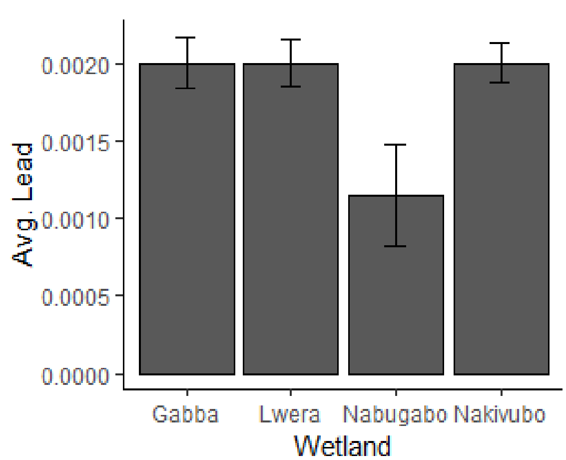
	Gabba	Lwera	Nabugabo	Nakivubo	Overall		
Variable	Mean	Mean	mean	mean		F-value	P-value
Cadmium	0.189±0.062[a]	0.099±0.030[b]	0.010±0.006[c]	0.166±0.054[a]	0.116±0.082	33.17	0.0001
Chromium	4.989±1.054[a]	5.068±0.618[a]	5.028±0.665[a]	5.147±1.447[a]	5.058±0.966	0.046	0.987
Lead	0.002±0.001[a]	0.002±0.000[a]	0.001±0.001[b]	0.002±0.000[a]	0.002±0.001	4.257	0.0113
Cobalt	0.002±0.002[a]	0.002±0.001[a]	0.001±0.000[a]	0.001±0.001[a]	0.001±0.001	1.821	0.161
Nickel	2.930±1.090[a]	3.089±0.784[a]	3.129±0.994[a]	3.249±1.831[a]	3.099±1.196	0.113	0.952

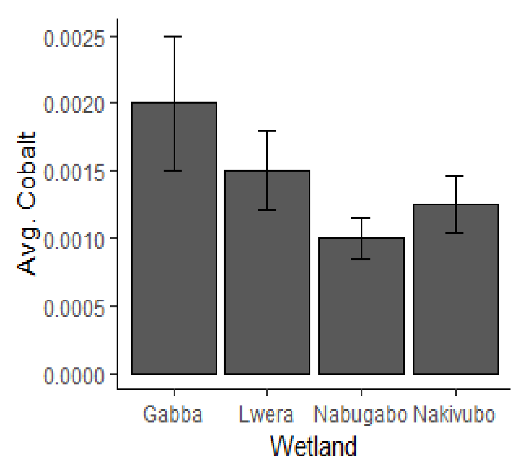
Note: Different letters imply significantly different

Further analysis proved that the concentration of Cadmium in fish from Lwera (0.099±0.030[b] mg/Kg) and Nabugabo wetland (0.010±0.006[c] mg/Kg) was significantly different from each other than that from other wetlands. In addition, the concentration of Lead (0.001±0.001[b] mg/Kg) in fish from Nabugabo wetland significantly differed from that in fish from other wetlands.









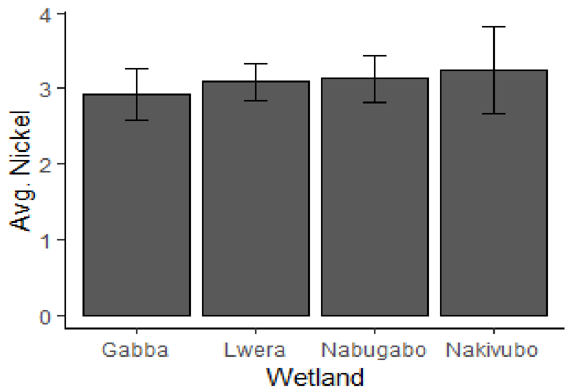


Figure 4. 2: *Concentrations of different Heavy metals in Fish from different wetlands*

The correlational matrix among heavy metals concentrations in fish from different wetlands showed that the Pb and Cd are correlated among the five metals examined (r = 0.48, p = 0.002). On the other hand, Ni were also correlated with Cr (r = 0.70, p = <0.001) as shown in the Table 4-8 below.

Table 4. 7: *Correlational matrix of heavy metal concentration in fish and that in Sediments from different wetlands*

	Cadmium fish	Chromium in fish	Lead in fish	Cobalt in fish	Nickel in fish
Cadmium in sediment	-0.077 (0.8111)				
Chromium in segment		-0.098 (0.7613)			
Lead in sediment			0.217 (0.4973)		
Cobalt in sediment				0.210 (0.5114)	
Nickel in sediment					0.124 (0.701)

Values in the brackets are p-values

There is no significant difference between heavy metals in sediment and heavy metals in fish because the $p>0.05$ and the correlation is weak.

The correlation in Cadmium and Chromium was negative which meant that is heavy metals increase in sediment, it reduces in fish and vice versa is true.

The study found concentrations of Cadmium, Chromium, Lead, Cobalt and Nickel in fish tissues, however, the major prevalent heavy metals from fish in the studied wetlands were Chromium (4.98 – 5.147 mg/Kg) and Nickel (2.90 mg/Kg - 3.2 mg/Kg). Findings were in line with those of Abdolahpur et al (2013). These elements were specifically higher than their respective WHO and FAO standards of 0.1 - 1 mg/Kg and 0.5 mg/Kg respectively.

CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This section comprises of three sub sections that is summary, conclusions and recommendations. The summary sub section presents study purpose, research questions, specific objectives, methodology and major findings. The conclusion section presents major deductions drawn from the research findings on the basis of the research questions whereas the last sub section presents recommendations from the study results. It further includes suggestions for further research based on the findings and conclusions generated from the study.

5.2 Summary

This study aimed at understanding the relationship between heavy metal contaminations in water, sediments and fish from selected Lake Victoria basin wetlands in Uganda. It was hypothesized that location of a wetland close to heavy industrialised and urbanised areas with heavy settlements influences the amount of heavy metals in both wetland water, sediments and fish which might in turn affect the humans and other key components of their food value chain. This study was guided by three hypotheses: 1.There are the variations in heavy metal concentrations of water from Gabba, Nakivubo, Lwera and Nabugabo wetlands, 2.There are the variations of heavy metals (chromium, cadmium, lead, cobalt and nickel) in sediments of Gabba, Nakivubo, Lwera and Nabugabo wetlands, 3.There are the variations in heavy metal concentrations in the different fish species *Clarias galiepinus, Clarius liocephalus* and *Protopterus sp* inhabiting Gabba, Nakivubo, Lwera and Nabugabo wetlands.

These were drawn from the three specific objectives of the study that include;1. Assess the concentration of heavy metal - cadmium, chromium, lead, cobalt, and nickel in the water of Gabba, Nakivubo, Lwera and Nabugabo wetlands. 2. Analyze the concentration of heavy metals - cadmium, chromium, lead, cobalt, and nickel in the sediments in Gabba, Nakivubo, Lwera and Nabugabo wetlands.3. Determine the concentration of heavy metals in different fish species *Clarias galiepinus, Clarius liocephalus* and *Protopterus sp* inhabiting Gabba, Nakivubo, Lwera and Nabugabo wetlands.

The study undertook a quantitative approach for physicochemical and heavy metal concentration in water samples collected from selected wetlands, twelve random sample sites (three per wetland) were monitored over a period of three months. Some parameters were measured in-situ whereas others were analysed at the Nation Water Quality Laboratory in Entebbe. Furthermore, sediments samples at a depth of 5cm were also collected depending on exposure of wetland sites to waste. Also, twelve fish samples for each fish type considered were collected according to availability as informed by the fishermen in the area. These were obtained fresh and kept in plastic bags put in ice-box for transportation to the Laboratory for further analysis. Results portrayed differing water quality among water samples from different wetlands though all of the heavy metals were below detection limits of the method. There also appeared differing concentrations of heavy metals in sediments analysed from different wetlands with concentration of chromium and lead in different examined sediments significantly different among sites. In particular, Nakivubo and Gabba wetlands had relatively high concentrations of all heavy metals analysed. Furthermore, the concentration of heavy metals in different fish muscles significantly differed among various wetland sources examined ($P < 0.05$). The inter-correlational analysis among heavy metal assessed showed correlation between source and difference in others

5.3 Conclusion

The following conclusions were drawn from the study in line with the research question set;

This study used physicochemical as the first indicator of pollution in the wetlands. From the results of the physicochemical analysis, the water quality of the wetlands is still good. This is so in comparison with the stricter East African Drinking Water standards for natural waters. Similarly, the emerging concern of heavy metal pollution showed no contamination within the water column of the wetlands as none of the analysed metals was detected in the analysis. The absence of the trace metals in the water column may not mean no ongoing pollution activities within the catchment of the wetlands, but rather a possibility of sinking of these trace elements to the sediments. As the trace elements leach out of the water column, they tend to adsorb on suspended matter, thereby forming heavier colloids which accumulate in the sediments.

Contrary to the analysis of heavy metals in the water samples, there were considerable amounts of these trace pollutants in the sediments. All analysed elements (Cadmium, Chromium, Lead, Cobalt and Nickel) were present in the sediments. In comparison with the East African standards, lead and nickel concentrations exceed the set thresholds. This observation may not be conclusive to infer limited pollution of trace elements into these ecosystems but may be an indicator of the water quality remediation nature of wetlands to remove some of the trace elements through adsorption on the vegetation of the wetland or absorption into the vegetation's biomass.

The study also looked at the concentration of heavy metals in fish muscles as an indicator of bioaccumulation of the pollutants into the food chain. All the metals analysed were found present in the fish tissue. Notably however, chromium and nickel had concentrations that exceed the WHO standard. This observation not only provides evidence of significant bioaccumulation of toxic elements into the food web that would cascade to zoonosis but could also imply a novel sink of these emerging pollutants within the ecosystem.

5.4 Recommendations

The study recommends the following as means of improving the wetlands physical parameters, heavy metals and thus improves their functionality:

i) Wetland management and conservation policies should be implemented by relevant government authorities which will be aimed at reducing the values of turbidity values at the inlet of the wetlands.

ii) All stakeholders of wetlands are fully involved in the management and conservation of wetlands as anthropogenic activities do have a direct effect on the wetland physicochemical properties and heavy metals.

iii) Implement prudent agricultural policies to protect wetland ecosystems from sedimentation and increase of pollutants from farms within the adjacent areas.

iv) Further research is needed to assess the heavy metal pollutant retention ability of these wetlands, other heavy metal concentrations in the same fish or in the different organisms within the wetland, different fish parts like the gills should also be analyzed since the current research looked at only fish muscles

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APPENDICES

Appendix 1: Physical parameters of Water

Parameter		Turbidity	pH	Electrical Conductivity	Total Dissolved Solids	Biological Oxygen Demand	Chemical Oxygen Demand	Total Suspended Solids
Wetland	**Sample no**	**NTU**	pH units	µS/cm	mg/l	mg/l	mg/l	mg/l
Nakivubo	1	1.4	6.9	640	448	17	81	115
Nakivubo	2	1.8	7.4	700	490	25	45	215
Nakivubo	3	2.78	7.1	350	340	35	56	156
Gabba	1	1.04	6.9	225	158	1.6	<5	29
Gabba	2	3.09	7.3	1280	896	5.7	19.5	20
Gabba	3	26.8	6.7	265	186	6.1	36	180
Lwera	1	1.2	6.4	230	161	<0.5	28	32
Lwera	2	1.4	6.2	125	88	<0.5	26	48
Lwera	3	0.9	6.4	255	179	<0.5	61	66
Nabugabo	1	1.9	6.3	29	20	<0.5	42	28
Nabugabo	2	3.4	6.7	24	17	1.7	25	48
Nabugabo	3	2.6	6.5	18	13	3.8	18	26

Appendix 2: Chemical parameters of water

Parameter		Total Nitrogen-N	Total Phosphate-P	Reactive Phosphorus-P	Nitrates-N	Ammonium-N	Sulphates	Chloride
Wetland	**Sample no**	mg/l	mg/l	mg/l	mg/l	mg/l		
Nakivubo	1	16.5804	1.40	1.12	0.13	13.35	10.00	54
Nakivubo	2	4.8216	3.83	3.06	0.01	3.91	9.8000	34
Nakivubo	3	6.7158	4.28	3.42	0.04	5.42	4.21	32
Gabba	1	3.7638	0.20	0.16	0.27	2.79	3.50	12
Gabba	2	9.9384	0.34	0.27	1.72	6.36	13.20	43
Gabba	3	1.0209	0.20	0.16	0.66	0.17	0.40	8.2
Lwera	1	1.60269	0.00	0.002	1.28	0.023	0.4	18.6
Lwera	2	**0.03567**	0.21	0.167	<0.02	0.029	3.9	14.5
Lwera	3	0.21156	0.03	0.025	0.137	0.035	1.0	19.5
Nabugabo	1	0.29889	<0.001	<0.001	0.167	0.076	0.2	1.7
Nabugabo	2	0.09717	<0.001	<0.001	0.04	0.039	<0.02	1
Nabugabo	3	0.05043	<0.001	<0.001	0.02	0.021	0.3	2.1

Appendix 3: Heavy metal of water

Wetland	Sample no	Cadmium	Chromium	Lead	Cobalt	Nickel
Units		mg/l	mg/l	mg/l	mg/l	mg/l
Nakivubo	1	<0.001	0.0059	<0.002	0.0017	<0.005
Nakivubo	2	<0.001	<0.001	<0.002	0.0010	<0.005
Nakivubo	3	<0.001	<0.001	<0.002	0.0013	<0.005
Gabba	1	<0.001	<0.001	<0.002	<0.001	<0.005
Gabba	2	<0.001	<0.001	<0.002	0.0014	<0.005
Gabba	3	<0.001	<0.001	<0.002	<0.001	<0.005
Lwera	1	<0.001	<0.001	<0.002	<0.001	<0.005
Lwera	2	<0.001	<0.001	<0.002	<0.001	<0.005
Lwera	3	<0.001	<0.001	<0.001	<0.001	<0.005
Nabugabo	1	<0.001	<0.001	<0.002	<0.001	<0.005
Nabugabo	2	<0.001	<0.001	<0.002	<0.001	<0.005
Nabugabo	3	<0.001	<0.001	<0.002	<0.001	<0.005

Appendix 4: Heavy metal of Sediments

Wetland	Sample no	Cadmium	Chromium	Lead	Cobalt	Nickel
Units		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Nakivubo	1	<0.001	69.4644	23.0962	1.7182	11.9014
Nakivubo	2	<0.001	32.8831	19.2649	7.8085	12.6367
Nakivubo	3	<0.001	15.6707	15.6099	2.0905	5.1295
Gabba	1	<0.001	37.9932	14.9528	5.1835	9.3828
Gabba	2	<0.001	14.5730	11.8216	0.4738	8.4551
Gabba	3	<0.001	50.5435	14.0050	3.7888	11.0169
Lwera	1	0.203	36.8071	22.7366	6.0639	18.0230
Lwera	2	0.001	16.0131	4.1580	1.5350	6.1967
Lwera	3	0.128	18.7269	5.2143	0.4510	10.0604
Nabugabo	1	<0.001	34.5730	13.1885	4.7867	9.7997
Nabugabo	2	<0.001	19.1080	8.3729	2.5280	7.5356
Nabugabo	3	<0.001	15.2342	6.4567	4.2345	5.6782

Appendix 5: Heavy metal of Fish from Nabugabo and Gabba wetlands

Nabugabo					
SAMPLE NO	Cadium	Chromium	Lead	Cobalt	Nickel
1	0.01	3.890318	0.0003	0.002	4.66786
2	0.009	5.281723	0.0005	0.0005	1.8191
3	0.013	5.106698	0.002	0.0011	3.04678
4	0.013	4.401998	0.0002	0.0012	3.12823
5	0.001	4.609623	0.00032	0.0001	1.92104
6	0.011	4.754548	0.003	0.001	3.32765
7	0.02	5.85737	0.001	0.0011	3.98171
8	0.01	5.380018	0.002	0.001	4.41971
9	0.001	6.09669	0.00013	0.001	2.70114
10	0.012	4.903843	0.002	0.001	2.27616
Gabba					
SAMPLE NO	Cadium	Chromium	Lead	Cobalt	Nickel
1	0.0912	3.1861	0.0019	0.0059	1.9413
2	0.1918	6.0084	0.0019	0.0029	4.5286
3	0.2091	5.1084	0.002	0.0009	2.9104
4	0.1024	4.1681	0.0009	0.0017	2.7276
5	0.1804	5.1413	0.0021	0.0019	2.9486
6	0.1854	3.9688	0.0019	0.0015	1.3304
7	0.1968	5.8091	0.0029	0.0026	4.2599
8	0.2748	4.8359	0.0026	0.0005	3.1314
9	0.286	6.7911	0.0021	0.0007	3.9177
10	0.1681	4.8688	0.0017	0.0014	1.5991

Appendix 6: Heavy Metal of Fish from Lwera and Nakivubo wetlands

Lwera					
SAMPLE NO	Cadium	Chromium	Lead	Cobalt	Nickel
1	0.0506	4.594535	0.00245	0.00395	4.12255
2	0.1004	4.555045	0.0012	0.0017	2.361
3	0.11105	5.104995	0.002	0.001	3.0195
4	0.0577	4.635895	0.00145	0.00145	3.0481
5	0.0907	4.077945	0.00265	0.001	2.12655
6	0.0982	5.540295	0.00245	0.00125	2.9282
7	0.1084	5.90564	0.00195	0.00185	4.03735
8	0.1424	5.924135	0.0023	0.00075	4.16205
9	0.1435	5.40228	0.0017	0.00085	2.94445
10	0.09005	4.938885	0.00185	0.0012	2.14075
Nakivubo					
SAMPLE NO	Cadium	Chromium	Lead	Cobalt	Nickel
1	0.08105	6.00297	0.00231	0.00298	6.3038
2	0.16895	3.10169	0.00138	0.0011	0.1934
3	0.18459	5.10159	0.002	0.00105	3.1286
4	0.09123	5.10369	0.00131	0.00133	3.3686
5	0.15798	3.01459	0.00251	0.00055	1.3045
6	0.1636	7.11179	0.00231	0.00113	4.526
7	0.1747	6.00218	0.00219	0.00148	3.8148
8	0.2417	7.01237	0.00238	0.00088	5.1927
9	0.25038	4.01346	0.0018	0.00093	1.9712
10	0.14859	5.00897	0.00181	0.0011	2.6824

Appendix 7: Field work at Nakivubo Wetland

Appendix 8: Gabba wetland