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ASSESSMENT OF HEAVY METAL CONCENTRATIONS IN WATER, SEDIMENT AND WATER HYACINTH OF THE INNER MURCHISON BAY, LAKE VICTORIA.

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(RM21M45/004)

A DISSERTATION SUBMITTED TO THE FACULTY OF ENGINEERING, DESIGN AND TECHNOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN WATER AND SANITATION OF UGANDA CHRISTIAN UNIVERSITY

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ABSTRACT

This study assessed heavy metal pollution in the Inner Murchison Bay within Lake Victoria region. The assessment was based on determination of concentrations of heavy metals in water, sediment and water hyacinth (*Eichhornia crassipes*). The Bay is the abstraction point of water supplied in Kampala City and metropolitan areas. It is also the recipient of partially treated and untreated wastewater from the City. There is a potential for continuous deterioration of the Bay's water quality due to anthropogenic activities carried out in its catchment.

Twelve sampling locations that are representative of the Bay were used to gather samples of water, sediment, and water hyacinth based on cross-sectional study. Atomic Absorption Spectrophotometer (AAS) analysis was performed on the samples to ascertain their lead (Pb), cadmium (Cd), and mercury (Hg) concentrations.

Results showed that the concentration of Pb and Cd in water was above the permissible limits set by WHO and NEMA (Pb:0.01ppm and Cd:0.003) at all sites. In sediment, Pb was below the LEL (31.0) while Cd exceeded both the LEL (0.60) and TEL (0.99) signifying that the values of Pb and Cd were permissible as per the sediment assessment guidelines Contamination Factor and Pollution Load Index indicated moderate pollution of the sediment with Pb and Cd (CF>1, PLI>1). The values of Bioconcentration factor for water hyacinths were above 1 indicating that the plants were able to take up Pb and Cd from water. Mercury (Hg) was below the detectable levels in all the samples.

Pb and Cd are from agricultural fertilizers, industrial effluent, urban runoff, wastewater effluent, navigation and recreational activities carried out in the catchment of the Bay.

Evidence of concentration of heavy metals in water, sediment and water hyacinth indicates pollution of the Bay by heavy metals thus continuous monitoring of the Bay's state is crucial.

Key words: Inner Murchison Bay, Heavy Metals, Contamination Factor, Pollution Load Index, Water hyacinth, Bioconcentration Factor, Lowest Element Level (LEL), Threshold Element Level (TEL), Probable Effect Concentration (PEC) and Severe Effect Level (SEL)

DECLARATION

I, ZAWADI LOKUNI ROSETTE hereby declare that this is my original work, is not plagiarized and has not been submitted to any other institution for any award.

Signature, ...

Date, 8th |09| 2023..............................

APPROVAL

I hereby certify that this study titled "Assessment of heavy metal concentration in water, sediment and water hyacinth of the Inner Murchison Bay, Lake Victoria", has been prepared under my supervision and is therefore ready for submission.

(For reference see appendix 20)

Signature………………………….   Date…………………………………

Assoc. Prof. Sarah Kizza-Nkambwe

For

DEDICATION

I dedicate this work to my parents Mr and Mrs Lokuni for their unconditional love and support during my academic journey.

ACKNOWLEDGEMENT

Words cannot express my gratitude to the Almighty God for the Gift of life, protection, provision and good health that have enabled me to complete this research.

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ABBREVIATIONS AND ACRONYMS

BAF:	Bioaccumulation Factor
Cd:	Cadmium
Hg:	Mercury
IMB:	Inner Murchison Bay
Pb:	Lead
SPSS:	Statistical Package for the Social Sciences,
UIRI:	Uganda Industrial Research Institute
WHO:	World Health Organisation

CHAPTER ONE: INTRODUCTION

1.1 Background

Water is an essential natural resource and a key food component for both flora and fauna. Water pollution is an increasing global challenge that threatens the survival of human beings and wildlife. Millions of tonnes of industrial, agricultural and sewage wastes are released into global waters. According to the United Nations Water Development report (2021), about 80% of wastewater is discharged into the environment without proper treatment and about three billion people's health is threatened as a result of insufficient data on freshwater quality that they rely on. Heavy metal pollution of surface water bodies has therefore become a global concern due to their excessive accumulation in living organisms and their toxicity that pose a significant threat to public health (Khan et al. 2018). Heavy metals that find their way into surface waters are both from natural and anthropogenic activities. Those heavy metals collect in one point such as water reservoirs where they can dissolve in water or can settle on sediments and later enter the food chain through water as well as plants or fish that accumulate them (Astatkie et al. 2021). Sources of heavy metals around the world include: the use of fertilizers and pesticides, mining, manufacturing, wastewater discharge, volcanic eruption and rock weathering. However, the sources differ with the activities in different continents. For example, the use of fertilizers and pesticides alongside rock weathering were found to be the great contributors of heavy metals in African surface water bodies (Zhou et al. 2020).

African surface water bodies are experiencing pollution due to rapid population growth and industrialization in their catchment. For example, sediment pollution of

Lake Naivasha in Kenya is as the result of shoreline discharge and agricultural effluents that are drained into the Lake (Olando et al., 2020). Heavy metals detected in sediment of streams in Ethiopia were attributed to wastewater effluent, e-waste and car washing discharges (Astatkie et al., 2021). In Uganda, most of the population that reside in the rural areas depend on unsafe water sources such as boreholes, shallow wells, rivers and lakes (Kim, 2019). In the South-western part, surface water constitutes 99% of the total community water supply where nearly 75% of it is contaminated (Mugira, 2015). According to a study by Basooma,et al. (2021), heavy metals detected in River Rwizi, in Uganda were attributed to sand and gold mining, settlement and agricultural activities around the river.

On the other hand, water used in Kampala is sourced from Lake Victoria in the Inner Murchison Bay. However, the Lake is affected by eutrophication and low levels of dissolved oxygen. Eutrophication of the lake, particularly in the Murchison Bay is a result of point-source and non-point source releases of industrial, residential and agricultural inputs from its catchment (Kabenge et al., 2016). Besides eutrophication of the Lake, heavy metal pollution is another major threat to the lake ecology and public health. Whereas heavy metals occur naturally and can enter the aquatic system through geological weathering and volcanic eruptions, anthropogenic activities have hastened heavy metal concentration in the lake. Part of Lake Victoria in the Inner Murchison Bay, is affected by both point source and non-point source pollution from its catchment. This includes, the secondary effluent from wastewater treatment plant, industrial effluent and runoff from Kampala city, agricultural activities among others (Fuhrimann et al., 2015). Furthermore, the rising use of electronic gadgets such as mobile phones and careless disposals of the same is a serious ecological threat. Electronic wastes (e-wastes) which contain heavy metals like lead and copper could be contributing to heavy metal pollution of the aquatic environment as there is no e-waste monitoring in Uganda (Nuwematsiko et al., 2021). Thus, there is a need for close monitoring of heavy metal concentrations in the Inner Murchison Bay given that it is the water abstraction point for Kampala and metropolitan areas.

1.2 Problem Statement

Kampala City obtains its water from the water abstraction point, which is situated in the Inner Murchison Bay of Lake Victoria, however the quality of the Bay's water has been declining over time. In this area, high environmental damage has taken a major toll on water quality (Akurut, 2017). There is evidence of heavy metal pollution in Nakivubo wetland which surrounds the Inner Murchison Bay. In this wetland, Pb in soil, Cd and Cr in plants were found to be beyond the recommended threshold (Fuhrimann et al., 2015). Furthermore, a limitation in the capacity of the wetland to absorb heavy metals has been reported (Mbabazi et al., 2010, Bulonza and Nyakabasa, 2015) leading to concentration of the same in the Lake's water. Studies have been and are still being carried to suggest measures against environmental pollution of heavy metals in the Bay. For example, the use of clay in wastewater treatment to absorb heavy metals (Tebandeke et al., 2020), monitoring and regulation of industrial effluents (Dielter et al., 2019).

Despite all the previous studies, rapid urbanization and related anthropogenic activities leading to wetland encroachment have continued therefore impacting the Bay's water quality (Sridhar et al. 2020). In addition, Nuwematsiko et al. (2021) noted no mechanism for e-waste management in Uganda. There is a potential for continuous deterioration of the Bay's water quality due to anthropogenic activities carried out in its catchment. Hence, it has been identified as critical to assess the heavy metal pollution in the Inner Murchison Bay owing to their harmful effects on human. These metals are found in water while some deposit on sediment where they can be more concentrated than in water (Shyleshchandran et al., 2018) and can be taken up by aquatic plants. Heavy metals of interests in this quantitative study included: Mercury (Hg), Lead (Pb) and Cadmium (Cd). The data gathered has useful information to help policy decision making related to heavy metal pollution in the Inner Murchison Bay in Uganda and the surrounding countries that share Lake Victoria.

1.3 Objectives

1.3.1 General objective

The overall objective of this study was to assess heavy metal concentration in the Inner Murchison Bay within Lake Victoria region with a view of generating scientific information for policy formulation and decision making in Uganda as regards to protection of water resources.

1.3.2 Specific Objectives

1. To describe pollution loading sources of the inner Murchison Bay, Lake Victoria.
2. To determine the concentration of Pb, Cd and Hg in water, sediment and water hyacinth of the Inner Murchison Bay.
3. To assess the variation of Pb, Cd and Hg in water, sediment and water hyacinths of the Inner Murchison Bay.

1.4 Research questions

Q_1: What are pollution loading sources into the Inner Murchison Bay?

Q_2: What is the concentration of Pb, Cd and Hg in water, sediment and water hyacinth of the Inner Murchison Bay?

Q_3: What is the variation of Pb, Cd and Hg in water, sediment and water hyacinth of the Inner Murchison Bay?

1.5 Scope of the study

This study assessed heavy metal concentration in the Inner Murchison Bay within Lake Victoria region. Pollution loading sources into the Bay were described. Water samples, sediment samples and water hyacinths samples were collected from sites that are representative of the Bay and analysed to determine the concentration of heavy metals in the Bay. Sampling was done in rainy season between May and June 2022. Variation of heavy metals in the samples was assessed. Literature in this study is limited to heavy metals in water, sediment and water hyacinth.

1.6 Justification of the study

This study was crucial for providing data related to heavy metal concentration in the Inner Murchison Bay in consideration of the fact that streams that flow into the Bay pass through agricultural, informal and densely-populated settlements and industrial areas. Furthermore, the lake is the abstraction point of water that is supplied to Kampala City and metropolitan areas as well the recipient of the wastewater effluent.

1.7 Significance of the study

This study has generated some important insights into water quality as relates to the concentrations of heavy metals in the Inner Murchison Bay. Data is needed to inform evidence-based pollution monitoring, and to guide policy makers on appropriate management measures. Accordingly, the following immediate results were generated:

i. Documentation of the concentration of heavy metals in water, soil sediments and water hyacinths.
ii. Data on pollution loadings sources that lead to into heavy metals concentration in the Bay.
iii. Data sets for publication in open access databases to facilitate global access and further analysis for better interpretation of results and future research.

1.8 Conceptual framework

The conceptual framework (Figure1.1) summarises the relationship between variables. In this study, heavy metal concentration of the Inner Murchison is from both point sources and non-point sources such as sewerage discharge, industrial effluent, agricultural runoff, commercial activities in the catchment and constitute the independent variables. The dependent variables are the concentrations of heavy metals (Pb, Hg and Cd) in water, sediment and water hyacinth of the Bay which are influenced by the activities in the catchment.

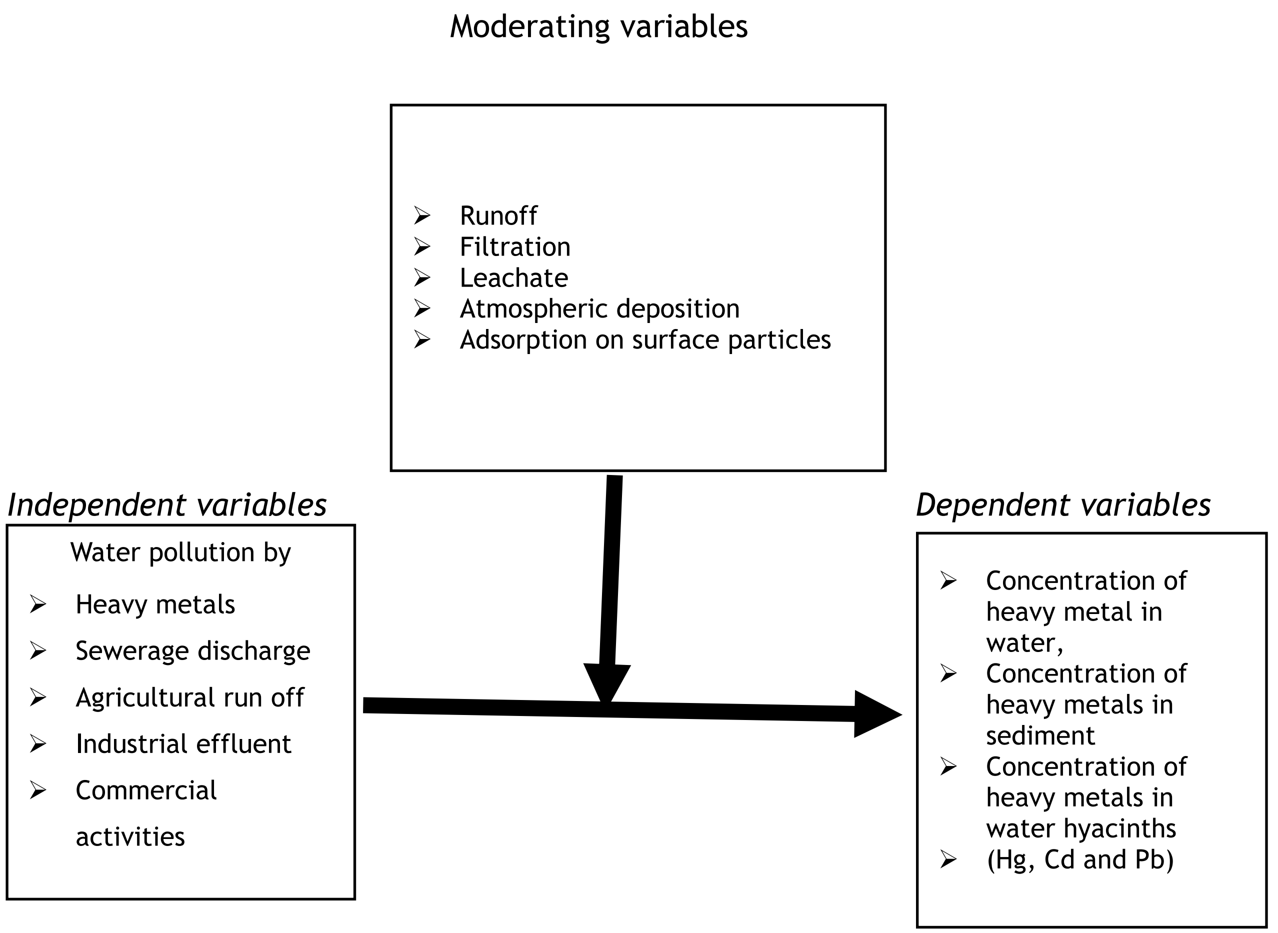

Figure 1.1: Conceptual framework

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

This chapter presents a review of the existing literature on heavy metal pollution in aquatic system specifically, in water, sediment and water hyacinths. The literature was reviewed according the research objectives presented in chapter one.

2.1 Overview of heavy metal contamination in aquatic system

Heavy metals are defined as naturally occurring elements that have high atomic weight and a density of at least five times greater than that of water. They are known as toxic at low concentration and their level of toxicity depends on numerous factors including the dose and route of exposure among others. Examples of heavy metals include: Arsenic, Cadmium, Chromium, Lead, and Mercury among others (Vardhan et al., 2019). According to Simionov et al. (2019), some heavy metals are considered as essential due to their catalytic role in cell functioning. These elements include Zinc, Iron, Manganese among others and they are only needed in trace amounts. On the other hand, other metals are non- essential elements and they present hazard of acute or chronic toxicity to organs when exposed to them. Non-essential elements include Cadmium, Lead and Mercury. However, heavy metals are now a global health concern since they end up in aquatic system. Water being a universal solvent that dissolves quiet a number of elements, presents a favourable environment for the metals to either dissolve, settle or suspend. Once in the aquatic system, heavy metals can pose adverse effects to plants, animals and human through bioaccumulation in the food chain (Ali et al., 2019). This public health threat does not spare Lake Victoria from whose catchment various anthropogenic activities are carried out. Literature by Ogoyi et al. (2011) shows heavy metals were detected in water, sediment and micro algae in the Tanzanian side of Lake Victoria as well as in the Inner Murchison Bay (Mbabazi et al., 2010) which was the study area for this particular research. Heavy metals are from different sources thus those sources are discussed in the next subchapter.

2.2 Sources of heavy metals contamination in aquatic system

Heavy metals pose a major threat to human health due to their toxicity, persistence and non-biodegradability (Islam et al., 2018). It has raised a major concern worldwide given that heavy metal concentrations have significantly increased in surface water bodies due to rapid urbanization, industrialization, agricultural activities and other anthropogenic activities which discharge waste materials containing heavy metals into rivers and lakes (Ahmed et al., 2019). Rajeshkumar et al. (2018) added that heavy metals found in aquatic environment are from human activities such as agriculture, fossil fuel combustion, corroded underground pipes, industrial effluent, sewage, melting and vehicles. Heavy metal pollution of surface water has therefore been attributed to agricultural runoff containing pesticides, fertilizers and industrial effluents. Angiro et al. (2020) indicated sources of heavy metals into the inner Murchison Bay from Namavanve industrial park through streams that flow into the lake. Fuhrimann et al. (2015) also identified Pb in soil, Cd and Cr beyond the national threshold heavy in Nakivubo wetland. The Nakivubo channel is an open channel that feeds the wetland and carries domestic, industrial wastewater and stormwater. It also transports the secondary effluent from Bugolobi wastewater treatment plant as well as untreated wastewater from informal settlement along the wetland. The Nakivubo channel discharges its water into the Inner Murchison

Bay which is also the abstraction point for drinking water supply for Kampala city. Unfortunately, the wetland's natural capacity is insufficient to filter pollutants due to encroachment for farming and settlement. This is in agreement with the findings of Mbambazi et al. (2010) who noted the ineffectiveness of Nakivubo wetland to absorb heavy metals as a result of wetland encroachment. The study showed a decrease in the effectiveness of wetland to filer Cd, Cu, Zn and Pb as well an increase of those heavy metals in the shoreline of the lake, around 2km from the wetland. Therefore, there is need for surveillance of lake water quality in the Inner Murchison Bay given that several anthropogenic activities take place in its catchment. Addo-Bediako et al. (2021), noted that anthropogenic activities such mining, agriculture and urbanization have led to metal contamination of most freshwater ecosystems. A particular attention should be given to heavy metals given that they pose serious threat to the population that rely on lake water for domestic and industrial use as well as fish consumption.

Another source of heavy metals that find their way into the aquatic system is from e -waste. Increased use of electronic and electric equipment has been seen over the recent years. Nuwematsiko et al. (2021) mentioned that there was no clear mechanism for e-waste management in Uganda reporting that users usually sell or donate gadgets to repair shops as a way of disposal, while other informal collectors broke the gadgets, remove useful parts of the gadgets and improperly dispose of the rest. Another common behaviour includes; the perception of having personal attachment with the gadget leading to keeping it even when it is out of use. Furthermore, given that there is no disposal mechanism, people resort to burning e-waste which is a very dangerous practice due to toxic fume that can be emitted.

Lastly, e-waste is disposed together with other household waste and consequently ending into the nearest water bodies and streams.

Uganda just launched its first E-waste management centre in June 2021, recognizing the challenges posed by E-waste on the environment and public health. According to National Environmental Management Authority (NEMA), (2021, https://nema.go.ug/media/ugandas-first-national-e-waste-management-centre-launched), Most E-waste is being discarded together with other waste streams such as domestic waste. It is a fact that E-waste contains hazardous components, including cadmium, mercury, and lead and therefore must be handled and treated cautiously. Improper disposal of E-waste poses environment, health, safety and security risks; and can lead to pollution of our soil, air and water with undesirable chemicals. While this is a great step for Uganda in the management of E-waste, the unanswered question is what happened to the e-waste already discarded inappropriately into the environment. Hence this study focused on the consequences of such practices that contribute to heavy metal pollution into the aquatic system. Once in the aquatic system heavy metals can dissolve in water, settle on sediment or accumulate in plants. Literature in this section indicate that the concentration of heavy metals has been determined around the Inner Murchison and the activities that probably generate those heavy metals have been mentioned. However, it’s a continuous monitoring of the bay was crucial given that all the inland pollutants flow into the Bay leading to its pollution by heavy metals. Therefore, literature on heavy metals in the water, sediment and plants; is reviewed in the next subchapters.

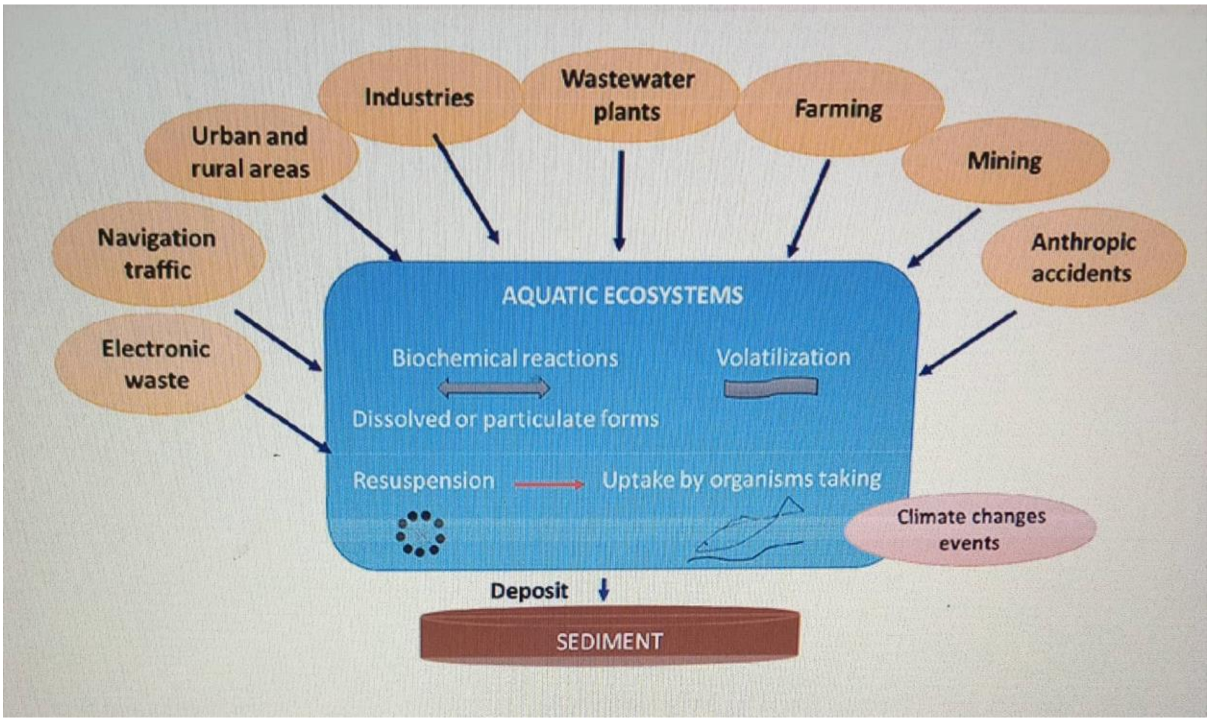

Figure 2. 1: Heavy metal sources and contamination in aquatic system

Source: Gheorghe et al. 2017

2.2.1 Heavy metals in sediments

Anthropogenic activities such as industrial activities, fossil fuel combustion, agricultural activities, wastewater discharge among others, are known as great contributors of surface water bodies pollution with heavy metals. Heavy metals are deposited on sediment posing a serious threat to aquatic organisms and human health (Dianpeng et al., 2022). Furthermore, literature has shown most heavy metals absorbed onto sediment can resuspend due to changes in environmental conditions such as electrical conductivity, pH, temperature, leading to secondary pollution of water. Thus, it is important to determine concentration of heavy metals in sediment as regard to protection of our drinking water sources. This confirms the findings of most research where concentrations of heavy metals in sediment are higher than the concentrations of heavy metals in water (Kouidri et al., 2016; Yongfeng et al., 2017). In addition, pollution of sediments by heavy metals affects benthic organisms through direct exposure of the organisms and definitely entering the food chain through accumulation (Fu et al., 2014). Similarly, Babatunde et al. (2020), attributed the concentration of heavy metals on sediment to their insoluble nature.

Several studies have detected heavy metals in sediments of water bodies. Rahman et al. (2022) used Atomic Absorption Spectrophotometer to detect the concentration heavy metals in sediment and the contamination factor, geo-pollution index and pollution index were used to determine the contamination levels of sediment. Astatkie et al. (2021) detected heavy metals in sediment. The findings of the study show that five heavy metals (Hg, Cr, Pb, As and Cd) were detected in all the samples in different concentrations. The following methods were used to assess the contamination of sediment: contamination factor; the geo-accumulation factor and the pollution load index. Similar method for assessment of sediment contamination by heavy metals was carried by Naggar et al. (2018). Conclusion can be drawn that there are various methods used to assess sediment contamination by heavy metals and can be used based on the objectives of the study. For example, the contamination factor shows the contamination of sediment by a given metal while the pollution load index shows the contamination of sediment based on the concentration of several metals (Calmuc et al., 2021). Heavy metals can accumulate in aquatic plant from water or sediment, thus this subchapter below reviewed literature on heavy metals in plants.

2.2.2 Heavy metals in aquatic plants

Heavy metals in aquatic system are found in water or can be deposited in soil sediment. However, aquatic plants have the capabilities to accumulate heavy metals in their organs and can be used as indicators of pollution in aquatic system. A study by Abbawy et al. (2020) analysed six heavy metals in six aquatic plants. The findings showed that all heavy metals of interest were found in the plants and the concentration of metals varied with plant species. Cr, Cd and Fe were higher than the recommended concentration by WHO while the water samples were within the permissible ranges indicating the uptake of metals by the plants. It is important to note that the whole plant was analysed and the concentration of metals was compared among the species. In addition, the bioconcentration factor was calculated as ratio between the concentration metal in plant and its concentration in water to determine the ability of the plant to store heavy metals. Studies have used both edible and non-edible plants in assessing heavy metal pollution. For example, Uddin et al. (2021); determined the concentration of heavy metals in rice and other edible plants. The findings shows that the heavy metals of interest were detected in all the samples at various concentration depending on the species. In addition, the study categorised some metals such as Zinc, Fe among others as micronutrients needed plants, while other such as Cd, Pb were considered as non-essential causing multiple damages to plants and eventually to human when consumed. On the other hand, this particular study by Bai et al. (2018) assessed the levels of heavy metals in common aquatic plants in Taihu Basin and furthermore, focused on the capabilities of plants to accumulate heavy metal in its different organs. In addition, the study mentioned the use of plants in bioremediation of aquatic system, since they have ability to take up heavy metals from either water or sediment. Thus, it is important to monitor heavy metal concentration in aquatic plants. Whether edible or not, plant still constitute source of food for aquatic animals that are consumed by humans and their capability to take up heavy metals helps in assessing the state of the aquatic system.

Toxic concentrations of heavy metals in aquatic system result into negative effects on plants. Such as the excessive production of Reactive oxygen species (ROS) resulting into oxidative stress (Berni et al., 2019).

Water hyacinth of its scientific name *Eichhornia crassipes* is one of the most common aquatic plants that cover the shores of Lake Victoria, is discussed in the subchapter below.

2.2.3 Heavy metal contamination of water hyacinth

In Lake Victoria, water hyacinth poses a great ecological and economic threat. From preventing navigation, to hindering light from penetrating the water column by forming a thick mat on the water surface; it depletes oxygen from the water thus resulting in suffocation of aquatic organism (Güereña et al., 2015). Water hyacinth is a floating plant and rapidly growing that can double its biomass in less than two weeks (Figure 2.1). Despite, the threat that water hyacinth poses on the aquatic organisms; research has mentioned its use in handicraft industry and furthermore its importance in wastewater treatment. In case of wastewater treatment, the findings by Huynh et al. (2021) confirmed the capability of water hyacinth to remove heavy metals such Cd, As, Zn, Pb and Cu. This reveals that water hyacinth can be used as bio-monitor of aquatic system given its ability to accumulate heavy metals. A similar experimental study also used water hyacinth for cleaning up heavy metal polluted water and the findings indicated that the plants showed great capabilities to absorb heavy metals (Jones et al., 2018). Since, the study area was the inner Murchison Bay where water hyacinth covers most of its shores, it was of great importance to determine the concentration of heavy metals in water hyacinth which can be used for further study as bio-indicator of pollution in aquatic system. Lead (Pb), Cadmium (Cd) and Mercury (Hg) were the heavy metals of interest and literature is reviewed below on those heavy metals.

2.3 Lead (Pb)

Lead is a non-essential heavy metal that is known for great toxicity at low level. Sources of Pb include: lead-based paints, leaded gasoline, batteries, mining and industrial processing, soldering, metal water pipes. However, Pb availability in aquatic system depends on various factors such pH, alkalinity, hardness among others; thus, influencing the distribution of Pb in the aquatic system (Tamele and Loureiro, 2020). Pb can be found in water, absorbed or deposited on sediment but also be taken up by aquatic plants. This explains how Pb enters the food chain. The findings of Nsabimana et al. (2020) showed heavy metals in water samples collected from Lake Kivu indicated that among the heavy metals detected in water samples, Pb concentration (11.02ppm to 35.24ppm) exceeded the EPA permissible limits for surface water. Pb has also been detected in sediments and aquatic plants. Muneer et al. (2022), found Pb among the heavy metals in both water and sediment. On the other hand, among the ten heavy metals analysed in sediment and plants, Bai et al (2018); found Pb and other metals such Cu, Cr, Mn, Ni, Zn, Co; in aquatic plants to be higher than the normal limits. Regardless of the routes of exposure to Pb such as direct injection through water or consumption of organisms that have accumulated Pb, the later remains toxic to human health. In humans, Pb can cause acute toxicity such as abdominal pain, constipation, tiredness, headache among others but long-term effects of Pb poisoning can lead to anaemia, weakness, kidney and brain damage and even death (Isangedighi et al., 2019).

2.4 Cadmium (Cd)

Cadmium is a non-essential heavy metal. It is one of the most toxic heavy metals even at low levels. Sources of Cd include; batteries in which it is found as electrode, coatings, pigment and plastic stabilizer. Cd is a very persistent metal and can remain in soil for decades (Jaishankar, 2014). Cd is usually in water in ionic form and can be absorbed by aquatic organisms especially fish through the gills during ionic exchange from water as Cd^{2+}. Cd have been detected by several researchers in sediments of lakes and rivers. For example, Cd was among the metals detected by Outa et al. (2020) in water and sediment of Lake Victoria in Kenya. The study attributed the concentration of cadmium in sediment to agriculture activities that take place in the catchment of the Lake. Phosphate fertilizers contain Cd which can be carried by runoffs to the aquatic system. The findings of Custodio et al. (2019) in Peru, also pointed out agricultural activities as the main source of Cd in sediment beside other sources like wastewater, detergents, insecticides and electronics. Beside water and sediment, Cd is also known to bioaccumulate in plants. Outa et al. (2019) detected heavy metals including Cd in the roots and stems of aquatic plants in the Kenyan part of Lake Victoria. Research has further shown the health effect of Cd to human as renal dysfunction and borne damage among others (Isangedighi et al., 2019). Cd ingestion through contaminated food, water and smoking can cause serious health complications. Public health risk related to Cd is classified as carcinogenic and can cause toxic effects to kidneys, skeleton and respiratory system (WHO, 2019; Genchi et al., 2020).

2.5 Mercury (Hg)

Hg can naturally be present in water, soil and air in trace amount resulting from natural activities such as geological weathering and volcanic eruption. Whereas, human activities such as mining, solid waste composting, fossil fuel burning, waste incineration, can increase the levels of Hg in the environment (Sarasiab et al., 2014). As other heavy metals, studies have detected Hg in water, sediment as well as in aquatic plants. For example, a study carried out in Busia, Uganda detected Hg in water and sediment. The concentration of Hg in water samples showed that more than 90% of water samples had Hg levels beyond levels required by WHO/US EPA for drinking water. It is important to mention that the study was carried out in an area known for gold mining activities and Hg was the only heavy metal being investigated (Omara et al., 2019). On the other hand, Cosio (2020), detected Hg into aquatic plants. The study noted that plants which are primary producers are great facilitators for Hg uptake and transfer to the next trophic level, this is a result of plant being source of food for aquatic animals and also ensures nutrient cycling in the aquatic system. According to WHO report (2017), Hg is persistent in the environment, highly bio accumulative and all forms of Hg are toxic. Furthermore, Mercury is known for causing the following toxic effects to human: nephrotoxicity, teratogenicity and damage to the cardiovascular system among others. In addition, pregnant women are the most vulnerable group to Hg exposure, given that Hg interferes with the foetus development. Thus, it is important to monitor the levels of Hg in the aquatic system owing to its harmful effect on human health.

From the reviewed literature, we can vividly confirm that human activities have polluted surface water bodies around the world with heavy metals; heavy metals are toxic to aquatic organisms such as plant, fish and human beings. Heavy metals in the water bodies enter the food chain through direct ingestion of water or consumption of organisms like plants and fish that have accumulated them. Heavy metals are passed to the upper tropic levels from the producers that accumulate them through water or sediment. They are essential and non-essential heavy metals and they are all toxic beyond the threshold, however non-essential metals are toxic even at low levels, given that they are not required for body functioning. Thus, this study aimed at informing decision makers on urgence to obtaining useful data concerning heavy metal pollution in the Inner Murchison Bay through assessment of the concentrations of Lead (Pb), Mercury (Hg) and Cd (Cd) in water, sediment and water hyacinth. The study also highlights the need for continuous monitoring of heavy metals concentration. The chapter below explains the methods used to assess heavy metal pollution in the Inner Murchison Bay.

CHAPTER THREE: METHODOLOGY

3.0 Introduction

This chapter discusses the methods and materials that were used to conduct this study. It also describes the study area.

3.1 Study Area

The Murchison Bay is within the Lake Victoria region (Figure 3.1). It is located in the southern part of Kampala City which is characterized by industrial and commercial activities as well as high population density. Both the inner and the outer part of the Bay covers an area of 62km^2. The Inner Murchison Bay which is the study area covers about 18km^2 with a mean depth of 3.2m (Akurut et al., 2017). The Bay lies between latitude 0^{o}10' 0''N-0^{o}30'00''N and longitude 32^o 35'00''E-32^{o}00'50''E and an elevation of about 1224m above sea level. The climate in the area is tropical with two peak rainy seasons, March to May and October to November (Kiyemba, 2021). The mean temperatures range from 23^o C to 32 ^{o} C (Zawadi et al., 2020).

The Inner Murchison Bay is an abstraction point of water that is supplied to Kampala and also the recipient of partially treated wastewater that is discharged into the Bay through Nakivubo Channel. The channel is the main drainage that discharges its waters into the Bay. It carries water from both the Bugolobi wastewater treatment plant which is a secondary effluent and the polluted untreated City water. The papyrus wetland in the outer part of the Bay has been encroached for agriculture, industries, commercial purposes and residential area (Isunju and Kemp, 2016), thus the water does not undergo an effective purification process before entering the Bay. Apart from Nakivubo channel, other channels include; Kansanga channel that stretches to Ggaba shoreline; Kinawataka from industrial areas of Nakawa; Kyambogo and the gazetted industrial park of Namanve stream (Akurut et al., 2017). Various anthropogenic activities occur in the catchment and on the shores of the IMB indicating potential sources of the Bay's pollution by heavy metals.

Water hyacinth (*Eichhornia crassipes*) is the most dominant and common plant species at all the sites and was therefore identified as the plant species to be considered for this study. Heavy metal pollution of water hyacinth in the Bay was assessed by determining the concentration of heavy metals in the plant.

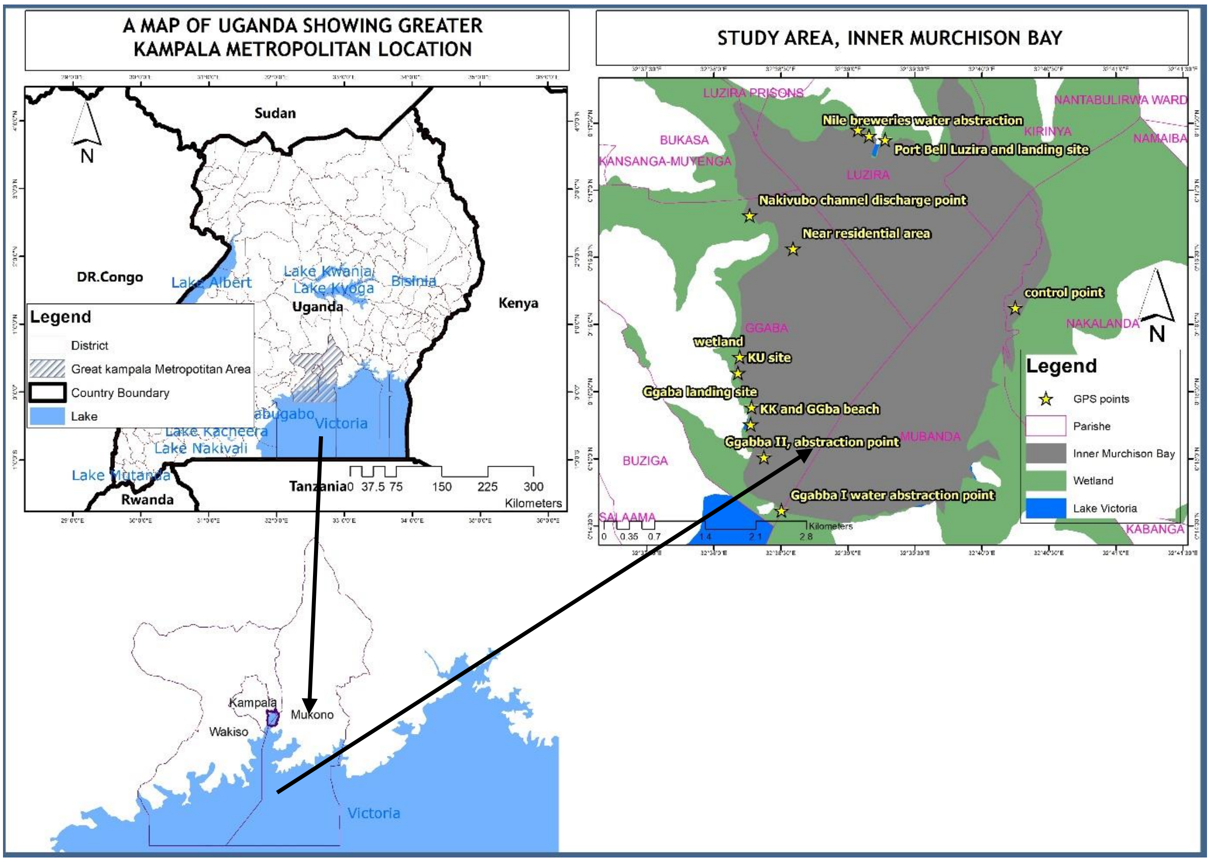

Figure 3. 1: Inner Murchison Bay within Lake Victoria region

Source: Google Maps,2022.

3.3 Research design

a) observation and pilot study were carried out long with secondary data to describe pollution loading sources of the Inner Murchison Bay.
b) Cross-sectional design (sampling)

A cross-sectional study gathers data from a given population at a specified point in time. Cross-sectional studies are known as descriptive design that provide information from a selected group without influencing the variables (Setia, 2016). This study adapted the cross-sectional design because data gathered from the study is important baseline information in planning, monitoring and evaluation of future investigations.

A cross-sectional study was conducted between May and June which is a rainy season, through sampling of water, sediment and water hyacinth in the Inner Murchison Bay (Figure 3.1). The selection of the sampling point was based on the various activities identified on the shores of the IMB. The number of sampling points and the distribution was guided by GPS coordinates and this was identified as an appropriate sampling strategy because the samples were representative of the study area. Sampling was done in triplicate at an interval of one week to ensure accuracy of data.

An experimental design (laboratory analysis)

Concentrations of Lead (Pb), Mercury (Hg) and Cadmium (Cd) in water, sediment and water hyacinth were determined through laboratory analysis. Sample preparation and analysis were based on Atomic Absorption spectrophotometer (AAS Perkin Elmer Analyst 400) operating procedure. AAS operation procedure for sample preparation involves acid digestion (Method 3005A for water and 3050B for sediment). This is an important procedure in determination of total amount of heavy metals. Acid digests organic/inorganic particles in order to release the bound metals as soluble ions which is crucial in increasing the sensitivity of heavy metal detection by AAS (Mohammad et al., 2017). For each sample, the following three heavy metals were analysed; Mercury (Hg), Lead (Pb) and Cadmium (Cd).

C) to assess the variation of Pb, Cd and Hg in water, sediment and water hyacinth, T-test was used. Variation was assessed among sites for water samples, bottom sediment and water hyacinth.

Table 3. 1: Sampling sites

Sampling sites based on activities on the shores	Sampling sites coordinates
Ggabba I water abstraction point (S1)	Latitude: 0.243580 Longitude 32.641725
Ggabba II, abstraction point (S2)	Latitude: 0.250192 Longitude: 32.639556
KK and GGba beach(S3)	Latitude: 0.254272 Longitude: 32.637882
Ggaba landing site (S4)	Latitude:0.256407 Longitude: 32.638007
KU site (S5)	Latitude: 0.2881234 Longitude: 32.381075
Near residential area (S6)	Latitude:0.262666 Longitude: 3.2636525
wetland (S7)	Latitude: 0.276099 Longitude: 32.643181
Nakivubo channel discharge point (S8)	Latitude: 0.2802224 Longitude: 32.637773
Nile Breweries wastewater discharge point (S9)	Latitude: 0.290855 Longitude: 32.651229
Nile breweries water abstraction point(S10)	Latitude: 0.2881234 Longitude: 32.381075
Port Bell Luzira and landing site (S11)	Latitude: 0.289636 Longitude: 32.654602
Control site (S12)	Latitude: 0.2971211 Longitude: 32.401486

3.3.1 Water, sediment and plant Sampling

Assessment of heavy metal pollution of the Inner Murchison Bay involved identification of twelve representative sites in the Bay (Table3.1. and Figure 3.1). selection of the sites was based on activities carried out along the shores of the Bay. The Control site was identified in the area known to have negligeable anthropogenic activities and also in the same geographical area as the study area. The coordinates of the sampling sites were marked with a Global Positioning System (GPS) to ensure that consecutive samplings were conducted at the sites. Water, sediment and water hyacinth samples were collected once a week in triplicate (three samples collected from each site) to ensure adequate laboratory analysis. The samples were preserved in an ice box (4^{o}C) and transported immediately after collection, to the Chemistry Laboratory, Uganda Industrial Research Institute (UIRI), Kampala. The analysis of heavy metal was done to determine total Pb, Cd and Hg using acid digestion as the extraction method.

3.3.1.1Water sampling

Water samples were collected from the twelve identified sampling sites in the Bay. The samples were collected in polythene bottles kept in 1% nitric acid. Water was collected below the water surface to exclude suspended dust and oil substance that are found above the Lake water (Gerenfes et al 2018). The bottles were filled in a way that no bubble was left in. The samples were analyzed following the UIRI guidelines for determination of mineral content in water samples ISO 6332:1988, ISO 8288:1986, ISO 7980: 1986.

3.3.1.2 Sediment sampling

According to Jun et al. (2019), to study the most recently deposited layers of sediments in the streams, ponds, rivers and lakes, it is often sufficient to take the upper most centimetres of sediments with a Van Veen grab sampler (0-10cm). in the Inner Murchison Bay, the depths varied between 2-3 meters. In this study, a pair of weighted semi-cylindrical jaws (Van Veen grab sampler) was pressed into the sediment at the bottom of the lake by their own weight while they were open. The sediment sampler was then lifted, the two jaws were closed by their own weight or by a tension spring. The samples were transferred to a sterilized plastic bag, tightly sealed and labelled and preserved. The grab sampler was thoroughly cleaned several times with deionised water to avoid cross-contamination and interference.

3.3.1.3Plant sampling: water hyacinth

Whole water hyacinth plants were collected for each site in triplicate. The plants were collected (uprooted) manually, washed with lake water and put in a polythene bag and thereafter, transported to the laboratories for analysis.

3.3.2 Laboratory analysis

3.3.2.1 Analysis of water samples

Water samples were analyzed following the AWWA/APHA 3500 method for the determination of heavy metals in water samples. Each sample was filtered using a membrane filter to avoid clogging. Afterwards, concentration of the metals of interest was read following the Atomic Absorption Spectrophotometer (AAS) operating procedure. The adapted flame was air acetylene. The corresponding lamp for each heavy metal was used during analysis as source of light.

Blank sample and standard reference materials were used for quality control during analysis.

3.3.2.2 Analysis of sediment samples

The samples were air-dried and crushed with a mechanical device. Then screened to pass a 20-mesh sieve. 2.5grams of sediment was weighed in a 125ml Erlenmeyer flask and 25ml of 1N NH_4OAc, pH7.0 was added. The sample was placed in a shaker for 15 minutes. The solution was then filtered and analysed using flame Atomic Absorption Spectrophotometer Perkin-Elmer Analyst 400 based on the USEPA method 3051A(http://www1.lasalle.edu/~prushan/Intrumental%20Analysis_files/AA-Perkin%20Elmer%20guide%20to%20all!.pdf). Calculation of the detected metals was done using the calculation sheets for specific minerals. A blank sample and material standard were used for quality control. The results were compared against the sediment quality guidelines and the sediment assessment indices (contamination factor and pollution load index).

3.3.2.3Analysis of water hyacinth

A whole plant (leaves, stem and roots) was used for heavy metal analysis.

One gram of dried and grounded whole plant was placed in a porcelain crucible. It was then placed in a muffle furnace and ash at 500 °C overnight. The ash was allowed to cool and later dissolve in 5-mL of 20% HCl. if necessary, the solution was warmed to dissolve the and then filtered through an acid washed filter paper into a 50-mL volumetric flask.

The solution was diluted to volume with deionized water and mixed well. The sample was then transferred into a sample vial and read using the AAS Sperkin Elmer, Analyst 400 based on dry ash method.

(http://www1.lasalle.edu/~prushan/Intrumental%20Analysis_files/AA-Perkin%20Elmer%20guide%20to%20all!.pdf)

3.3.3 Bioconcentration factor (BCF)

Bioconcentration Factor refers to the ability of the plant to take up metals from its surrounding (Singh et al. 2017). The bioconcentration factor was calculated as the ratio of heavy metals concentration in plant's tissue relative to its concentration in water. BCF>1 meant higher ability of plant to accumulate a particular heavy metal (Azeez, 2021). BCF=metal concentration in plant (ppm)/ metal concentration in water (ppm)

3.3.4 Sediment quality assessment

Assessment of sediment quality can be done using various sediment assessment indices. For this study, Contamination Factor (CF) and Pollution Load Index (PLI) were used to evaluate the sediment contamination with heavy metals in the Inner Murchison Bay.

3.3.4.1Contamination factor (CF)

CF assessed the level of pollution with individual metals showing the enrichment of sediment by metals. The following equation proposed by Hakanson 1980, was used to calculate the CF:

(Equation1): $CF = \frac{C_{sample}}{C_{background}}$

Where:

C_{sample} is the mean metal content in sample sediment

$C_{background}$ is the mean natural background value of the metal.

The background sample was collected from the control site (S12, Table 3.1) known to be of negligeable anthropogenic activities. The contamination was determined based on three grades as follows: Low degree (CF<1), moderate degree ($1 \le CF < 3$), considerable degree ($3 \le CF < 6$), and very high degree ($CF \le 6$) (Astatkie et al., 2021).

3.3.4.2 Pollution load index (PLI)

PLI was used to determine the quality of sediment based on the concentration of various metals of interest (Tomlinson in 1980). PLI was calculated as the nth root of the multiplications of the Contamination factor of the heavy metals of interest (LI et al 2022).

The control sample was considered as the background sample and the results were compared against the contamination factor and the pollution load index grades (Table 4.4, Appendix 10).

3.4 Sources of data

Primary sources of data: This was first hand evidence that was generated from laboratory analysis concerning the concentration of heavy metals in water, sediment and water hyacinth of the Inner Murchison Bay.

Secondary sources of data: include standards and guidelines for heavy metals in water, sediment and plants and guiding information related to heavy metals.

3.5 Quality control

All the requirements for sample integrity were adhered to from sampling to laboratory analysis and data analysis, thus ensuring the quality and reliability of results. All the samples were analyzed from laboratories recognized by the National Standard body and Uganda National Bureau of Standard under laboratory recognition program scheme: CERT/LRS/F03, 2020.

3.6 Data analysis

After detection of heavy metals in water, sediment and water hyacinth, statistical analysis was done using IBM SPSS 20.0 software.

Descriptive statistic was used to determine the mean values of heavy metals in water, sediment and plant. Excel was used to calculate the values of Bioconcentration factor in water hyacinth, Contamination factor and Pollution load index for heavy metals in sediment (Appendices 7,8,9 and 10). T-test was used to determine the difference in means of the variables between sites, and the means generated in T-test table were separated using the least significant difference at 5% significance level (Appendices 1,2,3,4,5 and 6). The concentrations of heavy metals in water, and water hyacinth were assessed against World Health Organization (WHO) guidelines for water and plant respectively (Table 4.1 and Table 4.5). Sediment quality was assessed using the sediment quality guidelines, Contamination factor and pollution load index (Table 4.2, Table 4.3 and Table 4.4).

3.7 Methodology constraints

- Time constraint; Heavy metals concentrations are affected by seasonality changes hence the research results could vary if data was collected in different seasons of the year (dry and wet seasons). However, there was limited time for data collection and data was collected in one season hence the research outcomes might not show the impact of seasons on heavy metal concentration.

CHAPTER FOUR: RESULTS PRESENTATION AND DISCUSSION

4.0 introduction

This chapter presents the findings of this study and discusses those findings based on the literature reviewed and general body of knowledge.

4.1. Description of pollution loading sources of the Inner Murchison Bay (IMB)

Several pollution sources both point-sources and non-point sources have been identified along the IMB. Basically, there are anthropogenic activities that are potential sources of pollution of Bay and have been used for the selection of sites during this study (Table 3.1). Major activities identified during this study are the following:

- Abstraction of water for domestic and industrial purposes. Water is abstracted by National Water and Sewerage Corporation, where two abstraction points Ggaba I and Ggaba II with water treatment plants. Generally, water treatment plants have strategy to treat waste generated during treatment. However, in this area of intense anthropogenic activities, abstracting water can result into high water treatment cost, showing the need for pollution assessment as far as heavy metals are concerned.
- Two main landing sites are found in the Inner Murchison Bay; Port Bell in Luzira which is the main inland port of Uganda and a landing site. On the other hand, Ggaba has a landing site and market. The landing site has contributed to plastic pollution of the lake (Asiimee, 2021), the area has been reported to have several other activities such as navigation, boat fishing, garages, car washing, recreational activities such as beaches. These activities

are potential sources of heavy metals such as Pb. Pb is found in small amount in earth crust however, most of it is released from human activities such as fossil fuel burning, manufacturing, garages among others (Muneer et al., 2022)

- Agricultural activities have also been reported in the wetland around the Bay. The papyrus wetland in the outer part of the Bay has been encroached for agriculture, industries, commercial purposes and residential area (Isunju and Kemp, 2016), thus the water does not undergo an effective purification process before entering the Bay. It is important to note that the wetland encroachment for agriculture and residence impacts on the quality of water in the Bay (Sridhar and Gidudu, 2020). Wetland purifies wastewater water by absorbing heavy metals through plant uptake (Schück et al., 2020). Part of Nakivubo wetland have been encroached which could result into inefficiency of water purification by the wetland. On the other hand, use of chemical fertilizers in agriculture has resulted into water pollution with cadmium (Ali et al., 2019). These contaminants can be washed by rain as run off thus entering the Bay.
- Industrial activities in Namanve Industrial Business Park: this area located in the catchment of the Inner Murchison Bay and it is characterized by several industries including steel industries. 18% of waste generated in Namanve are metallic (Omara et al., 2019). Industries in Namanve Industrial Business Park include: Century Bottling Company, Roofings Rolling Mills, Steel and Tube industries, Hima cement limited. Various heavy metals are released from the industries and are potential sources of heavy metal pollution of the Bay. Heavy metals are transported to the Bay by rain, the streams around the

industrial areas also flow into the Bay. Nile breweries is also located at the shores of the Bay. It abstracts its water from the Bay and discharged its effluent from the same (Akurut et al., 2017).

- Nakivubo channel which is the main drainage that discharges its waters into the Bay. It carries water from both the Bugolobi wastewater treatment plant which is a secondary effluent and the polluted untreated City water. Untreated city urban runoff carries a variety of waste that probably contain heavy metals. The most common method used in wastewater treatment does not guarantee efficient removal of many contaminants such as heavy metals (Agoro et al., 2020). Pb, Cd, Hg are among the heavy metals discharged from wastewater effluent. Besides Navibubo channel several other channels such as Kansanga Channel also discharge its water into the Bay at Ggaba shores.

  Basically, all the inland pollutants from Kampala are carried into the Bay through streams and channels while some are directly discharged into the Bay. This signifies that anthropogenic activities result into heavy metal pollution of the Inner Murchison Bay. Therefore, the concentrations of Pb, Cd and Hg were determined in water, sediment and water hyacinth showing the impacts of human activities on the Bay.

4.2 Heavy metal concentrations in water, sediment and water hyacinth

4.2.1Lead in water

The concentration values of Lead (Pb), Cadmium (Cd) and Mercury in water samples are presented in Table 4.1. The highest mean value for Pb (0.129 ± 0.123) While the lowest value of Pb (0.033 ± 0.057), was recorded near the wetland (S7). Pb was not detected in water samples at control site (S12). The concentration of Pb in all the water samples was beyond the permissible limits for both WHO and NEMA/EAC (Table 4.1) at all the sites. The presence of Pb is attributed to activities such as car washing, garages in the catchment of the Lake. Use and poor disposal of paint-based Pb materials, batteries. The findings are consistent with those of Outa et al (2020), who detected Pb and Cd in water of the Kenyan part of Lake Victoria attributing it to anthropogenic activities and industrial effluent contributing in lake pollution. Similarly, Ouma et al. (2016); detected low Pb in water samples in the its Kenyan part of Lake Victoria emphasizing the impacts of anthropogenic activities on pollution of Lake Victoria with heavy metals. Pb that pollute water bodies are generally from wastewater effluent and industrial effluent (Afzaa et al., 2022). Pb is toxic and at low levels can have adverse impacts on living organisms. Garai et al. (2021) pointed out deformities in fish and decrease in levels of hemoglobin content in fish exposed to Pb. In humans, Pb attacks the nervous system and can hinder brain development especially in children. Furthermore, exposure to Pb can result into high blood pressure, kidney damage among others (Collin et al., 2022). In conjunction with all the above, the findings of Pb contamination are useful in policy formulation of monitoring of heavy metal pollution.

4.2.2 Cadmium in water

Cd was detected in all the water samples, expect at the control site (S12, Table 4.1). The highest values (0.079 ± 0.010), were recorded at Ggaba water abstraction point2 (S2) and lowest (0.021 ± 0.037) was recorded near the wetland areas (S7). Table 4.1 shows evidence that Cd concentration exceeded the WHO and NEMA/EAC limits at all the sampling sites.

The presence of Cd is due to activities such as poor disposal of plastic products knowing that Cd is used as stabilizer in plastics, runoff from waste batteries and paint (Qin et al., 2022). The use of fertilizers and pesticides in the vicinity of the Bay is as well a source of Cd pollution in water. The findings of study are consistent with those of Malau et al. (2021), who attributed water pollution with Cd, to agriculture activities. Monitoring of Cd is critical given that Cd is a non-essential metal and is toxic at low levels. Cherif et al. (2015) established that high levels of Cd can inhibit egg production in fish resulting into decrease in fish population. In humans, Cd can attack renal and skeletal pulmonary and can lead to a cancer and damage to the livers and kidneys (WHO,2019).

Table 4. 1: Heavy metals in water (ppm)

SITES (S1)	Lead (Pb) (mean ±SD)	Mercury (Hg) (mean ±SD)	Cadmium (Cd) (Mean ±SD)
S1	0.123 ± 0.012	ND	0.071[a] ± 0.008
S2	0.124 ± 0.018	ND	0.079[a] ± 0.010
S3	0.114 ± 0.015	ND	0.062[a] ± 0.007
S4	0.118 ± 0.015	ND	0.067 ± 0.008
S5	0.077 ± 0.067	ND	0.04[a] ± 0.0347
S6	0.111 ± 0.014	ND	0.074[a] ± 0.007
S7	0.033 ± 0.057	ND	0.021 ± 0.037
S8	0.039 ± 0.067	ND	0.026 ± 0.044
S9	0.108 ± 0.013	ND	0.063 ± 0.012
S10	0.086 ± 0.025	ND	0.038 ± 0.033
S11	0.129 ± 0.123	ND	0.061 ± 0.008
Control site (S12)	ND	ND	**ND**

WHO and NEMA/EAC permissible limits of Pb and Cd in water			
***WHO (2017)**	0.01		0.003
****NEMA/EAC (2018)**	0.01		0.003

Note:

**World Health Organization (WHO) 2017, allowable limits of heavy metals in surface water: Pule et al., 2022*

***National Environmental Management Authority/ East African Community 2018: Pule et al., 2022*

Means with different superscripts within the rows are significantly different at a 5% level of significance; (among the sites)

ND: Non-detectable levels

SD: Standard Deviation

4.2.2 Heavy metals in sediment

4.2.2.1 Lead in sediment

Table 4.2 shows the concentration of Pb in sediment at all the sampling sites. The highest value of Pb (5.232 ± 0.546) was recorded at Ggaba water abstraction point1 (S1) while the lowest (3.357 ± 0.569) was at control site (S12). Pb was present in sediment of all the sampling sites.

This study recorded lower Pb values in the sediment at all the sites compared to the sediment quality guidelines: Lowest Element Level (LEL), Threshold Element Level (TEL), Probable Effect Concentration (PEC) and Severe Effect Level (SEL) (Table 4.2). This signifies that the concentration Pb in sediment is still within the permissible limits of sediment assessment guidelines. The presence of Pb in the sediment at all the sites is attributed to activities generating Pb in the catchment of the study area. These activities include: navigation, industries, poor waste disposal and used lead-based paints. In addition, the insoluble nature of Pb in water, allows it to settle with particulate on sediment. Besides, anthropogenic activities, rock weathering is a natural source of Pb in sediment (**Bakyayita et al., 2019).** Referring to previous studies that have been conducted in Lake Victoria and other

African lakes, the concentration of Pb recorded in this study, is lower than 42.184ppm reported by Baguma et al. (2022) in Uganda and 195ppm by Outa et al. (2020) in Kenya. Similarly, Jonathan et al (2016) recorded high concentrations of Pb (100.23± 10.23 to 126.83 ± 10.24.) in Lake Chad compared to the values recorded in the Inner Murchison Bay (3.357 ± 0.569 to 5.232 ± 0.546). The comparison of Pb concentration in sediment from the Inner Murchison Bay with those recorded in other parts of lake Vitoria and Lake Chad indicates that high concentration of Pb is attributed to local anthropogenic activities.

4.2.2.2 Cadmium in sediment

Cd was detected at all the sites. The highest value of Cd in sediment (2.509 ± 0.257) was recorded at Ggaba water abstraction point2 (S2), and the lowest (2.004 ± 0.201) at the control site (S12). The concentration of Cd recorded in sediments exceeded the LEL(0.6ppm) and the TEL(0.99ppm). The concentrations of Cd were below the PEC(4.90ppm) of the sediment quality guidelines (Table 4.2). The presence of Cd in the sediment of the Inner Murchison Bay is as a result of poor disposal of Cadmium containing paints, plastics, agricultural runoff and industrial effluent, which are released from the catchment of the Bay (Algül et al., 2020). Cd pollution of sediment is largely from phosphate fertilizers that are used in agriculture in the catchment of the water body (Redwan et al., 2022). The findings indicate that increased level of Cd from its current concentration can reach the Probable Effect Concentration (PEC). PEC indicates the concentration above which adverse effects on benthic organisms can be seen (Islam et al., 2022)

Table 4. 2 : Heavy metals in sediment (ppm)

SITES	Lead (Pb) (mean ±SD)	Mercury (Hg) (mean ±SD)	Cadmium (Cd) (mean ±SD)
S1	5.232[a] ± 0.546	ND	2.405 ± 0.185
S2	4.973 ± 0.495	ND	2.509 ± 0.257
S3	4.945 ± 0.279	ND	2. 264 ± 0.067
S4	5.005 ± 0.660	ND	2.319[b] ± 0.091
S5	4.112 ± 1.106	ND	2.235 ± 0.075
S6	4.114 ± 1.086	ND	2.125 ± 0.124
S7	4.105 ± 0.188	ND	2.186 ± 0.058
S8	3.888 ± 0.744	ND	2.400 ± 0.173
S9	3.719 ± 0.607	ND	2.314 ± 0.076
S10	3.619 ± 0.413	ND	2.319 ± 0.106
S11	3.774[a] ± 0.115	ND	2.182[b] ± 0.057
Control site (S12)	3.357 ± 0.569	ND	2.004 ± 0.201

Sediment quality guidelines			
***LEL**	31.0		0.60
***TEL**	35.8		0.99
***PEC**	128.00		4.90
***SEL**	250.00		10.0

Note:

**Sediment quality guidelines: Lowest Element Level (LEL), Threshold Element Level (TEL), Probable Effect Concentration (PEC) and Severe Effect Level (SEL): Muneer et al., 2022*

Means with different superscripts within the rows are significantly different at a 5% level of significance;

ND: Non-detectable levels

SD: Standard deviation

4.2.3 Heavy metals in water hyacinth

Water hyacinth was the most dominant and common plant in the Inner Murchison thus, it was identified for heavy metal assessment of the Bay. Water hyacinth was taken from 8 sampling sites (Table4.3). The plant was absent in the four sampling sites. Pb and Cd were detected at all sites while Hg was below the detected level as presented in Table 4.3.

4.2.3.1 Lead in water hyacinth

The highest mean value of Pb (0.665 ± 0.103), was recorded in water hyacinth at Nakivubo Channel discharge point (S8) while the lowest value of Pb (0.387 ± 0.058), was recorded where Nile Breweries releases its wastewater in the Lake (S9). The results presented in Table 4.3, show the concentration of Pb was below the recommended limits set by WHO for aquatic plants at all the sampling sites. However, the concentrations of sampling sites were not significant among the sites ($p>0.05$). The presence of Pb in all the samples showed contamination of the Bay by Pb which probably resulted into uptake of the same by water hyacinth. This is in agreement with Kabeer and Varghese (2013), who pointed out the uptake of heavy metals by water hyacinth at the wetland. Fahruddin (2020), also noted the capability of water hyacinth to take up heavy metals in its tissues. The plant has been suggested for phytoremediation in wastewater containing heavy metals (Huynh et al., 2021).

4.2.3.2 Cadmium in water hyacinth

Results of Cd concentration in water hyacinth are presented in Table 4.3. The highest value of cadmium (0.222 ± 0.008) was in water hyacinth of the wetland (S7) and the lowest (0.182 ± 0.012) was recorded at the water intake of Nile breweries (S10). The concentration of Cd across the sites did not have significant variation ($p>0.05$). Cd in the Inner Murchison Bay are from industrial activities in the catchment of the Bay. This is in agreement with Angiro (2020) attributed the pollution of the Inner Murchison Bay to industrial activities. The presence of Cd can be attributed to runoff from agriculture activities in the wetland thus entering the Bay. Roberts (2014) and Cakovik et al. (2021), noted that phosphate fertilizers and its use in agriculture leads to pollution of aquatic system by the metal. Water hyacinth as shown great ability to take up heavy metals such as Cd in its tissues.

Table 4. 3: Heavy metals in water hyacinth (ppm)

SITE	Lead (mean ±SD)	Mercury (mean ±SD)	Cadmium (mean ±SD)
S4	0.637 ± 0.054	ND	0.208 ± 0.216
S5	0.634[a] ± 0.018	ND	0.212 ± 0.018
S6	0.650 ± 0.006[a]	ND	0.222 ± 0.011
S7	0.629 ± 0.042	ND	0.206 ± 0.008
S8	0.665 ± 0.103	ND	0.213 ± 0.016
S9	0.387 ± 0.058	ND	0.192 ± 0.006
S10	0.469 ± 0.137	ND	0.182 ± 0.012
S11	0.468 ± 0.009	ND	0.187 ± 0.020
***WHO**	**2**		**0.2**

Note:

**WHO permissible limits of heavy metals in aquatic plant: Felfet et al 2020*

Means with different superscripts within the rows are significantly different at a 5% level of significance;

ND: Non-detectable levels

SD: Standard Deviation

4.2.4 Mercury (Hg) in water, sediment and water hyacinth

Results of Hg in water, sediment and water hyacinth (Tables 4.1, 4.2 & 4.3) show that Hg was not detected in any sample. Non-detection of Hg to poor solubility of Hg in water (Jabłońska & Kluska, 2020). These results are comparable with those of Mhina (2016) in Lake Victoria, Kenya; attributing low level of Hg to dilution due to rain and sedimentation. The low levels or non-detection of Hg can also be attributed to source factor. Mercury can be emitted naturally through weathering of rocks, volcanic activities as well as from anthropogenic sources such as untreated sewage, industrial waste, domestic waste, waste incineration and medical waste such as in dental amalgams (Verma et al., 2018). From different sources of Hg, certain source such as goldmining is a great contributor of air and aquatic environment pollution by Hg. Artisanal and small-scale goldmining has the largest demand for Hg in the world and their activities release great quantities of Hg into the environment (Soe et al., 2022). There is no known documented information of existence of goldmining in the study area. This also explains low level of Hg below the detectable limits in the Inner Murchison Bay. It is also important to note that Hg was not detected in water hyacinth as well owing to the fact that plants accumulation metals from water or sediment yet in this study mercury was below the detectable level in both water and sediment. During transport, heavy metals can be transformed to different chemical forms. Mercury can be carried by runoff and can bind with organic or inorganic particle. Inorganic Hg can be biodegraded by aerobic or anaerobic bacteria forming Methylmercury through a process called methylation (Lin et al., 2021). MeHg is very toxic and can easily accumulate in fish. The study analysed total Hg, this can be one of the reasons of non-detection of mercury in the study area.

Avoid these spaces

4.3 Assessing variation Pb, Cd and Hg concentration in the Inner Murchison Bay

4.3.1 Variation of Lead (Pb)

4.3.1.1 Lead in water

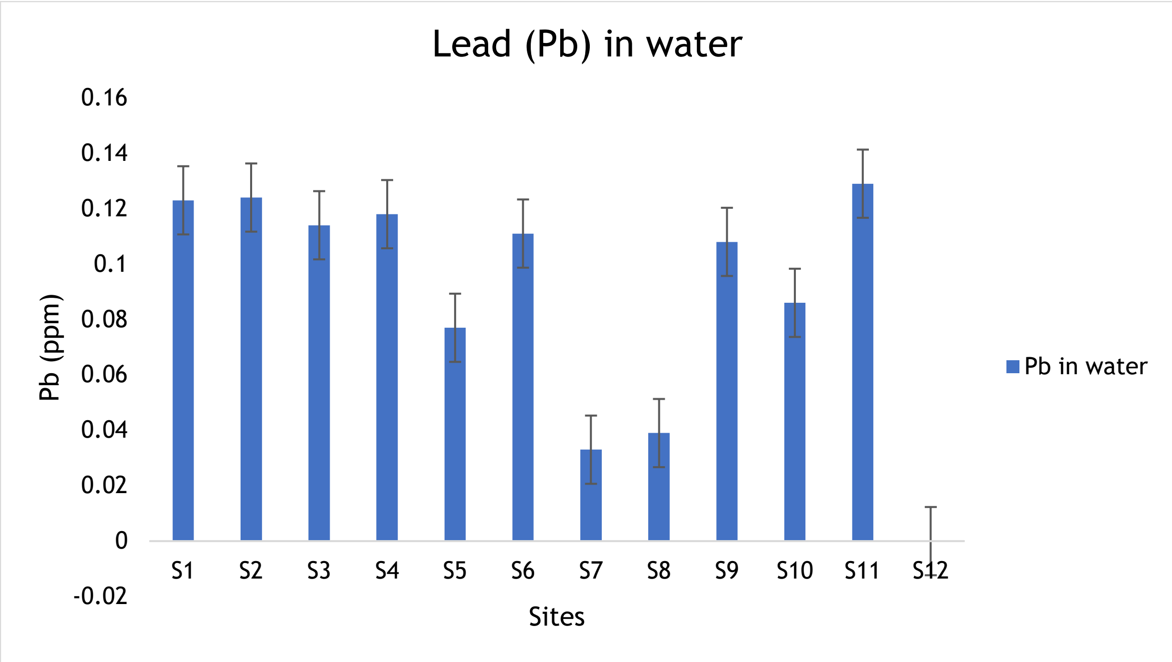

Figure 4. 1: Variation of Pb in water

The highest mean value for Pb (0.129 ± 0.123) in water was found in site located near Port Bell in Luzira(S11) which is the landing site and Port in Luzira (Figure 4.1). The high concentration at this site is probably due to Pb leaking from boat engines that are found at the Port. While the lowest value of Pb (0.033 ± 0.057), was recorded near the wetland (S7). This was as a result of wetland ability to purify runoff and water before reaching the Bay. Hassanzadeh et al. (2021), established that wetland absorb heavy metals thus purifies water. It is important to note that Pb was not detected in water samples at control site (S12). This can be as a result of dilution from the point where pollutant enter the Bay to the control site (S12, Table 4.1), located away from known sources of pollution. S1 and S2 (Ggabba I and II water abstraction point) had Pb probably resulting from runoff that are discharged through channels at Ggaba shoreline, S5 (Kampala University) had relatively low concentration, however its presence at S5 indicates pollution from cars, waste being discharge from the university. The presence of Pb in S6 located near residential are as a result of domestic waste from the residences. S8 was located near the Nakivubo channel discharge point. The concentration of Pb at this site was lower than the concentration of Pb in other sites except S7. The concentration of Pb did not have significant variation across the cross ($p>0.05$). Runoof, wastewater effluent, atmospheric deposition through transport of heavy metals as dust particles greatly contribute to Pb pollution of the Bay (Masindi et al., 2018),

4.3.1.2 Lead in sediment

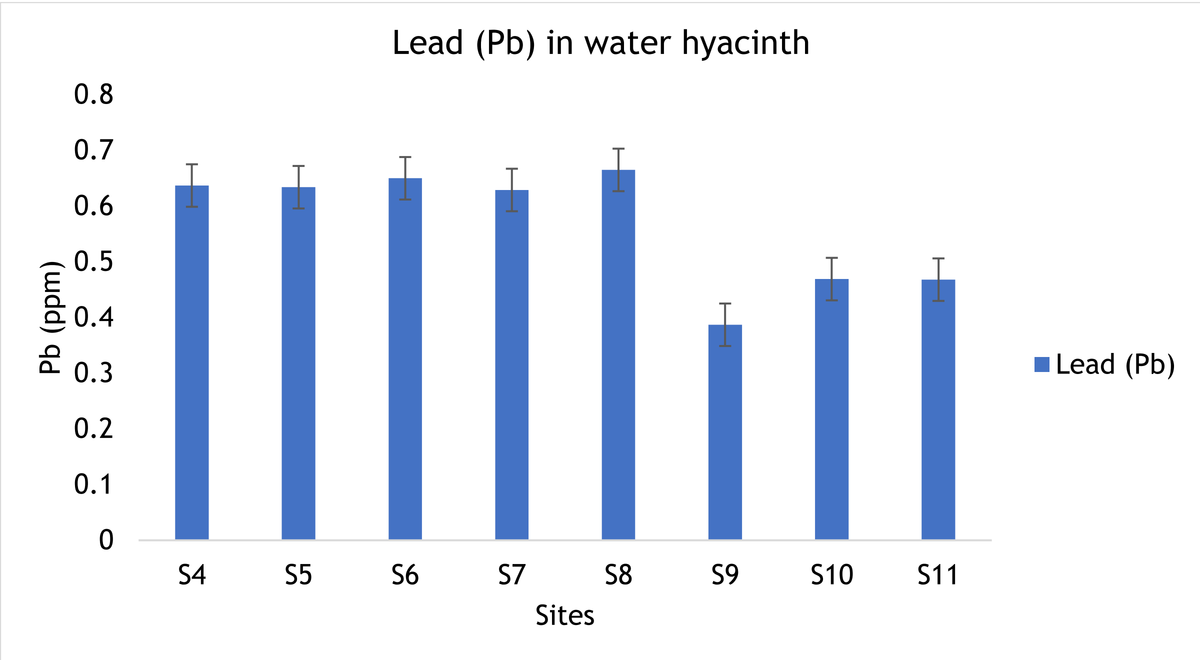

Figure 4. 2: Variation of Pb in sediment

The concentration of Pb in sediment was highest at Ggaba water abstraction point1 (S1) while the lowest (3.357 ± 0.569) was at control site (S12, Figure 4.2). Even though the control site was located away from sources of pollution, the concentration of Pb was significant. This is explained by the insoluble nature of Pb and its non-biodegradability; it thus ends up accumulating on sediment over time. All the sites did not show significant variation of the concentration of PB in sediment ($p>0.05$). Contamination factor (CF) was calculated for sediment at all sampling sites points while the sample in the Control site(S12) was used as the background sample (Appendix7). Contamination Factor results showed values >1 (Table 4.4) indicating moderate level of sediment pollution of the Inner Murchison Bay by Pb. These results indicate that CF should be used as one of the monitoring indices to assess the Bay's sediment quality with metals of interest. Furthermore, the findings indicate that anthropogenic activities result progressive accumulation of heavy metals in sediment the Bay.

Table 4. 4: Contamination factor

Sites	***Contamination factor Pb***
S1	1.56
S2	1.48
S3	1.14
S4	1.48
S5	1.22
S6	1.23
S7	1.22
S8	1.16
S9	1.08
S10	1.08
S11	1.12
Contamination factor (CF)	
Value	**Level**
CF<1	Low degree
CF 1-3	Moderate level
CF 3-6	Considerable level
CF>6	Very high level

4.3.2.1 Cadmium in water

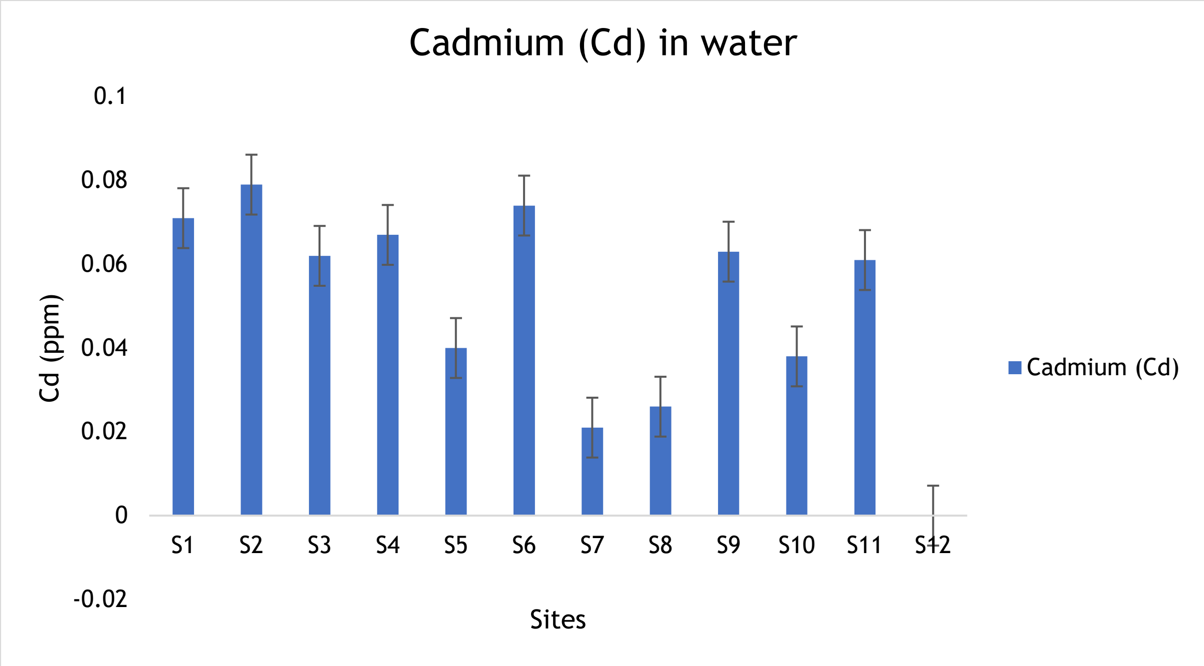

Figure 4. 3: variations of Cd in water

Cd was present in all the sediment samples (Figure 4.3). The highest concentration of Cd was in S2(Ggabba II, abstraction point). Cd in S1 and S2 can be as aresult of galvanized pipes used in water treatment plant. In S3(KK and GGba beach), Cd is as a result of recreational activities. S4 and S11(Ggaba landing site and Port Bell Luzira and landing site) presented the same characteristics of poor waste management in market resulting to Cd pollution of the Bay through runoff and leachate. S5, was located near the university indicating probably the discharge of Cd containing waste into Bay. High concentration of Cd in S6 located near residential areas can be attributed to domestic waste. S9 and S10 showed Cd pollution from Nile breweries activities. S8 (Nakivubo channel) had relatively low concentration of Cd attributing it to metal uptake by plants as well as metal deposit on sediment. The lowest concentration of Cd was at S7 located near the wetland, showed the absorption of Cd by wetland plant. This implies that wetland encroachment severely impacts on the Bay's water quality. The concentration of Cd in water at all sites did not differ significantly ($p>0.05$). The intensity of human activities around a water body influences the concentration of heavy metals such as Cd in lakes (Xia et al., 2020). Several activities are carried out on the shores and the catchment of the IMB, leading to the Bay's pollution by heavy metals.

4.3.2.2 Cadmium in sediment

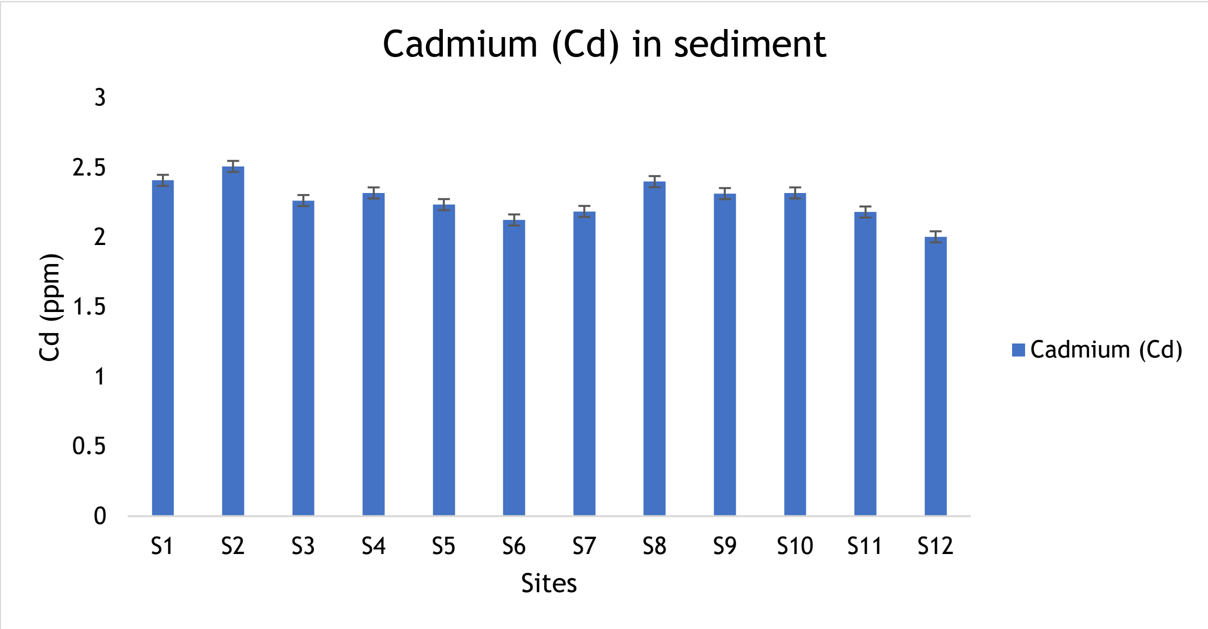

Figure 4. 4: variation of Cd in sediment

Cd was detected in all the sampling sites showing the impacts of anthropogenic activities on the Bay (Figure 4.4), however the concentration of the metal did not have significant variation ($p>0.05$). The high concentration of Cd in sediment is attributed to the insoluble nature of the heavy metal in water and ends up deposited on sediment. The lowest concentration of Cd was at site 12 (Control Site), the presence of Cd was as a result of Cd accumulation on sediment. Contamination Factor (CF) was calculated using the concentration of Cd at the S12 as the background concentration. The values of CF at all sites were greater than 1 (Table 4.5). This means that the sediment of the Inner Murchison Bay is moderately polluted with Cd that is discharges by anthropogenic activities. Sources of Cd include corrosion of galvanized pipes, phosphate fertilizers, waste incineration, fossil fuel burning (Halwani et al., 2020), which are common activities around the Bay.

Table 4. 5: Contamination factor of Cd

Sites	***Contamination factor Cd***
S1	1.20
S2	1.25
S3	1.13
S4	1.16
S5	1.12
S6	1.06
S7	1.09
S8	1.20
S9	1.15
S10	1.16
S11	1.09
Value	
CF<1	Low level
CF 1-3	Moderate level
CF 3-6	Considerable level
CF>6	Very high level

4.3.3 Heavy metals in water and sediment

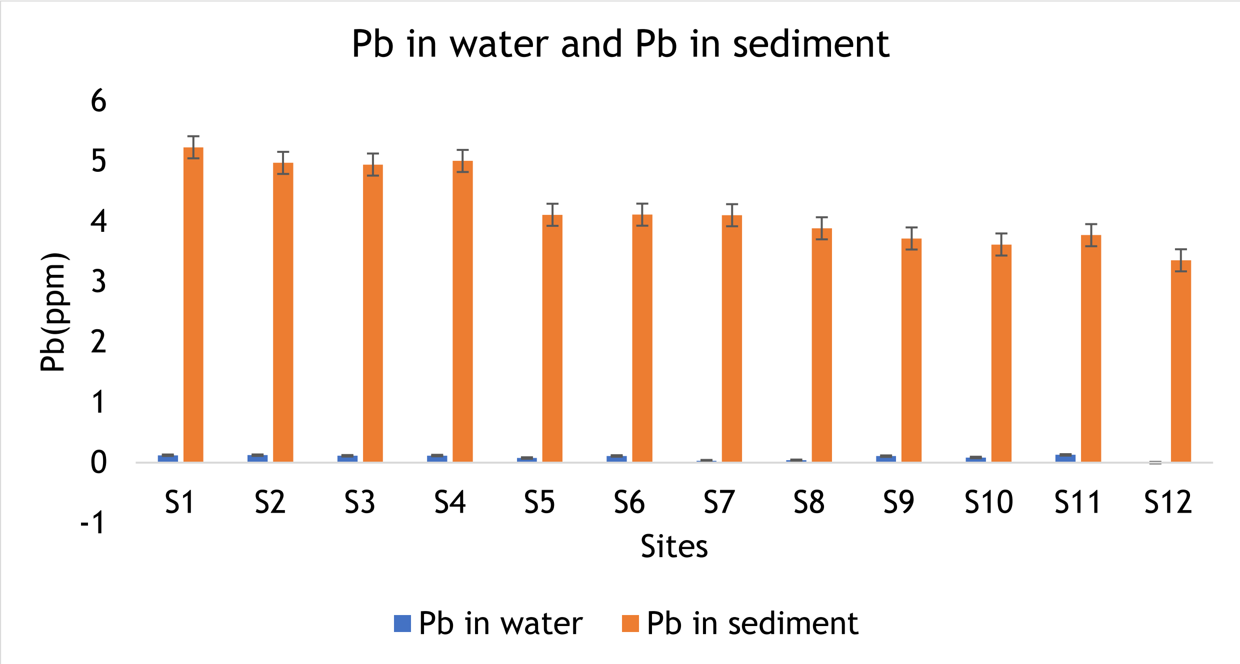

Figure 4. 5: variation of Pb in water and sediment

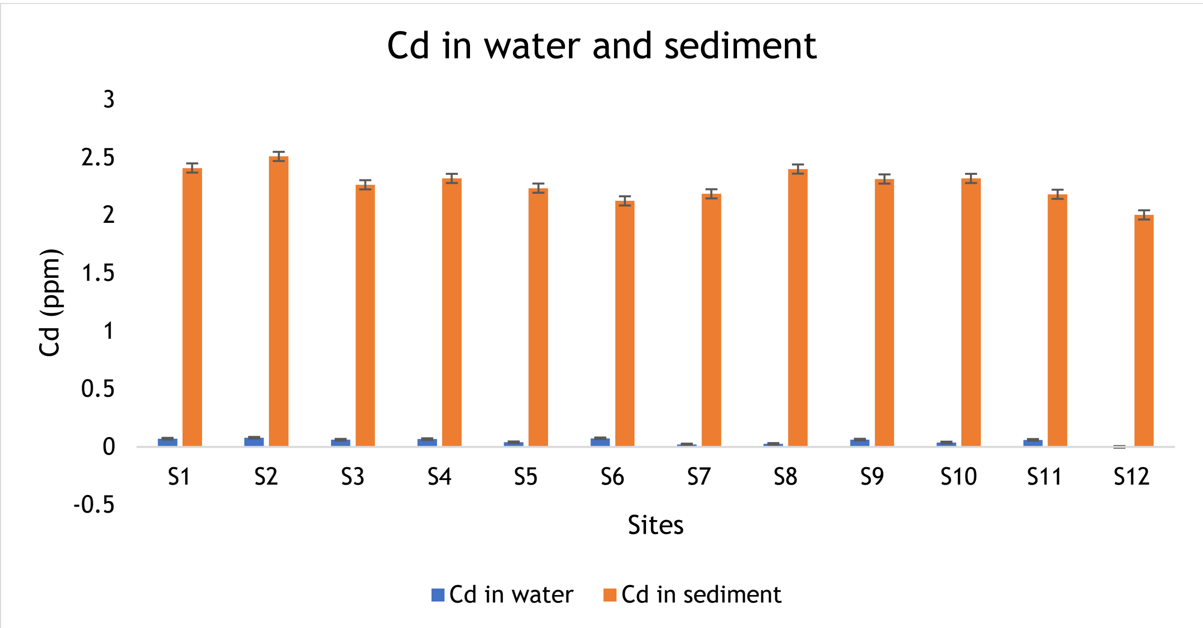

Figure 4. 6: variation of Cd in water and sediment

Concentrations of both Pb and Cd were higher in sediment than in water at all the sampling site (Figure 4.5 and Figure 4.6). There was significant variation between the concentration Pb and Cd in water and sediment ($p<0.05$, Appendix 14,16). Higher concentrations of Pb and Cd in sediment are attributed to the ability of sediment to act as metal sink for metals released from human activities. Most heavy metals that find their way into the aquatic system tend to deposit on sediment and this is due to their ability to bind with organic matter and settle to the bottom of water (Malau et al., 2021). Anthropogenic activities greatly increase the existing levels of heavy metals rendering them toxic to human and wildlife. Pollution of sediment by heavy metal can as well result into secondary pollution of the water column during sediment disturbance or changes in physio-chemical parameters of water thus causing heavy metals to be released in water (Astatkie et al., 2021; Li et al., 2022). Since the findings reported the presence of Pb and Cd in the Inner Murchison Bay's sediment, it is essential to monitor the concentration of heavy metals due to its negative impacts on living organisms leaving in aquatic system. Kumar et al. (2020) noted that heavy metals in sediment negatively impact benthic species through direct contact or feeding habit resulting into accumulation of heavy metals by the organism.

Pollution load index (PLI) was used to assess the quality of sediment of the Inner Murchison Bay and the results are presented in Table 4.6. and Appendix9. PLI values are classified as follow: PLI=0 shows excellent sediment quality, PLI=1 indicates baseline element level and PLI>1 indicates progressive deterioration of sediment quality. From Table 4.6, all the sites have values of PLI>1 for Pb and Cd. This means that the sediment at all sites of the Inner Murchison is in state of the progressive deterioration by Pb and Cd. This is due to gradual increase of activities that release these heavy metals into the Bay. Shah et al. 2020, reported progressive deterioration of sediment quality using PLI thus suggesting close monitoring of sediment quality.

Table 4. 6: pollution load index (PLI)

Sampling sites	*Pollution load index*
Ggaba water abstraction point 1 (S1)	1.34
Ggaba water abstraction point 2 (S2)	1.52
Kk Beach and Ggaba Beach (S3)	1.38
Ggaba landing site (S4)	1.31
Kampala International university (S5)	1.17
Residential area (S7)	1.14
Wetland (S6)	1.15
Nakivubo channel discharge point (S8)	1.38
Nile breweries waste water discharge point (S9)	1.14
Nile breweries water abstraction point (S10)	1.12
Port Bell Luzira landing site (S11)	1.10
Pollution load index (PLI)	
Value	**Level**
PLI=0	Excellent
PLI=1	Baseline
PL>1	Progressive deterioration

4.3.4 heavy metals in water and water hyacinth

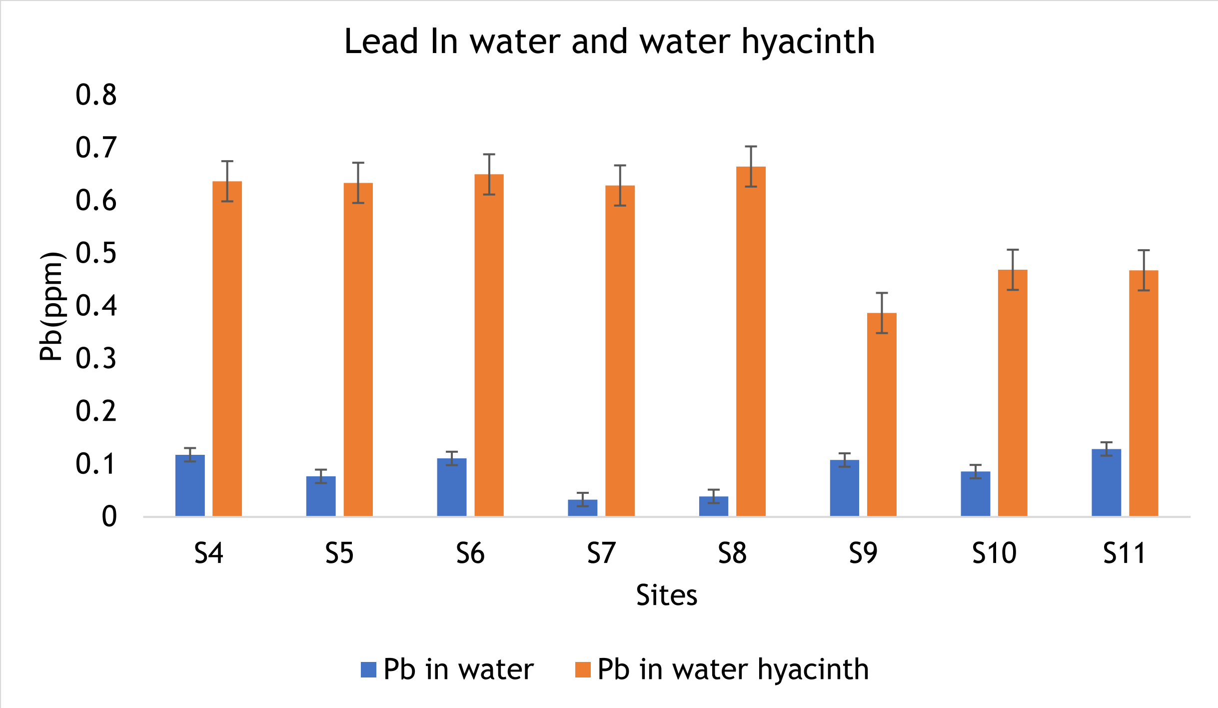

Figure 4. 7: variation of Pb in water and water hyacinth

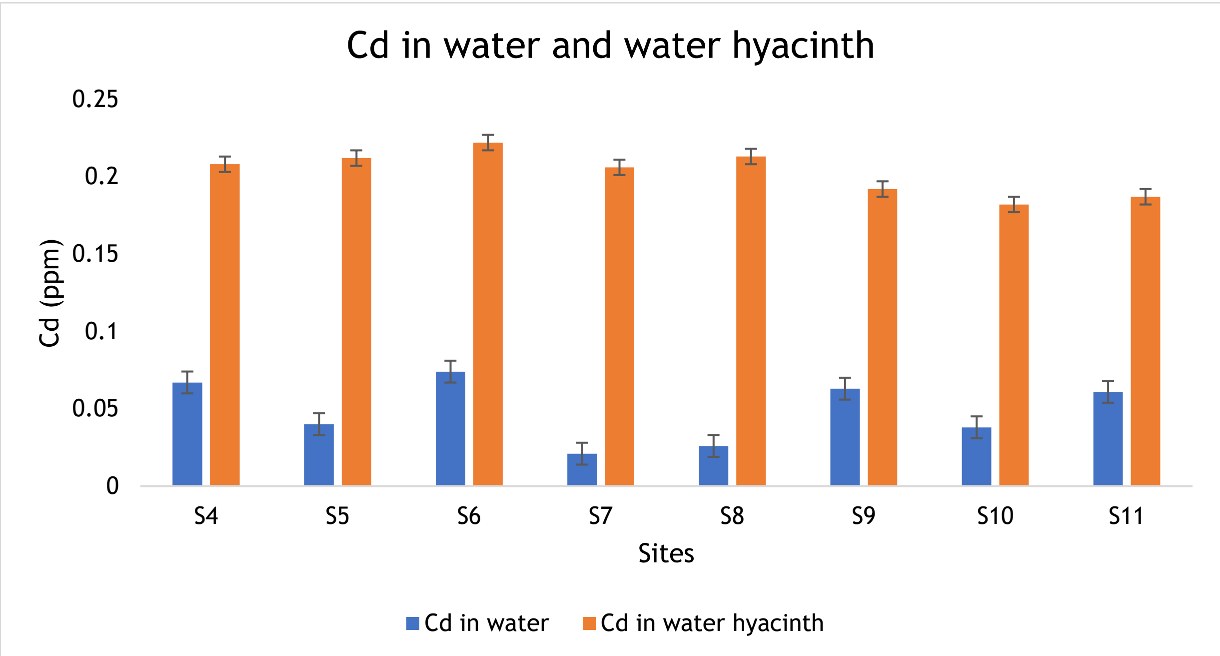

Figure 4. 8: variation of Cd in water and water hyacinth

Cd and Pb were detected in water hyacinth at all the sampling sites (figure 4.7, Figure 4.8). The concentration of Pb and Cd in water hyacinth exceeded the concentration of Pb and Cd at all the sampling points. There was significant variation between the concentration Pb and Cd in water and water hyacinth ($p<0.05$, Appendix 15,17). The findings of this study confirm the uptake of both Cd and Pb by the plant as reported in similar studies (Table 4.8). The presence of Cd and Pb in water hyacinth indicates the ability of the plant to uptake heavy metals. The results affirm the findings of Matindi et al. (2014), in Winam Gulf in Kenya as related to heavy metal uptake by water hyacinth which is also an indicator of deposits of heavy metals in Bay's water from its catchment. Nakivubo channel discharge point (S8) recorded the highest concentration of Pb (0.665 ± 0.103) in water hyacinth and the lowest concentration of the metal (0.039 ± 0.067). This is in agreement with the findings of Huynh et al. (2021), who noted gradual reduction in the concentration of heavy metals from polluted water as the plant grows. Due to the ability of water hyacinths, to take up heavy metals from water, the study suggests the use of the plant to purify water contaminated with heavy metals. The results are comparable with those Matindi et al. (2014) while Salman et al. (2022) reported high concentrations of both Pb and Cd in water hyacinths (Table 4.8). Based on the findings, it is essential to monitor heavy metal concentration in the Bay and water hyacinth can be used as a bioindicator of pollution due to its ability to take up and store heavy metals in its tissues. Water hyacinth is currently being used as fish feed (Prasetyo et al., 2021). Therefore, it is critical to assess the metal uptake by the plan given that it can direct introduce heavy metal into the food chain. Bioconcentration was calculated to affirm the uptake of Cd and Pb by water hyacinth.

Table 4. 7: Bioconcentration factor (BF)

SITES	*Pb*	*Cd*
Ggaba landing site (S4)	5.39	3.10
Kampala International university (S5)	8.23	5.3
Wetland (S6)	5.86	2.78
Residential area (S7)	19.06	10.57
Nakivubo wetland (S8)	17.05	8.19
Nile breweries waste water discharge point	3.58	3.05
Nile breweries waste water discharge point	4.76	4.79
Port Bell Luzira landing site (S11)	3.63	3.07

The bioconcentration factor (BCF) was calculated as the ratio of heavy metals concentration in plant's tissue relative to its concentration in water. Values of BCF<1 indicate that the plants excluded the element from uptake, BCF value of 1 show that the plant is not influenced by the particular metal and BCF>1 indicates that the plant takes up more heavy metal compared to what they excrete resulting to increase of the concentration of the metal in the plant. The calculated values of BCF for Pb and Cd in water hyacinth are presented in Table 4.7. The values of BCF for Pb and Cd at all sampling points were >1. This signifies that water hyacinth has ability to accumulate Pb and Cd in their tissues from water. Thus, at all the sampling sites the values of Pb and Cd in water hyacinth were greater than values Pb and Cd in water. Zhou et al. (2020), reported BCF greater than one (BCF>1), establishing that water hyacinth takes up accumulate heavy metals such Pb and Cd among others.

Table 4. 8: Comparison of heavy metal concentration in water hyacinth

Concentration of Pb and Cd in this study (ppm)	Concentration of Pb and Cd in previous studies (ppm)	References
Pb: 0.387- 0.650 **Cd: 0.182-0.222**	Pb: 0.046-0.263 Cd: 0.0049- 0.1300	Matindi et al 2014, Kenya
	Pb: 23.3-64.2 Cd: 3.28-9.06	Salaman et al 2022,Trigris River.
	Pb: 0.95-1.41 Pb: 0.00 - 0.14	Olutona et al 2011, Nigeria
	Pb: 36.4 Cd: 0.52	Kisamo 2003, Tanzania

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The results of this study demonstrate the presence of Pb and Cd in the water, sediment, and water hyacinth of Inner Murchison Bay while describing the pollution loading sources of the Inner Murchison Bay. In contrast, Hg levels in the samples were below detectable levels. The study shows the need to continuous monitoring of the Bay’s state raising concern about heavy metal contamination of the Bay. Furthermore, the findings provide a snapshot of the Bay's current state, based on the pollution loading sources that pollute the Bay.

The Inner Murchison Bay is therefore contaminated with Pb and Cd, and the levels of these heavy metals are higher than the WHO and NEMA/EAC-permitted limits. Heavy metal pollution of the Inner Murchison Bay water, is attributed to the activities in the catchment which include; littering and dumping waste, sewage discharge into the lake, industrial effluent discharge, pollution of stream that discharges into the lake, among others. However, it is important to note that water pollution will eventually lead to high cost of water treatment given that the Inner Murchison Bay is the extraction point of water that is supplied to Kampala and metropolitan areas.

Furthermore, this study has affirmed that heavy metals deposit on sediment thus the concentration of heavy metals was higher in sediment than in water and water hyacinth. This is a result of heavy metals being insoluble in water and settling onto the sediment. Based on the sediment assessment indices: Contamination Factor and Pollution Load Index; sediment of the Inner Murchison Bay is moderately polluted by Pb and Cd. As indicated in the previous chapter, sediment pollution can lead to a secondary pollution of water but also affect benthic species that are in direct contact with the contaminated sediment.

The study findings also confirm the capacity of water hyacinth to take up heavy metals from water and store in its tissues (BCF>1). The results clearly indicate the presence of Pb and Cd in water hyacinth of the Inner Murchison Bay. Based on the fact that water hyacinth takes up heavy metals, the plant can be used as indicator of pollution in Inner Murchison Bay of Lake Victoria.

5.2 Recommendations

Based on the findings of this study, it is recommended that:

I. Regular monitoring of heavy metals in the lake should be done in order to know the state of the aquatic system that is a resource to millions of people.
II. Dumping wastes and anthropogenic activities such as recreational activities, garage and car washing locations should be regulated in the catchment and near the shores of the Inner Murchison Bay. Solid waste should be disposed in designated areas far from the aquatic system.
III. Studies should be carried in the Inner Murchison Bay to determine the concentration of heavy metals other than Pb, Hg and Cd. In addition, future studies should determine the concentration of heavy metals and assess their accumulation in tissues of fish that are caught from the Inner Murchison Bay to investigate if fish in this area is free from harmful substances assess the biomagnification of heavy metals along the food chain.
IV. Further studies to be carried out in dry season.
V. Industrial effluent released into channels that are drained into the lake should be treated and abide by the effluent discharge guidelines.
VI. Prevent encroachment and destruction of the wetland around the Inner Murchison Bay since wetlands play crucial role in absorbing heavy metal thus purifying water that reaches the lake.
VII. Agricultural activities should be regulated in the areas surrounding the lake as well as the used of fertilizers, pesticides and herbicides should be regulated.

VIII. Further studies on water hyacinth capacity to absorb heavy metals should be carried out. This will help in improving water treatment techniques regarding heavy metals.

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Appendices

Appendix: 1: Lead in water samples T-test

Paired Samples Test									
		Paired Differences					T	df	Sig. (2-tailed)
		Mean	SD	Std. Error	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	S1: Pb -S2: Pb	-.0006	.006	.0038	-.0172	.015	-.173	2	.878
Pair 2	SITE 2: Lead in water -	.0100	.012	.0072	-.0210	.041	1.387	2	.300

	site3: Lead in water								
Pair 4	site4: Lead in water - site5: Lead in water	.0413	.053	.031	-.092	.175	1.328	2	.315
Pair 5	site5: Lead in water - site6: Lead in water	-.0346	.053	.030	-.166	.097	-1.130	2	.376
Pair 6	site6: Lead in water - site7: Lead in water	.078	.070	.040	-.097	.253	1.919	2	.195
Pair 7	site7: Lead in water -	-.005	.009	.005	-.030	.018	-1.000	2	.423

	site8: Lead in water								
Pair 8	site8: Lead in water - site9: Lead in water	-.069	.056	.032	-.208	.070	-2.141	2	.166
Pair 9	site9: Lead in water - site10: Lead in water	.021	.038	.022	-.073	.117	.975	2	.433
Pair 10	site10: Lead in water - site11: Lead in water	.005	.032	.019	-.076	.086	.263	2	.817
Pair 11	site11: Lead in water -	.081	.0424	.0245	-.024	.186	3.316	2	.080

	site12: Lead in water								

Appendix: 2:. Cadmium in water samples T-test

Paired Samples Test									
		Paired Differences					T	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	site1:Cd in water - site2: Cd in water	-.007	.002	.001	-.013	-.001	-5.75	2	.029
Pair 2	site2: Cd in water - site3: Cd in water	.016	.002	.001	.009	.023	9.80	2	.010
Pair 3	site3: Cd in water - site4: Cd in water	-.004	.000	.000	-.006	-.003	-14.00	2	.005

Pair 4	site4: Cd in water - site5: Cd in water	.027	.027	.016	-.041	.095	1.688	2	.234
Pair 5	site5: Cd in water - site6: Cd in water	-.033	.040	.023	-.135	.068	-1.423	2	.291
Pair 6	site6: Cd in water - site7: Cd in water	.052	.0308	.017	-.024	.128	2.937	2	.099
Pair 7	site7: Cd in water - site8: Cd in water	-.004	.007	.004	-.022	.014	-1.000	2	.423
Pair 8	site8: Cd in water - site9: Cd in water	-.037	.032	.018	-.119	.043	-1.989	2	.185

Pair 9	site9: Cd in water - site10: Cd in water	.024	.0453	.026	-.087	.137	.943	2	.445
Pair 10	site10: Cd in water - site11: Cd in water	-.004	.004	.002	-.014	.005	-2.000	2	.184
Pair 11	site11: Cd in water - site12: Cd in water	.043	.037	.021	-.050	.137	1.989	2	.185

Appendix: 3:: Lead in sediment T-test

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	site1: pb in sediment - site12: Pb in sediment	1.875	.546	.315	.518	3.231	5.948	2	.027
Pair 2	site2: pb in sediment - site12: Pb in sediment	1.616	.495	.286	.385	2.847	5.650	2	.030
Pair 3	site3: pb in sediment - site12: Pb in sediment	1.588	.279	.161	.894	2.281	9.858	2	.010

Pair 4	site4: Pb in sediment - site12: Pb in sediment	1.648	.660	.381	.008	3.287	4.325	2	.050
Pair 5	site5: Pb in sediment - site12: Pb in sediment	.755	1.106	.638	-1.992	3.502	1.182	2	.359
Pair 6	site6: Pb in sediment - site12: Pb in sediment	.757	1.086	.627	-1.940	3.454	1.207	2	.351
Pair 7	site7: Pb in sediment - site12: Pb in sediment	.748000	.187928	.108500	.281161	1.214839	6.894	2	.020
Pair 8	site8: Pb in sediment - site12: Pb in sediment	.531	.744	.429	-1.317	2.379	1.236	2	.342

Pair 9	site9: Pb in sediment - site12: Pb in sediment	.664	1.001	.577	-1.822	3.150	1.149	2	.369
Pair 10	site10: Pb in sediment - site12: Pb in sediment	.200	.491	.283	-1.021	1.422	.705	2	.554
Pair 11	site11: Pb in sediment - site12: Pb in sediment	.417	.1150	.066	.131	.702	6.281	2	.024

Appendix: 4: Cadmium in sediment T-test

Paired Samples Test										
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	site1: pb in sediment - site12: Pb in sediment	1.875	.546	.315	.518	3.231	5.948	2	.027
Pair 2	site2: pb in sediment - site12: Pb in sediment	1.616	.495	.286	.385	2.847	5.650	2	.030
Pair 3	site3: pb in sediment - site12: Pb in sediment	1.588	.279	.161	.894	2.281	9.858	2	.010

Pair 4	site4: Pb in sediment - site12: Pb in sediment	1.648	.660	.381	.008	3.287	4.325	2	.050
Pair 5	site5: Pb in sediment - site12: Pb in sediment	.755	1.106	.638	-1.992	3.502	1.182	2	.359
Pair 6	site6: Pb in sediment - site12: Pb in sediment	.757	1.086	.627	-1.940	3.454	1.207	2	.351
Pair 7	site7: Pb in sediment - site12: Pb in sediment	.748000	.187928	.108500	.281161	1.214839	6.894	2	.020
Pair 8	site8: Pb in sediment - site12: Pb in sediment	.531	.744	.429	-1.317	2.379	1.236	2	.342

Pair 9	site9: Pb in sediment - site12: Pb in sediment	.664	1.001	.577	-1.822	3.150	1.149	2	.369
Pair 10	site10: Pb in sediment - site12: Pb in sediment	.200	.491	.283	-1.021	1.422	.705	2	.554
Pair 11	site11: Pb in sediment - site12: Pb in sediment	.417	.1150	.066	.131	.702	6.281	2	.024

Appendix: 5: Lead (Pb) in water hyacinth T-Test

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	site4: Pb in plant - site5: Pb in plant	-.013	.063	.036	-.171	.144	-.372	2	.745
Pair 2	site5: Pb in plant - site6: Pb in plant	-.024	.003	.002	-.033	-.015	-12.166	2	.007

Pair 3	site6: Pb in plant - site7: Pb in plant	.055	.020	.011	.004	.107	4.648	2	.043
Pair 4	site7: Pb in plant - site8: Pb in plant	-.010	.166502	.096130	-.423615	.403615	-.104	2	.927
Pair 5	site8: Pb in plant - site9: Pb in plant	.226	.206	.119	-.286	.739	1.898	2	.198
Pair 6	site9: Pb in plant - site10: Pb in plant	-.082	.173	.100	-.514	.349	-.820	2	.499
Pair 7	site10: Pb in plant - site11: Pb in plant	.001	.132	.076	-.328	.330	.013	2	.991

Pair 8	site11: Pb in plant - site4: Pb in plant	-.152	.054	.031466	-.287	-.016	-4.841	2	.040

Appendix: 6: Cadmium of water hyacinth samples T-Test.

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	site4: Cd in plant - site5: Cd in plant	-.003	.004041	.002	-.013	.006	-1.571	2	.257
Pair 2	site5: Cd in plant - site6: Cd in plant	.005333	.028	.016	-.064	.075	.327	2	.775

Pair 3	site6: Cd in plant - site7: Cd in plant	-.016	.019	.011	-.063	.031	-1.455	2	.283
Pair 4	site7: Cd in plant - site8: Cd in plant	.030	.030	.017	-.045	.106	1.735	2	.225
Pair 5	site8: Cd in plant - site9: Cd in plant	-.003	.028	.016	-.070	.069	-.020	2	.986
Pair 6	site9: Cd in plant - site10: Cd in plant	.010	.006	.003	-.005	.026	2.818	2	.106
Pair 7	site10: Cd in plant -	-.005	.032909	.019	-.086	.076	-.263	2	.817

	site11: Cd in plant								
Pair 8	site11: Cd in plant - site4: Cd in plant	-.021	.042	.024	-.126	.083	-.876	2	.473

Appendix: 7: Contamination Factor of Pb in sediment calculated using Excel

contamination factor: Lead (Pb)		
S1	5.232	1.558
S2	4.973	1.481
S3	4.945	1.473
S4	5.005	1.490
S5	4.112	1.224
S6	4.114	1.225
S7	4.105	1.222
S8	3.888	1.158
S9	3.719	1.107
S10	3.619	1.078
S11	3.774	1.124
S12	3.357	1

Appendix: 8:: Contamination Factor of Cd in sediment calculated using Excel.

contamination factor: Cadmium (Cd)		
S1	2.405	1.200
S2	2.509	1.251
S3	2.264	1.129
S4	2.319	1.157
S5	2.235	1.115
S6	2.125	1.060
S7	2.186	1.090
S8	2.4	1.197
S9	2.314	1.154
S10	2.319	1.157
S11	2.182	1.088
S12	2.004	1

Appendix: 9:: Pollution Load index of Pb and Cd in sediment calculated using Excel

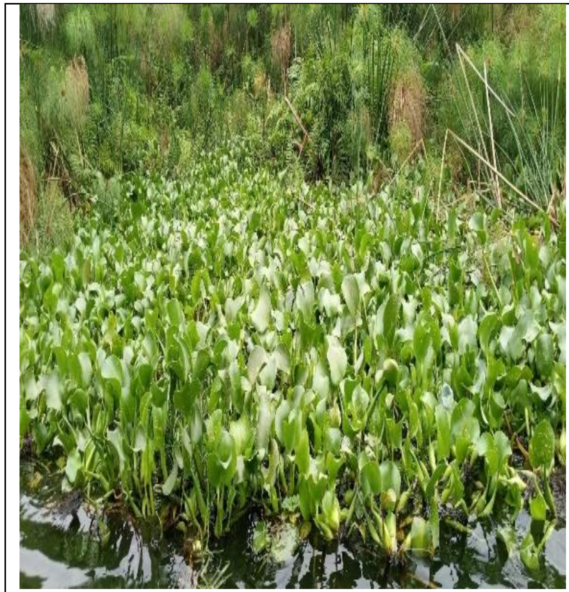
Pollution load index			
	Contamination Factor: Pb	Contamination Factor: Cd	Pollution Load index
S1	1.558	1.200	1.367
S2	1.481	1.251	1.361
S3	1.473	1.129	1.290
S4	1.490	1.157	1.313
S5	1.224	1.115	1.168
S6	1.225	1.060	1.139
S7	1.222	1.090	1.154
S8	1.158	1.197	1.177
S9	1.107	1.154	1.131
S10	1.078	1.157	1.116
S11	1.124	1.088	1.106
S12	1	1	1

Appendix: 10:: Bioconcentration Factor of Pb and Cd in water hyacinth calculated using Excel.

Bioconcentration Factor (BCF)			
SITES	Pb means of water hyacinth	Pb means of water	BCF values
S4	0.637	0.118	5.398
S5	0.634	0.077	8.233
S6	0.65	0.111	5.855
S7	0.629	0.033	19.060
S8	0.665	0.039	17.051
S9	0.387	0.108	3.583
S10	0.469	0.086	5.453
S11	0.468	0.129	3.627
Bioconcentration Factor (BCF)			
SITES	Cd means of water hyacinth	Cd means of water	BCF values
S4	0.208	0.067	3.104
S5	0.212	0.04	5.3

S6	0.222	0.074	3
S7	0.206	0.021	9.809
S8	0.213	0.026	8.192
S9	0.192	0.063	3.047
S10	0.182	0.038	4.789
S11	0.187	0.061	3.065

Appendix: 11: water hyacinth at the shores of the Inner Murchison Bay	*Appendix: 12: Ggaba landing site and Market on the shores of the Inner Murchison Bay*



Appendix: 13: Ggaba water abstraction point	Appendix: 14: Atomic Absorption Photo spectrometer
	
	s

Appendix 15. variation among sites.

Sites	Water	Sediment	Water hyacinth
S1-S2	0.878	0.012	-
S2-S3	0.300	0.920	-
S3-S4	0.221	0.922	-
S4-S5	0.315	0.074	0.745
S5-S6	0.376	0.878	0.007
S6-S7	0.195	0.991	0.043
S7-S8	0.423	0.720	0.927
S8-S9	0.166	0.907	0.198
S9-S10	0.433	0.290	0.499
S10-S11	0.817	0.433	0.991
S11-12	0.080	0.024	-

Appendix 16. Cd water and sediment T-test

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	site1:Cadmium in water - site1: Cd in sediment	-2.333667	.177652	.102568	-2.774979	-1.892354	-22.752	2	.002
Pair 2	site2: Cd in water - site2: Cd in sediment	-2.430667	.246812	.142497	-3.043783	-1.817551	-17.058	2	.003
Pair 3	site3: Cd in water - site3: Cd in sediment	-2.201667	.059652	.034440	-2.349850	-2.053483	-63.928	2	.000
Pair 4	site4: Cd in water - site4: Cd in sediment	-2.252000	.083289	.048087	-2.458900	-2.045100	-46.832	2	.000
Pair 5	site5: Cd in water - site5: Cd in sediment	-2.195333	.051287	.029610	-2.322737	-2.067930	-74.141	2	.000
Pair 6	site6: Cd in water - site6: Cd in sediment	-2.051000	.116632	.067337	-2.340730	-1.761270	-30.459	2	.001

Pair 7	site7: Cd in water - site7: Cd in sediment	-2.164333	.052596	.030366	-2.294989	-2.033678	-71.274	2	.000
Pair 8	site8: Cd in water - site8: Cd in sediment	-2.374667	.215533	.124438	-2.910080	-1.839254	-19.083	2	.003
Pair 9	site9: Cd in water - site9: Cd in sediment	-2.190000	.179733	.103769	-2.636482	-1.743518	-21.105	2	.002
Pair 10	site10: Cd in water - site10: Cd in sediment	-2.293000	.060357	.034847	-2.442936	-2.143064	-65.801	2	.000
Pair 11	site11: Cd in water - site11: Cd in sediment	-2.139000	.079076	.045654	-2.335435	-1.942565	-46.852	2	.000

Appendix 17. Cd in water and water hyacinth T-test

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	site4: Cd in water - site4: Cd in plant	-.141000	.028931	.016703	-.212868	-.069132	-8.441	2	.014
Pair 2	site5: Cd in water - site5: Cd in plant	-.171667	.052444	.030278	-.301944	-.041389	-5.670	2	.030
Pair 3	site6: Cd in water - site6: Cd in plant	-.132667	.017616	.010171	-.176428	-.088905	-13.044	2	.006
Pair 4	site7: Cd in water - site7: Cd in plant	-.201000	.028583	.016503	-.272005	-.129995	-12.180	2	.007
Pair 5	site8: Cd in water - site8: Cd in plant	-.166000	.066686	.038501	-.331657	-.000343	-4.312	2	.050
Pair 6	site9: Cd in water - site9: Cd in plant	-.128667	.006506	.003756	-.144829	-.112504	-34.252	2	.001

Pair 7	site10: Cd in water - site10: Cd in plant	-.143000	.046033	.026577	-.257351	-.028649	-5.381	2	.033
Pair 8	site11: Cd in water - site11: Cd in plant	-.143333	.017388	.010039	-.186527	-.100140	-14.278	2	.005

Appendix 18. Pb in water and sediment T-test

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	SITE 1: Lead in water - site1: pb in sediment	-5.108667	.552592	.319039	-6.481382	-3.735951	-16.013	2	.004
Pair 2	SITE 2: Lead in water - site2: pb in sediment	-4.849333	.507697	.293119	-6.110523	-3.588144	-16.544	2	.004
Pair 3	site3: Lead in water - site3: pb in sediment	-4.831000	.288255	.166424	-5.547065	-4.114935	-29.028	2	.001
Pair 4	site4: Lead in water - site4: Pb in sediment	-4.887000	.651113	.375920	-6.504454	-3.269546	-13.000	2	.006
Pair 5	site5: Lead in water - site5: Pb in sediment	-4.035333	1.045875	.603836	-6.633431	-1.437236	-6.683	2	.022
Pair 6	site6: Lead in water - site6: Pb in sediment	-4.002667	1.071501	.618631	-6.664423	-1.340911	-6.470	2	.023

Pair 7	site7: Lead in water - site7: Pb in sediment	-4.072000	.130771	.075501	-4.396853	-3.747147	-53.933	2	.000
Pair 8	site8: Lead in water - site8: Pb in sediment	-3.849333	.802699	.463438	-5.843348	-1.855319	-8.306	2	.014
Pair 9	site9: Lead in water - site9: Pb in sediment	-3.913000	.994564	.574212	-6.383633	-1.442367	-6.815	2	.021
Pair 10	site10: Lead in water - site10: Pb in sediment	-3.470767	.511438	.295279	-4.741250	-2.200284	-11.754	2	.007
Pair 11	site11: Lead in water - site11: Pb in sediment	-3.692667	.107072	.061818	-3.958647	-3.426686	-59.735	2	.000

Appendix 19. Pb in water and water hyacinth

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	site4: Lead in water - site4: Pb in plant	-.502333	.056297	.032503	-.642182	-.362484	-15.455	2	.004
Pair 2	site5: Lead in water - site5: Pb in plant	-.557333	.083345	.048119	-.764373	-.350294	-11.582	2	.007
Pair 3	site6: Lead in water - site6: Pb in plant	-.547333	.031342	.018095	-.625192	-.469475	-30.247	2	.001
Pair 4	site7: Lead in water - site7: Pb in plant	-.570000	.060655	.035019	-.720675	-.419325	-16.277	2	.004
Pair 5	site8: Lead in water - site8: Pb in plant	-.574333	.230817	.133262	-1.147714	-.000953	-4.310	2	.050
Pair 6	site9: Lead in water - site9: Pb in plant	-.278667	.065919	.038058	-.442419	-.114914	-7.322	2	.018

Pair 7	site10: Lead in water - site10: Pb in plant	-.382667	.126469	.073017	-.696832	-.068501	-5.241	2	.035
Pair 8	site11: Lead in water - site11: Pb in plant	-.386667	.037528	.021667	-.479891	-.293443	-17.846	2	.003

Appendix 20: Approval letter

UGANDA CHRISTIAN UNIVERSITY

A Centre of Excellence in the Heart of Africa

FACULTY OF ENGINEERING, DESIGN AND TECHNOLOGY

September, 7th 2023

Dear Sir/Madam,

Presentation of Zawadi Lokuni Rosette (RM21M45/004) results to Postgraduate Board

I hereby certify that I have been the main academic supervisor for Zawadi Lokuni Rosette (RM21M45/004) who has successfully carried out and completed the study titled *Assessment of heavy metal pollution in the Inner Murchison Bay, Lake Victoria.*
Rosette's work has been examined internally, externally and also through oral defence with pass marks. The work is officially ready for presentation to Postgraduate Board. I am presently away on UCU official duties, unable to append a physical signature on Rosette's thesis; this will be done as soon as l am back.

Based on all the above, l authorize the Faculty of Engineering, Design and Technology to present Zawadi Lokuni Rosette (RM21M45/004) to the Postgraduate Board.

Yours sincerely,

S. Kizza-Nkambwe (PhD)
Associate Professor
Faculty of Engineering, Design and Technology
Uganda Christian University, Mukono
Tel +256-0312350-830
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UGANDA CHRISTIAN UNIVERSITY

DIRECTORATE OF POSTGRADUATE STUDIES

DISSERTATION CORRECTION COMPLIANCE REPORT BY THE CANDIDATE (POST VIVA FORM)

Date: 8th 09/2023

Name of Candidate: ZAWADI LOKUNI ROSETTE Reg. No: RM21M45/004

Title of Dissertation: ASSESSMENT OF HEAVY METAL CONCENTRATION IN WATER, SEDIMENT AND WATER HYACINTH OF THE INNER MURCHISON BAY, LAKE VICTORIA

1

SN	COMMENTS BY EXTERNAL EXAMINERS	ACTION TAKEN	INDICATOR
1	The background makes a good case for the problem statement. However, the problem statement does not highlight the gaps in scholarly literature which the study aims to contribute to addressing. The conceptual framework is disconnected from the objective statement. Whereas the aim and objectives point to an exploratory study, the conceptual framework presents an explanatory study.	The gap was highlighted in the problem statement	Page 3 and 4
2	There are many references that have been consulted, most of which were published in the past five years. Most of the literature is related to the Lake Victoria Basin. It would have been useful to provide more evidence from other contexts. The literature could be better analysed and discussed, e.g. by carrying out a comparative analysis. The chapter should be concluded with a short sub-section showing the research gaps that the study contributes to, which then links to the next section on 'Methodology'.	Literature from contexts other than Lake Victoria were provided. A subsection was provided as a conclusion then links to the methodology section	Pages 17 and 19
3	Not so sure that you applied a cross-sectional study design for your research. How did you select the control site	A cross-sectional design gathers data from a given population at a specified point in time thus adapted for the study to provide baseline information that can be used for monitoring and further studies.	Page 21-23 Page 25

2

		The control site was selected in an area known to have negligible anthropogenic activities within the study area.	
4	How many samples did you collect for each site? How did you decide on the time to carry out sampling? It would have been useful to state in details measures taken as part of the quality control, to ensure validity and reliability of experimental data.	3 samples were collected from each site. The time for carrying out sampling was based on time allocated for research with recommendation of further studies to be carried out in dry season. Measures taken as part of quality control have been stated in the write up.	Page 25
5	It is stated that 'the concentration of Pb in all the water samples was relatively low' (Tables 4.1 & 4.2). The same applies to Cd levels. Relative to what standards, given the standards you apply (WHO and US EPA) both show that some samples showed higher concentrations? Please justify these statements.	The statement has been corrected in the write up.	Page 33
6	The results shown in Tables 4.1 and 4.2 with 'different subscripts within the rows' have not been adequately explained. Is the variation being tested for samples at the same site - not clear. We have not been told how many samples were drawn from each site, and if they were drawn at different times	The subscript indicated variation tested among sites. 3 samples were withdrawn from each site at an interval of a week, to ensure that laboratory analysis was done adequately.	Page 33, 88 Page 25

3

7	In Table 4.2, the Control had significant levels of Pb and Cd. This has not been adequately explained. What are the references for the rating of CF and PLI values?	Significant levels of Pb and Cd in the control sample has been explained in the write up. The references for CF and PLI were provided in the write up.	Page 36
8	Chapter 4 combined both results and discussion. However, there was inadequate discussion with respect to studies conducted in similar contexts and the overall body of knowledge	Literature was provided in the write up to ensure adequate discussion	Page 33, 34, 37, 38
9	The Conclusion should explicitly show how the study has contributed to the body of knowledge. What are the implications of the study on policy and practice? The conclusion should also provide a self evaluation of the whole research process	The implications of the study were given in the write up.	Page 56
10	The recommendations are rather too generic - some of them are not derived directly from the results of the study.	Recommendations were provided in the write up based on the study results.	Page 57
11	The dissertation is well written. However, the report could have been better structured, in terms of presentation of tables in the Appendices, starting new chapters on new pages etc.	Tables and new chapters were organized in the write up.	Overall dissertation

SN	COMMENTS BY INTERNAL EXAMINERS	ACTION TAKEN	INDICATOR
1	The abstract summarises the impact of heavy metals (Lead and Cadmium), but does not indicate the origin of the heavy metals in Lake Victoria. Generally, a paragraph or two about the origin of the heavy metals, sediments and water hyacinth is needed	The origin of heavy metals in Lake Victoria were indicated in the abstract.	Abstract
2	"Results showed that the concentration of Pb and Cd in water was above the permissible limits set by WHO and USEPA in most sites. In sediment, Pb and Cd had no significant difference in most sites compared to the control site ($p>0.05$)". From the above statement, what are those permissible limits? Is the value of Pb and Cd in sediment permissible, even if there's no significant difference?	The permissible values for Pb and Cd were indicated in the abstract. The values of Pb and Cd were permissible as per the sediment assessment guidelines.	Abstract
3	The problem statement indicates Pb (Lead), Cd (Cadmium) and Cr (Chromium) as the heavy metals found in soil and plants beyond recommended thresholds, but further the study only looks at	The study scope was limited to Pb, Hg and Cd. And further study was suggested on other heavy metals	Page 51

	Pb (Lead), Cd (Cadmium) and Hg (Mercury)...why was Cr left out in the study?		
4	Since the study was specific on the kind of heavy metals to be considered...its prudent to specify these heavy metals (i.e. Pb, Cr, & Hg) in the specific objectives and research questions	Pb, Cd and Hg were specified in specific objectives and research questions.	Pages 4,5
5	Scope of the study indicates a rainy period only for sample collection......Didn't this affect the concentrations of the heavy metals under study...since samples could be over diluted during the rainy season? Comparison of samples from both rainy and dry seasons could provide more results for better analysis, and possibly also proof about weather-induced concentration of heavy metals pollution	Further study in dry season was recommended.	Page 57
6	Under the conceptual framework, there's need to show the control variables (e.g. entry of heavy metals to land and water bodies), mediating variables (e.g. up take of heavy metals by plants from soils and aquatic life) and monitoring variables (e.g. leaching of heavy metals from the soils and pollution of water sources).	All the variables have been included in the conceptual framework.	Page 7
7	There is need to understand the mechanism of action for heavy metals based on the toxic mechanism of heavy metals functions in similar pathways usually via reactive oxygen species (ROS) generation, enzyme inactivation, and	Literature was provided on heavy metals and restricted to heavy metals in bottom sediment.	Page 12

	suppression of the antioxidant defence. This will provide literature about the assessment of heavy metals also in the surface sediments		
8	Cross-sectional design is one of the sampling techniques that was used. What was the given population and why the time period from May to June, and why in triplicate at a week's interval? Provide some reasons for the selection of the different sampling sites.	The given population and selection of site were provided in the write up	Page 22, 24
9	The samples were analyzed following the UIRI guidelines for determination of mineral content in water samples ISO 6332:1988, ISO 8288:1986, ISO 7980: 1986. These guidelines should be stated somewhere either in the literature review or this chapter three	The guidelines were provided in the write up.	Page 25
	More write-up has to be included as primary or secondary sources of data, since a lot of data sources are stated within the report	More write-up was included as primary and secondary sources of data.	Page 29
10	For quality control, the report only specifies laboratory control, yet sampling and software were also used. There is need to show how quality was controlled for the techniques and methods used for data collection and analysis.	Quality control was shown in the write up.	Page 29
11	Following the results: for example, Lead (Pb) in water; the report has statements like... "that it can or probably from......." Which shows that the report is not linking the literature review and	The statement was corrected in the write up thus linking the results to the reviewed literature.	Page 32

	the results during analysis. Let the report be clearly analysis results in relation to the literature reviewed.		
12	The findings of Pb contamination could be useful in policy formulation of monitoring of heavy metal pollution" ......this statement is not representative of the fourth objective, since words like "could" don't support the objective	The statement was corrected in the write up.	Page 33
13	The conclusion should be specific on the period for which the study was carried out (i.e. wet or rainy season), hence not a representative for the both the wet and dry seasons. Recommendation should be made for further studies during the dry season.	Conclusion was made based on rainy season and recommendation was made for further studies during the dry season.	Page 55

SN	VIVA COMMENTS	ACTION TAKEN	INDICATOR
1	Presentation of results should be beyond tables	Graphs were provided in the write up.	Pages 43,44,46
2	No units for the measured parameters	Unit of measured parameters was provided in the write up.	Pages 34, 39, 41
3	What species of lead, cadmium and Mercury were targeted in the study?	The species of Pb, Cd and Mercury were provided in the write up.	Page 23

4	The extraction methods for the different species will determine if its detectable	The extraction method was provided in the write up.	Page 23
5	Why only 2 sampling sites?	There were twelve sampling sites including the control site and all provided in the write up	Page 24
6	What informed the choice of the sampling sites?	The choice of the sampling sites was based by activities at the shores.	Page 24
7	Only considering the shoreline makes the research biased. It should have extended to about 1 meter or 2 meters beyond the shore line	Samples taken extended from the shoreline and sites were georeferenced.	Page 24
8	The statistics presented are too elementary	Statistics presentation was improved and graphs provided.	Pages 43,43,46
9	There is need to compare the sampling sites	Sampling sites were compared and presented in the appendices.	Appendices
10	The topic is about heavy metal pollution however the results only show 2 heavy metals Consider may be rephrasing the topic to be heavy metal concentration of inner Murchison Bay under uptake of the water hyacinth	The topic was rephrased to : Assessment of heavy metal concentration in water, sediment and water hyacinth of the Inner Murchison Bay Lake Victoria.	
11	Relationships beyond anthropogenic activities regarding the water chemistry	Anthropogenic activities were provided in the write up.	Pages 45, 47.
12	What was the depth of sampling and why?	Depth for sampling and the reason are provided in the write up.	Page 26
13	There is a concern on the sampling design	Sampling design was explained is the write up.	Page 23

14	Objectives 1 and 2 can be one objective	Objective 1 and 2 were merged	Page 4
15	Objective 4 is not an objective	Another objective was provided.	Page 4
16	Clearly indicate the depth of sediment sampling	The sampling depth was indicated in the write	Page 25
17	From the results, it showed that water hyacinth absorbs some of the Cd and Pb. What is the conclusion and recommendation from this	Conclusion and recommendation were provided	Page 56,57
18	Significance of concentration in water hyacinth compared with sediment and water	The significance was provided in the wripe and appendices	
19	Representation of results should be improved. Need for error bars on the bar graphs	Error bars were provided	Pages 43,44,46
20	Seasonal variation should have been taken into account because they affect pollution loading. If it wasn't done it need to be clear when the research was done	The time when the research was done is provided in the write up	Page 23
21	Show the standard deviation of the samples	Standard deviation was shown on the sample concentration	Pages 36,38,40
22	Did you consider the biomagnification levels in trophic levels due to consuming it	Recommendation was provided for further study of heavy metals and their biomagnification in trophic levels	Page 57
23	What is the concentration of Pb and Cd on the parts of water hyacinth plant	Whole plant was analyzed for heavy metals	Page 27
24	What is the contribution of this research to the body of knowledge	The contribution of this research is provided in the write up	Page 56
25	According to recommendation 2, what are the anthropogenic activities	Anthropogenic activities were provided	Page 57

26	The recommendations and conclusion are too generic and need to be on a Master level	The conclusion and recommendation were improved.	Pages 56, 57
27	Method of assessment of the third objective	The method is provided in the write up	Page 24
28	Show the limitation if only one season was considered	Seasonal variation affect pollution loading has been indicated in the write up.	Page 30
29	Justify why 12 points were selected.	The choice of the sampling points was explained in the write up	Page 22

ZAWADI LOKUNI ROSETTE .... [signature] ....

Candidate's Name Signature Supervisor's Name Signature