ECOLOGICAL RISK ASSESSMENT OF HEAVY METALS IN SEDIMENTS FROM OSSIOMO RIVER

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UNIVERSITY OF BENIN

BENIN-CITY.

NOVEMBER, 2022.

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AN UNDERGRADUATE PROJECT WORK SUBMITTED TO THE DEPARTMENT OF ENVIRONMENTAL MANAGEMENT AND TOXICOLOGY, FACULTY OF LIFE SCIENCES, UNIVERSITY OF BENIN, BENIN-CITY, EDO STATE, NIGERIA; IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR AWARD OF BACHELOR OF SCIENCE (B.SC) DEGREE IN ENVIRONMENTAL MANAGEMENT AND TOXICOLOGY.

NOVEMBER 2022.

CERTIFICATION

This is to certify that this research titled **Ecological Risk Assessment of Heavy Metals in Sediments from Ossiomo River** was carried out by **Emmanuel Oluwaseun Oyagha** and presented to the Department of Environmental Management and Toxicology, Faculty of Life Sciences, University of Benin, Benin City; in partial fulfillment of the requirements for the award of Bachelor of Science (B.Sc.) in Environmental Management and Toxicology. It was conducted under suitable conditions, was carefully supervised and subsequently approved as having met the requirements for the award of Bachelor of Science degree in Environmental Management and Toxicology.

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DECLARATION

I, **Emmanuel Oluwaseun Oyagha**, hereby declare that **Ecological Risk Assessment of Heavy Metals in Sediments from Ossiomo River** is my own work and that all sources that I have used or quoted have been acknowledged by means of complete references and that this work has not been submitted before for any other degree at any other University.

Emmanuel Oluwaseun Oyagha

…………………………….

Date

DEDICATION

This work is dedicated to God Almighty, who has been my sustainer all through my course of study, and my parents Mr. and Mrs. Oyagha for their unconditional love and support.

ACKNOWLEDGEMENTS

My heartfelt gratitude goes to God for the successful completion of this work. My immerse appreciation goes to my project supervisor, Dr. E. Biose for his tireless, selfless support and encouragement, and for practically carrying the work as his own. I appreciate the many corrections he gave to me and all his efforts to ensure that the work went as smoothly as possible. To my course advisor, Dr. Mrs. Edene, thank you so much.

I wish to specially thank my parents, Mr. and Mrs. Oyagha, who have been supportive and always there for me throughout my journey through school: I appreciate their financial and moral support and their unceasing words of encouragement which went a long way towards the completion of this work.

To my wonderful siblings, Mary, Oluwatosin and John, I am grateful that you were always there for me. To my friends Christain, Rukevwe, Favour, Joy, Mmesomachukwu, and Pabby who in one way or another contributed to the success of this work, I say a very big thank you.

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ABSTRACT

The quality of aquatic environments is an important contributor to good environmental health. This study assessed the ecological risk assessment of heavy metals in sediments from Ossiomo River, Edo State in order to ascertain the status and degree of contamination. Nine sediment samples were collected using an Eckman Grab from Ossiomo River from November 2021 to January 2022. Samples collected were air-dried, crushed and sieved through a 2mm sieve, pre-treated using standard methods before determining the heavy metal concentrations in Atomic Absorption Spectrophotometer according to the method of the Association of Analytical Chemists.

The average mean concentration of heavy metals in sediments from Ossiomo river were 1137±760.55 for Fe, 6.83±1.24 for Cu, 28.94±11.93 for Zn, 0.14±0.06 for Cd, 5.80±5.27 for Pb, 9.02±3.80 for Mn, 4.30±1.04 mg/kg for Cr respectively while total hydrocarbon content had an average mean value of 826.80±457.27 mg/kg. The result showed that the concentration of heavy metal were in the following decreasing order: Fe>Zn>Mn>Cu> Pb> Cr>Cd. The composition of computed Enrichment factor (EF) indicated that there is a moderate enrichment for Fe and Zn, a significant enrichment for Fe, Cr, Cd and a very high enrichment for Pb. Geoaccumulation index (Igeo) showed that sediments from Ossiomo River indicates Cu and Mn were practically unpolluted, Cr and Cd were moderately to heavily polluted, Pb was heavily polluted and extremely polluted. The contamination factor showed a moderate contamination exist for Cu and Mn across the sampled stations from Ossiomo River, a very high contamination exist for Cr, Cd, and Pb across the three sample stations. The contamination degree (CD) showed that a very high degree of contamination (CD ≥ 24) exists across all the three sample stations. Pollution load Index (PLI) showed that Ossiomo river is polluted (PLI>1) by metals. Potential ecological risk index (PERI) showed slight pollution degree of Cu, Zn, and Mn, a medium pollution degree of Cr, a strong pollution degree and a very strong pollution degree of Pb while Cd exhibited an extremely strong pollution degree. The risk level or risk degree for Ossiomo River indicated an extremely strong risk degree or level D across the sediments across the stretch of Ossiomo River. The potential ecological risk showed that station 1 and 3 indicates considerable ecological risk (300<RI≤600), while station 2 indicates a very high ecological risk (RI>600). The heavy metals content exhibited a positive and significant correlation.

Therefore the pollution by heavy metals in sediments from Ossiomo River should not be ignored.

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

Water bodies are major recipients of pollutants from land. These pollutants are transported into water bodies through runoff, underground seepage and wet or dry deposition from the atmosphere (Tchounwou*et al.,* 2012). Sediments are an essential component of aquatic systems. This is due to the roles they play in sedimentation and silting, chemical pollution and eutrophication in water bodies (Anyahara, 2021). Sediments are composed of unconsolidated materials which result from weathered rocks and soil, and organic matter which have passed through processes such as weathering, transportation, transformation and deposition (Hong *et al.,* 2020). They receive and accumulate portions of every material or compound that enters water bodies ranging from organic matter to contaminants depending on several factors including morphology, residence time of water and hydrologic conditions (Cardoso *et al.,* 2019). Due to the ability of sediments to accumulate contaminants, they are considered as secondary sources of pollution. In respect to this, the chemicals of most concern are heavy metals and organic pollutants (Sobek *et al.,* 2014).

Heavy metals exists naturally in the earth crust. They characteristically have high densities and are exhibit toxicity to living organisms at low concentrations (Duffus, 2002). Contamination of water bodies by heavy metals may occur due to corrosion of theses metals, atmospheric deposition, soil erosion and leaching, among others (Tchounwou*et al.,* 2012). Human activities such as smelting operations and mining, industrial activities and the addition of of heavy metals in domestic and agricultural products are contributors to heavy metal contamination of water bodies (He *et al.,* 2005). In water bodies, heavy metals react with several contents of the aquatic environment and can associate with geochemical processes in sediments (Morrilo*et al.,* 2004). When heavy metals are washed from contaminated soil into water bodies, they can affect aquatic organisms by inducing toxic effects that disturb their growth, metabolism or reproduction (Gheorghe *et al.,* 2017). Heavy metals can accumulate in the soft parts of aquatic organisms such as gills, digestive glands and gonads (Khan *et al.,* 2018) or on the surfaces of their skins (Hong *et al.,* 2020). Consumption of the affected organisms by predators or humans result in build-up of these metals in the food chain. Heavy metals and polycyclic aromatic hydrocarbons are toxic to aquatic organisms and may be passed along the food chain, building up with each trophic level and eventually ending up in humans where their adverse effects are diverse (Nwachukwu *et al.,* 2014).

1.2 STATEMENT OF THE PROBLEM

The contamination of water bodies by various substances including heavy metals, nutrients and organic compounds are causes for concern both in the short-term and long-term (Hussein *et al.,* 2016). Short-term concerns are due to exposure of living organisms to the portions of these compounds dissolved, suspended in or floating on the water column. However, the other portion of these contaminants is accumulated and concentrated within the sediments of the water body (Anyahara, 2021). Sediments are sinks for contaminants within aquatic systems and as such have higher concentrations of these substances (He *et al.,* 2014). The accumulation of such contaminants in sediments is determined by a variety of factors within the aquatic system including prevailing temperature, pH and available ionic groups. As long as the conditions in the water do not change, these contaminants are held bound in sediments (Alegbeleye*et al.,* 2017). However, such stability is almost non-existent due to natural and anthropogenic activities which affect the aquatic system. As such, when these conditions change these contaminants are released into the water column and become bioavailable again (Ghaleno*et al.,* 2015).

1.3 JUSTIFICATION OF THE STUDY

The health of aquatic ecosystems is a key facet of environmental health in general given the important roles these ecosystems play. Ossiomo River in Edo State, Nigeria is one of such ecosystems which also supports the surrounding communities. Natural runoff from rainfall and human activities such as agriculture in nearby areas, disposal of waste and domestic activities among others are sources from which heavy metals are inputted to the river (Ikhuoriah and Oronsaye, 2016). The presence of these pollutants in the water and sediments of the river present both short- and long-term environmental health threats. Therefore, this study attempts to determine the ecological risk associated with heavy metals in sediments of Ossiomo River. The data and information from this study is expected to assist in the decision-making process towards better protection of the aquatic system of Ossiomo River. Other contributions from this study will be addition to the existing body of knowledge and serving as a basis for carrying out future studies.

1.4 AIM AND OBJECTIVES

The aim of the study is to assess the ecological risk of heavy metals in sediments of Ossiomo River.

The specific objectives of the study are to determine the:

1. Concentrations of heavy metals in sediments from Ossiomo River.
2. Risk and degree of metal contamination in sediment samples using EF, Igeo, CF, PLI, and PERI and its anthropogenic influence on sediment quality.

CHAPTER TWO

LITERATURE REVIEW

2.1 ENVIRONMENTAL CONTAMINATION

The environment is made up of different compartments including the atmosphere, lithosphere, hydrosphere and biosphere. The biosphere cuts across the other three spheres and each of these spheres is in constant interaction with at least one other sphere (Masindi and Muedi, 2018).

Environmental contamination is the presence of elevated levels of harmful substances in any part of the environment, which are higher than background levels for the affected environments. Environmental contamination may be due to the accidental or deliberate release of contaminants into the environment, especially as a result of human activities (Duruibe *et al.,* 2007). Environmental contaminants include solid, liquid and gaseous compounds and substances. They may be inorganic e.g. metals, salts and minerals; organic e.g. human and food wastes and persistent organic pollutants; or biological e.g. microorganisms and waste from insects (Chopra and Sharma, 2020).

The sources of environmental contamination vary depending on the environmental medium. These sources can be classified as point and non-point sources (He *et al.,* 2014). The most common sources are fossil fuel usage, industrial activities and accidents, oil spillage, mining activities, production of ammunition and other weapons of warfare, among others. From these sources, contaminants such as polycyclic aromatic hydrocarbons, heavy metals, flame retardants, dioxins and furans, pesticides and both organic and inorganic solvents are produced (Chance, 2001; Chopra and Sharma, 2020).

Contamination of air, water and soil causes adverse effects on aquatic and terrestrial organisms and produced negative effects in humans which range from mild to severe. Some contaminants damage environmental structures, others damage plants while some harm fish and microorganisms (Suk *et al.,* 2016).

2.2 CONTAMINATION OF WATER BODIES

Water bodies include rivers, lakes, seas and the oceans. The quality of these sources of water has become a sources of environmental concern due to the level of contamination which has occurred and is still occurring in them especially in recent times (Nathanson, 2015). Water bodies are major recipients of pollutants from land. These pollutants are transported into water bodies through runoff, underground seepage and wet or dry deposition from the atmosphere (Tchounwou *et al.,* 2012). Contamination of water bodies may be due to contaminants from point or non-point sources. Point sources of water contamination are easy to control as these contaminants can be collected and subjected to treatment before discharge. Point sources of water contamination include discharges of wastewater and effluents from industries (Nathanson, 2015). Non-point sources of contamination in water bodies are harder to control because they are multiple and diffuse sources of contamination. They include stormwater from urban areas and agricultural runoff (Rinkesh, 2019).

The contamination of water bodies occurs due to natural and anthropogenic activities, although anthropogenic activities contribute a much higher quota to this contamination. Human activities which contribute to water contamination include industrial discharge of wastewater and sewage into water bodies, mining activities, dumping of waste into water bodies, oil spillage, combustion of fossil fuels, use of agricultural pesticides and fertilizers, etc. (CDC, 2018; Rinkesh, 2019). In water bodies, the major contaminants of concern include suspended solids, biodegradable organic entities such as macromolecules, pathogenic organisms, nutrients especially nitrogen, phosphorus and carbon, pollutants which have been designated as priority toxicants, refractor organic compounds, heavy metals and inorganic compounds/substances dissolved in water (FAO, 2006). The contamination of water bodies has adverse effects on aquatic animals and plants. Humans exposed to such waters may experience toxic effects associated with the contaminants present (Alegbeleye *et al.,* 2017; CDC, 2018).

2.3 HEAVY METALS

Heavy metals are natural elements characterized by their high atomic masses and densities. Some of them are essential for normal functioning of living things while others have no benefit at all (Koller *et al.,* 2018). Essential heavy metals are required as coenzymes in biological processes and are less toxic at low concentrations e.g. iron and cobalt, while non-essential heavy metals are highly toxic even at low concentrations, non-biodegradable and cause severe toxic effects in living organisms e.g. lead, arsenic and mercury (Jyothi, 2020).

2.3.1 Sources of Heavy Metals

There are various sources of heavy metals in the environment. They can be classified under natural and anthropogenic sources.

2.3.1.1 Natural Sources

These are heavy metal sources which are not influenced by human activities. The natural sources of heavy metals include processes such as volcanic eruptions and weathering of rock materials (Tchounwou *et al.,* 2012).

2.3.1.2 Anthropogenic sources

Anthropogenic sources are those heavy metal sources which are direct results of human activities. They include mining and metallurgical works, combustion of fossil fuels in power plants, smelting, the use of fertilizers and pesticides in agriculture, wastewater discharge and other industrial activities (Wuana and Okieimen, 2011).

2.3.2 Various Heavy Metals and Their Properties

This section gives a brief overview of some common heavy metals including lead, cadmium, chromium, arsenic, nickel and zinc.

2.3.2.1 Lead

Lead is a group IV and period 6 metallic element. Its properties include the following: atomic number - 83; atomic mass - 207.2 and density 11.4 g/cm^3. Lead is a bluish-gray element and often occurs as a mineral in combination with other elements. It is the fifth most used metal in industries. The uses of lead include manufacture of batteries, soldering, ammunitions, pigments, chemical installations and nuclear shielding (Manahan, 2003).

2.3.2.2 Chromium

Chromium occupies a position among the transition metals in group VIB of the periodic table. Some of its properties are: atomic number - 24; atomic mass - 52 and density 7.19 g/cm^3. It is never found free in the environment, only in the combined form. Chromium is extracted from chromite, a mineral ore (Wuana and Okieimen, 2011). The uses of chromium include use in pigment manufacture, electroplating, manufacturing of steel, wood preservation and tanning of leather (Tchounwou *et al.,* 2012).

2.3.2.3 Cadmium

Cadmium is designated one of the three most poisonous metal elements along with lead and mercury. Its properties include atomic number - 48; atomic mass - 112.4 and density 8.65 g/cm^3. The toxicity of zinc cadmium is often attribute to its chemical similarity with zinc (Wuana and Okieimen, 2011). The main uses of cadmium are in the industrial sector where it is used in producing alloys, pigments and batteries.

2.3.2.4 Zinc

Zinc is a transition metal element in group IIB and period 4. Its characteristics include atomic number - 30; atomic mass - 65.4 and density 7.14 g/cm^3. Zinc occur natural in soil and water bodies although the concentrations have increased rapidly due to human activities. Zinc is an essential element for proper functioning of living organisms. Other uses of zinc include production of alloys and galvanizing iron (Wuana and Okieimen, 2011).

2.3.2.5 Arsenic

On the periodic table, arsenic occupies a position in group VA and period 4 and can be found in many mineral ores. Some of its properties include the following: atomic number - 33; atomic mass - 75 and density 4.72 g/cm^3. Arsenic can occur in four different oxidation states (Wuana and Okieimen). Arsenic is a component of pesticides used in agriculture, it is used in the treatment of certain human conditions, wood preservation and dye production (Tchounwou *et al.,* 2012).

2.3.2.6 Copper

Copper is found in group IB and period 4 of the periodic table and is a transition metal. Its properties include the following: atomic number - 29; atomic mass - 63.5 and density 8.96 g/cm^3. It is one of the most used metals on earth. Copper is an essential micronutrient for the growth and development of plants, animals and humans. Other uses of copper include production of wiring materials, roofing and plumbing, and in parts of industrial machines (Manahan, 2003).

2.3.2.7 Mercury

Mercury is one of the most toxic elements on earth. It occurs as a liquid at room temperature. Its properties include atomic number - 80; atomic mass - 200.6 and density 13.6 g/cm^3.

Mercury has no known biological function. Its uses include manufacturing of thermometers, industrial chemicals and in some electrical and electronic appliances (Koller and Sal, 2018).

2.3.2.8 Nickel

A transition element, nickel possesses the following properties: atomic number - 28 and atomic mass - 58.69. Although nickel is often present in the environment, its concentrations are always very low. Nickel is used in the minting of coins, conducting wires, gas turbines and rocket engines, and manufacture of alloys (Wuana and Okieimen, 2011).

2.3.3 Effects of Heavy Metals in Water Bodies

Heavy metals get into water bodies from soil through the activities of thermal springs, erosion, leaching and infiltration. In water bodies, heavy metals react with various contents of the aquatic environment and can associate with geochemical processes in sediments (Morrilo *et al.,* 2004). When heavy metals are washed from contaminated soil into water bodies, they can affect aquatic organisms by inducing toxic effects that disturb their growth, metabolism or reproduction (Gheorghe *et al.,* 2017). Heavy metals can accumulate in the soft parts of aquatic organisms such as gills, digestive glands and gonads or on the surfaces of their skins (Hong *et al.,* 2020). Consumption of the affected organisms by predators or humans result in build-up of these metals in the food chain.

Deposition of dusts of certain heavy metals may render some essential nutrient non-bioavailable to aquatic plants and thereby limit their growth while dusts of essential plant nutrients increase the amount of nutrients present for plants (Desboeufs *et al*., 2014). A beneficial example of this is the use of compounds of copper e.g. copper sulphate and copper chelates in the treatment of algal blooms in water bodies (Wuana and Okieimen, 2011).

Upon entry into the aquatic systems, heavy metals are acted upon by a plethora of factors which affect their speciation in water. As a result of some of these processes, some portion of these heavy metals either remains in the overlying water column or is accumulated in the sediments at the of the water body (Duruibe *et al.,* 2007). sediments have been proven to be a source and sink for various contaminants in water bodies, among which are heavy metals. The presence of high concentrations of these heavy metals in sediments is a potential source of groundwater contamination (Ali *et al.,* 2019). The major processes which affect heavy metal accumulation in sediments are adsorption and desorption. Physicochemical conditions of the water such as temperature, organic matter concentration, salinity, particle size, redox state of sediments and presence of microorganisms influence heavy metal concentrations and accumulation (Nowrouzi *et al.,* 2014). Factors which are particular to sediments also influence heavy metal distribution; among these are organic matter content, particle size distribution, sediment composition and pH values. Conditions of low pH in water increases competition for binding sites between metals and hydrogen ions and may result in the release of heavy metal ions into overlying water. The occurrence of high concentrations of heavy metals in sediments have been shown to have adverse effects on benthic organisms in water (Ali *et al.,* 2019).

2.3.4 Effects of Heavy Metals on Human Health

Human intake of heavy metals from water occurs via various exposure pathways including ingestion in contaminated seafood and water, and dermal absorption during activities such as swimming or bathing (Duruibe *et al.,* 2007).

Different heavy metals have a variety of adverse effects on human health. Some of these are summarised below.

Cadmium: Cadmium is a known carcinogen. Acute ingestion may cause gastrointestinal disturbances, neurological problems and muscular problems. It is also the cause the well-known *Itai-itai* disease, also known as osteomalacia (Jyothi *et al.,* 2020).

Chromium: The main adverse effects of chromium on human health include induction of allergic dermatitis, renal damage, respiratory tract irritation and allergic reactions. Others include sperm damage and cancers (Tchounwou *et al.,* 2012).

Lead: the adverse human health effects of lead include lead poisoning (plumbism), gastrointestinal tract, kidney and nervous system damage, and in extreme cases, death. In children, lead may cause impairment of growth and development, lesser intelligence quotient, reduced attention span and hyperactivity. In adults, its effects include reduction of reaction time, memory loss, sleeplessness, weight loss and weakening of the joints (Wuana and Okieimen, 2011).

Mercury: Mercury is associated with kidney and nervous system damage, and may lead to poor reproductive capacity, tumours and hypertension (Kebir and Bouhadjera, 2011).

Nickel: Nickel may cause fibrosis, emphysema and impaired pulmonary function (Jyothi, 2020).

Arsenic: Arsenic causes skin damage and causes problems with the circulatory systems (Wuana and Okieimen, 2011). Chronic exposure to arsenic causes cancer of the liver, nasal cavity, lungs and bladder. It also causes Blackfoot disease. Arsenic causes carcinogenic effects in prostate glands and lesions in hepatic regions leading to prostate and liver cancers respectively (Jyothi, 2020).

2.4 REVIEW OF LITERATURE ON ECOLOGICAL RISK ASSESSMENT OF HEAVY METALS

Okafor and Opuene (2007) carried out a preliminary assessment of the concentrations of polycyclic aromatic hydrocarbons and heavy metals in sediments from Taylor Creek in Yenagoa, Bayelsa State. The heavy metals assessed during the study were cadmium, chromium, cobalt, iron, lead, nickel, manganese and zinc by way of atomic absorption spectrometry. PAHs in the study were evaluated through gas chromatography with a flame ionisation detector. Heavy metal concentrations in the study ranged from 113.2 to 5160.7mg/g of sediments while for PAHs, the values ranged from 178.1 to 1266.3mg/g of sediment. There were high values for metal pollution index in the study. It was concluded that the pollutants could bioaccumulate and affect biological diversity and cause changes in ecosystem composition.

Abata *et al.* (2013) assessed the degree of contamination and quality of sediments in Ala River of southwest Nigeria. Heavy metals assessed in the study were zinc, lead, nickel, iron, copper, chromium and cadmium using atomic absorption spectrophotometry. The results showed that the mean concentrations of the metals in the sediment samples were as follows: 0.09 µg/g for Cd; 20.30 µg/g for Cr; 6.61 µg/g for Cu; 648.04 µg/g for Fe; 1.50 µg/g for Ni; 16.90 µg/g for Pb; 3.78 µg/g for Zn dry weight. The concentrations followed the trend Fe> Cr>Pb>Zn>Ni>Cr>Cd. The index of geoaccumulation, contamination factor and degree of contamination were also calculated. Correlation analysis showed significant relationships between nickel, chromium and zinc, iron. Anthropogenic sources of heavy metals were deemed responsible for these metals in the sediments.

Akpan and Thompson (2013) investigated the levels of heavy metal contamination in sediments of the Cross River channel in Nigeria. A total of sixteen (16) sediment samples were collected from the study area in the rainy season of 2011 via core sampling and subjected to standard laboratory analytic methods. The heavy metals present in the samples were determined using Energy Dispersive X-Ray Fluorescence Spectrometry and included iron, copper, manganese, chromium, zinc, mercury, lead, cadmium, nickel, titanium and vanadium. From the results of the study, mercury, lead and cadmium were not found in any of the samples. The highest metal concentration in the samples was that of iron. The enrichment factor from the study ranged from 0.133 to 20.0. These values showed significant enrichment of sediments from some parts of the study area. The geoaccumulation indices calculated revealed contamination levels ranging from none to moderate contamination in the study area. The presence of heavy metals in the study area was attributed to agricultural activities undertaken in the surrounding communities.

Edward *et al.* (2013) undertook a study to determine the concentrations of heavy metals in samples of fish, sediments and water from the Odo-Ayo River in Ekiti State, Nigeria. The heavy metals considered in the study were zinc, manganese, copper, iron, lead and cadmium. Their concentrations in the samples were determined through atomic absorption spectrophotometry (AAS). From the results of the study, heavy metal concentrations were greatest in the sediment samples, followed by the water samples and least in fish samples. Heavy metal concentrations in water were within the acceptable limits prescribed by the WHO. However, the concentrations of heavy metals in fish organs were above the limits permitted for metals in food and so were deemed unsafe for human consumption. As per the study, it was recommended that the river be made the subject of routine heavy metal monitoring and assessment to protect environmental and human health.

Galeno *et al.* (2015) evaluated the potential ecological risk associated with heavy metals present in sediment samples collected from the Chah Nimeh of Sistan water reservoir. Surface sediment samples were collected using core sampling techniques from six random sampling locations with three representative samples from each point. The Samples were subjected to standard analytical procedures and analysed using flame atomic absorption spectrophotometry. The heavy metals assessed during the study were copper, cadmium and lead. The status of pollution of the samples was determined using indices including geo-accumulation index, contamination factor, pollution load index and potential ecological risk index. From the results of the study, the average concentrations of heavy metals in the samples was in the decreasing order Cu > Pb > Cd. Geo-accumulation index values ranged from the unpolluted to moderately contaminated categories. The pollution load index values were in the moderate pollution category. Potential ecological risk factors for each metal ranged from 45.3 to 165.2 which indicated moderate to very high ecological risk.

Dapam *et al.* (2016) carried out a comparative examination of the physicochemical properties and speciation of heavy metals in water and sediments from River Jibam in Plateau State, Nigeria. Samples of water and sediments were collected at four sampling stations along the course of the river in the dry and wet seasons. Physicochemical properties of the samples were determined by standard procedures and included pH, temperature, turbidity, electrical conductivity, sulphate, colour, acidity, phosphate, nitrate, total acidity and alkalinity, chloride and total hardness. Heavy metals of interest in the study were copper, lead, manganese, cadmium, zinc and nickel, and their concentrations were determined using atomic absorption spectrophotometry (AAS). The concentrations of heavy metals in the sediment samples were higher in the wet season than in the dry season. Heavy metal speciation analysis was carried out and revealed their occurrence in various fractions including Fe-Mn oxide, organic, carbonate and residual fractions. On comparison with the WHO standards for water quality, all parameter values fell within acceptable limits except turbidity.

Anani and Olomukoro (2017) determined the heavy metal content of sediments in Ossiomo River, Benin City by way of pollution indices. Heavy metals assessed during this study were iron, manganese, zinc, cadmium, copper, chromium, lead, nickel and vanadium, using atomic absorption spectrophotometry. The results showed that the concentrations of the heavy metals were in the following order: Fe > Mn > Zn > Cu > Cr > Cd > Pb > Ni > V. Indices calculated for the assessment of contamination were Nemerow Integrated Pollution Index, Pollution Index and Enrichment Factor. NIPI and PI values were above 3, while EF values were above 1. Source identification indicated that crustal sources and human activities were the main source of heavy metals in the sediments. It was then suggested to more robust investigations be carried out to ensure the protection of biodiversity and water quality in the study area.

Li *et al.* (2017) studied the distribution and determined the ecological risks associated with heavy metals present in sediment samples collected from collapsed lakes in China. A total of twenty-seven sediment samples were collected, 9 each from three separate collapsed lakes (Xiangcheng, Yangzhuang and Lieshan) in the Huaibei mining area. The samples were digested and analysed using atomic absorption spectrophotometer. The geo-accumulation index, pollution load index and heavy metal pollution sources were determined. The metals assessed during the study included cadmium, arsenic, zinc, lead and antimony. The levels of heavy metals were above background values but were below concentrations for threshold effects. There were medium ecological risks posed by antimony, while arsenic and cadmium posed the highest risk. Finally, the sources of heavy metal pollution were identified to include both point sources including gangue piles and industrial discharges; and non-point agricultural sources.

Jabbi *et al.* (2018) carried out a study aimed at assessing the contamination of sediments by heavy metals in Yardantsi reservoir in Gusau, Nigeria. Samples were collected from five stations in the reservoir and assessed using atomic absorption spectrophotometry while contamination level was determined using the contamination factor index. The results showed the following mean concentrations for the various heavy metals: Cd (1.81cmol/kg) Cu (3.40cmol/kg), Cr (0.99cmol/kg), Fe (46.71cmol/kg), Ni (0.50cmol/kg), Pb (0.14cmol/kg) and Zn (13.87cmol/kg). For the values for contamination factors, that of cadmium was above 6 indicating possible adverse effects in the aquatic environment. For other metals, the contamination factor values were below 1. Monitoring of inputs to the reservoir was then suggested.

Jiao *et al.* (2018) assessed the ecological risk associated with heavy metals present in sediments and water samples collected from the Pearl River Estuary in China. Grab sampling was used to collect a total of twenty-one (21) sediment samples from 21 sampling locations. After preparation and digestion, the samples were analysed using Inductively Coupled Plasma-Mass Spectrometry. Some of the metals present in the samples included zinc, chromium, cobalt, copper, cadmium and zinc. The analysis showed that lead was the most dominant metal in the samples and the heavy metals were mainly sourced from anthropogenic activities. The enrichment factor analysis showed relatively high enrichment factor in three sampling locations. According to the geo-accumulation index, Cr, Co and Ni presented "unpolluted to moderately pollute", Cu and Pb presented "moderately polluted", and Zn and Cd presented "moderately polluted to strongly polluted".

Ayoade and Nathaniel (2018) evaluated the heavy metal status of water and sediments in Dandaru reservoir, Ibadan, Nigeria. The determination of physicochemical properties and heavy metals followed standard procedures and results were compared with WHO and NESREA standards. The concentrations of heavy metals in the water samples were in the following order: Mn>Fe>Pb>Ni>Zn>Cu>Co>Cd>Cr, while in sediments, the trend was Fe>Zn>Mn>Pb>Cu>Co>Cd>Cr, with nickel not detected in sediments. Index of geo-accumulation values for the sediments fell within the range of values indicating uncontaminated to moderate contamination. It was also revealed that the concentrations of iron, nickel, cadmium and manganese in water samples were greater than the values recommended by WHO and NESREA standards. Recommendations made were monitoring of discharges into the reservoir and human activities in nearby areas.

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Luo *et al.* (2021) conducted a study to determine the pollution levels and risk associated with heavy metals present in sediments from Northern Tibet, China. Surface sediment samples were collected from the Bolong River in the area of the Tiegelongnan copper deposit area. The sediment samples were then digested and analysed using atomic fluorescence spectrometry. The heavy metals assessed included copper, lead, zinc, arsenic, cadmium, chromium and nickel. The geo-accumulation index, potential ecological risk and human health risk. The concentrations of heavy metals in the study area were higher than in other areas. The same trend was recorded for the heavy metal concentrations against background values. Geo-accumulation index indicated very high levels of pollution by copper, and moderate pollution by cadmium and zinc. The potential ecological risk index values showed high ecological risk downstream of the copper deposit. The non-carcinogenic risk values were within acceptable limits for adults and children while the carcinogenic risk was above acceptable limits for arsenic and cadmium.

CHAPTER THREE

MATERIALS AND METHODS

3.1 DESCRIPTION OF THE STUDY AREA

The study location was mapped on a stretch of Ossiomo River. Ossiomo River has a length of about 250km and is stretched between Edo and Delta States latitudes 6°30' - 6°32'0"N and longitude5°39'- 5°40'30"E. The water body supports communities such as Ologbo, Okuku, Ovade, Egho, Asabor, Ugbenu and Ogbogilete. The river receives water from rivers Akhaianwan, Okhuaihe and Ikpoba Rivers. It, in turn, empties into the Benin River at Koko in Delta State. The geology of the study area is made of the Benin formation as a lithostratigraphic units and a lower Miocene Age formation. The Tertiary Scarp of Benin makes up its sedimentary deposit. The Benin formation extends to 762.5metres deep and rest on top the Agbado formation, made of coarse sand and sandstone (Ikhuoriah and Oronsaye, 2016). For the course of this study, three sampling stations in the river were designated to show the upstream, midstream, and down-stream points of the river. The region is dominated by human activities such as agriculture. The sediment samples were collected at three stations and they are located at:

Station 1: Upstream	N 06° 03. 197° and E 005° 39. 905'
Station 2: Midstream	N 06° 03. 127° and E 005° 39. 835°
Station 3: Down-stream	N 06° 03. 121° and E 005° 39. 779°

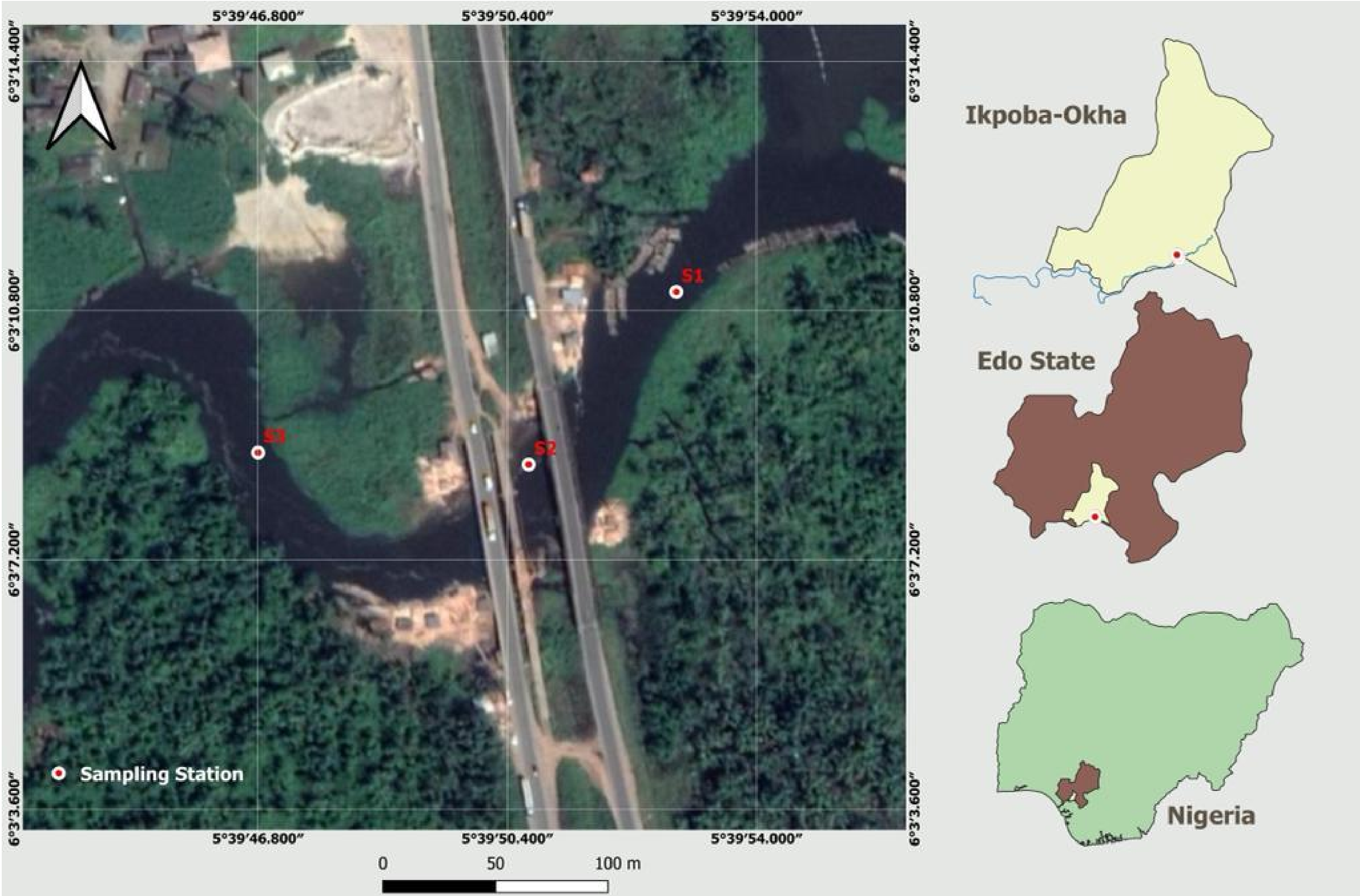

Figure 3.1: A map of the study area with sampling locations indicated

3.2 MICROCLIMATE OF THE STUDY AREA

The study location is within the Niger Delta rainforest ecological zone of Nigeria and is characterised by a wet season lasting from March to October, and a dry season lasting from November to March. Ossiomo River serves as a source of water for domestic use in the communities it passes through (Ikhuoriah and Oronsaye, 2016).

3.3 VEGETATION OF THE STUDY AREA

Ossiomo River is quite wide and on both sides of it are rich vegetation with trees including bamboo trees (*Bambusa*sp.), palm trees (*Elaesisguinensis*), rubber trees (*Heveabrasilensis*) and many shrubs. Floating on the river are various plant species including *Eichorniacrassipes, Lemna*sp, and *Salvinia* sp. (Ikhuoriah and Oronsaye, 2016).

3.4 SAMPLING STATIONS

The sediment samples were collected at three sampled stations from Ossiomo River based on accessibility. The river was delineated into three sample stations with station 1 designated as upstream, stations 2 designated as midstream, while station 3 was designated as downstream.

Station 1: Station 1 lies between latitude N 06° 03. 197° and longitude E 005° 39. 905° (plate 3.1) and is located upstream of the river and it served as the control point for the study. This station (Station 1) maintains a distance of about 2 km away from station 2 at Ologbo community. The activities observed in this station include boating and fishing activities and the marginal vegetation here is mainly grasses and macrophytes like water hyacinth (E. crassipes). This station was not very transparent. The river bank is flanked by oil palm trees (*Elaeisguineensis*), rubber trees (*Haveabrasiliensis*), *Bambusa vulgaris* and other plants which provides a canopy for the underlying vegetation including the antelope grass (*Echinochloapyramidalis*). Apart from using the river as a means of transportation using canoes by indigenes of Ologbo, occasional fishing activities and human disturbance at this site is minimal.

Plate 3.1: Station 1 lies between latitude N 06° 03. 197° and longitude E 005° 39. 905°

Station 2: Station 2 lies between latitude N 06° 03. 127° and longitude E 005° 39. 835° (Plate 3.3). Station 2 is under the bridge side at Ologbo community; it is characterized by encroachment of vegetation into the river especially shrubs and grasses. There is a high level of human activities/disturbance in this station. These activities include; swimming, bathing, and washing of clothes and household utensils. This station was transparent. Human activities such as washing, fishing, farming and bathing are evident in this station by the indigenes of Ologbo as they didn't have other source of water. The water is also fetched home for various uses. The vegetation found hereinclude, *Bambusa vulgaris*, *Theobroma cacao*, and water lily (*Nymphaea lotus*). Flood and other earth run-offs enter into the waterbody.

Station 3: Station 3 lies between latitude N 06° 03. 121° and longitude E 005° 39. 779° (Plate 3.3). This station is also about 2 km downstream from station 2. Human activities and disturbances were at the highest levels. Some of these activities are fishing, dredging, lumbering and oil spillage. Although the river is so wide in this station, and surrounded on the bank by forests and arable farmlands. Anthropogenic activities around the station includes dredging of the river sediments, farming around the station, fishing by artisans and swimming. The river is transparent while the substratum is composed of sand which is whitish at the upper layer.

Plate 3.2: Station 2 lies between latitude N 06° 03. 127° and longitude E 005° 39. 835°

Plate 3.3: Station 3 lies between latitude N 06° 03. 121° and longitude E 005° 39. 779°

3.5 SAMPLE COLLECTION AND PREPARATION

The study lasted a period of three months between November 2021 and January 2022. Sampling campaigns were undertaken once a month. Sediment samples for each month were collected from the three sampling locations along the course of the river. The collection of samples were done using a 20cm Birge-Eckman grab sampler after which the samples were transferred to clean polyethylene bags. The bags were then appropriately labelled and transported to the laboratory for analysis. The various sampling locations are shown in Figure 3.1.

The sediment samples were air-dried in the laboratory at room temperature (25°C - 27°C) for three days. Samples were then crushed, sieved through a 2mm mesh sieve and stored foe analysis.

Plate 3.4: Sediment samples after collection

3.6 LABORATORY ANALYSIS

Physicochemical properties, heavy metal concentrations and polycyclic aromatic hydrocarbons content of the samples were determined following standard procedures as described below.

3.6.1 Physicochemical Properties of Sediment

3.6.1.1 pH

The pH measurements were done with distilled water in the ratio of 1:1 (soil:water). Twenty grams (20g) of the sediment sample was weighed and put in a 100ml beaker. 20ml of distilled water was added to the sample. The suspension was left for 2 minutes, with intermittent stirring using glass rod to enable it reach equilibrium. The pH of the suspension was determined using a pH meter by inserting the pH meter into the beaker and taking the readings. The determination of the pH was carried out in duplicate and the average results were recorded.

Plate 3.5: Determination of pH and electrical conductivity

3.6.1.2 Electrical Conductivity (EC)

The electrical conductivity of the sediment samples was determined after the determination of the pH of the samples. A conductivity meter was used to measure electrical conductivity.

3.6.1.3 Total Organic Carbon (TOC)

The amount of organic carbon present in the sediment samples was determined using the Walkley and Black method. 0.2g of the sediment sample was weighed into a 500mL flask. 10mL of 0.167M potassium dichromate ($K_2Cr_2O_7$) and 20mL of concentrated H_2SO_4 was added. The mixture was stirred intermittently for 30 minutes after which 200mL of distilled water, 10mL of concentrated H_2PO_4 and 1mL of 0.16% diphenylamine were added. The mixture was titrated with ammonium ferrous sulphate and the result was recorded.

The organic carbon value was converted to organic matter by multiplying by a factor of 1.724 and recorded in g/Kg.

$$OM = OC \times 1.724$$

Where OM is the organic matter and OC is the organic carbon content.

3.6.1.4 Total Nitrogen

The Kjeldahl wet digestion method was used in the determination of ammonium nitrogen in sediment samples. One gram of the sample was weighed into a digestion flask and 15ml of concentrated H_2SO_4 was added. One gram of catalyst mixture ($CuSO_4$:K_2SO_4, 1:9) was added to the mixture after which it was heated to boil for about 1 hour when white fumes were produced. The mixture was then allowed to cool and distilled water was added up to the 250ml mark. 10ml of the aliquot was measured and 15ml of 40% NaOH was added after which the mixture was heated. 25ml of the distillate was collected in 5ml of boric acid and indicator (4:1). This was then titrated against 0.1N HCl. The concentration of nitrogen was determined using the formula:

$$\%N = V_a \times N_a \times \frac{14 \times V_1}{V_2 \times w}$$

Where, V_a = volume of acid used in the titration, N_a = concentration of the acid, V_1 = final volume of digestate, V_2 = volume of aliquot, and w = weight of sample used.

3.6.1.5 Potassium, Sodium and Magnesium

Five grams of the prepared sediment samples was weighed into a 250cm^3 conical flask and digested using 150cm^3 nitric acid and 2cm^3 perchloric acid. The mixture was then placed on a hot plate for about three hours. After that, the mixture was allowed to cool and filtered into a 100cm^3 volumetric flask. Distilled water was then added to make up to mark. The determination of magnesium was done using atomic absorption spectrophotometer, while sodium and potassium were determined using a flame photometer (Aremu*et al.,* 2011). All analyses were carried out in triplicates and the mean of the values were recorded in mg/kg.

3.6.1.6 Total Hydrocarbon Content (THC)

For the determination of total hydrocarbon content in sediment samples, 5 grams of prepared sediment sample was weighed into a 100ml plastic cup. 15ml of n-hexane was added and the mixture was vigorously shaken for 10 minutes after which it was allowed to rest. The resulting solution was then read using a spectrophotometer set at 460nm. Standard solutions were prepared using 0.60ml of Forcados Blend Crude Oil in 500ml of n-hexane. Working standards of 0, 5, 10, 20, 30, 40 and 50ppm were prepared and used to plot a graph of the concentrations of total hydrocarbons.

3.6.1.7 Particle Size Distribution

One hundred grams (100g) of the sediment sample was accurately weighed into a 1 litre-shaking bottle, and then added 50ml Calgon solution, 3ml of 1N Sodium Hydroxide and 200ml of distilled water and shake on the mechanical shaker for 3 hours and the resultant solution was transferred to a measuring cylinder and made up to mark (the volume of 1000ml) with distilled water. The solution was further mixed by inverting it a few times, and then placed on the bench and read with time. After 4 minutes, with the hydrometer and again read 5 minutes later.

Calculation:

$$\text{Temperature coefficient} = (\text{Temp} - 19.4) \times 0.3$$

$$\%\ \text{Clay} = H_2 + \text{its temperature coefficient}$$

$$\%\ \text{Silt} = H_1 + \text{its temperature coefficient} - (H_2 + \text{its temperature coefficient})$$

$$\%\ \text{Sand} = 100 - (\%\ \text{Clay} + \%\ \text{Silt})$$

Where H_1 is the first hydrometer reading and H_2 is the second hydrometer reading.

3.6.2 Heavy Metal Analysis of Sediments

One gram of the prepared sediment sample was weighed using a top loading balance and placed in a 250ml flask which had been previously washed with nitric acid and distilled water. The sample was reacted with 5ml of HNO_3, 15ml of concentrated H_2SO_4 and 0.3ml of $HClO_4$ using dropping pipette. The mixture was digested in a fume cupboard and heating continued until a dense white fume appeared. The mixture was then set aside to cool and diluted with distilled water. The mixture was filtered through Whattman filter paper into a 50ml volumetric flask and diluted to mark volume. The samples were analysed in triplicates using atomic absorption spectrophotometer (AAS) and the mean concentrations were recorded in mg/kg.

CHAPTER FOUR

RESULTS

4.1 HEAVY METAL CONTENT IN SEDIMENTS FROM OSSIOMO RIVER

The results of the heavy metal content of sediments from the three sampled stations from Ossiomo River collected November 2021 – January 2022 are presented in table 4.1. The table shows the mean, standard deviation, minimum and maximum of each analysed parameter at the different stations of the study location. Also shown are the p-values of the one way analysis of variance (ANOVA) and superscripts of post hoc (Duncan multiple range – DMR) test. The superscript indicate the case where the ANOVA showed a significant difference.

In table 4.1, the following heavy metals such as Iron (Fe), Copper (Cu), Zinc (Zn), Lead (Pb), Manganese (Mn), and Chromium (Cr) showed no difference ($p>0.05$), while Cadmium (Cd) and total hydrocarbon content (THC) exhibited a significant difference ($p<0.05$) between the sediments samples of the three stations sampled from Ossiomo River collected between November 2021 – January 2022.

Table 4.1: Heavy Metals Content in Sediments from Ossiomo River

Parameters	Station 1 x̄±SD (Min-Max)	Station 2 x̄±SD (Min-Max)	Station 3 x̄±SD (Min-Max)	p-value	Anova value
Iron (mg/kg)	821.17±592.56 (226.70-1411.80)	2005.33±1460.96 (555.00-3476.70)	586.43±188.54 (435.00-797.60)	p>0.05	0.117
Copper (mg/kg)	5.47±2.28 (3.00-7.50)	7.90±4.37 (3.30-12.00)	7.13±3.14 (4.80-10.70)	p>0.05	0.425
Zinc (mg/kg)	18.53±10.54 (9.70-30.20)	41.97±17.57 (30.60-62.20)	26.33±14.05 (11.40-39.30)	p>0.05	0.102
Cadmium (mg/kg)	0.10^{b}±0.06 (0.10-0.10)	0.21^{a}±0.01 (0.20-0.22)	0.11^{b}±0.06 (0.10-0.11)	p<0.05	0.039
Lead (mg/kg)	3.50±0.06 (3.00-4.00)	11.83±10.13 (0.50-20.00)	2.07±1.62 (0.20-3.00)	p>0.05	0.104
Manganese (mg/kg)	8.40±3.60 (4.50-11.60)	13.10±6.90 (6.30-20.10)	5.57±0.70 (4.90-6.30)	p>0.05	0.096
Chromium (mg/kg)	3.44±2.78 (0.32-6.67)	5.46±2.20 (3.08-7.42)	3.99±1.26 (2.77-5.29)	p>0.05	0.313
Total Hydrocarbon Content (mg/kg)	700.49^{b} ±129.42 (578.43-836.19)	445.96^{c} ±462.88 (31.11-945.25)	1333.94^{a} ±636.40 (741.11-2006.41)	p<0.05	0.063

x ± SD = average mean generated from values across the months per station, ± standard deviation; min–max = minimum and maximum values for each parameter per station; post hoc = values with different superscripts (a > b > c > d) are significantly different ($p < 0.05$ or 0.01) while values with same superscript are not significantly different ($p > 0.05$). *$p < 0.05$ (significant difference), **$p < 0.01$ (highly significant difference)

Figure 4.1shows the spatial and temporal variations recorded for iron (Fe) in the sediment samples from the three stations of the study location from between November 2021 – January 2022. The trends observed across the various areas were different. The lowest and highest Fe values across the sites were recorded in station 1 and station 2 respectively. The concentration of Fe across station 1, station 2, and station 3 ranged from 226.70-1411.80, 555.00-3476.70 and 435.00-797.60 (ppm) respectively while the average mean concentration of iron (Fe)were 821.17, 2005.33, and 586.43 (ppm) respectively. The Fe values across the sample locations showed no significant difference ($p>0.05$).

Figure 4.2 shows the spatial and temporal variations recorded for Copper (Cu) in the sediment samples from the three stations of the study location from between November 2021 – January 2022. The trends observed across the various areas were different. The lowest and highest Cu values across the sites were recorded in station 1 and station 2 respectively. The concentration of Cu across station 1, station 2, and station 3 ranged from 3.00-7.50, 3.30-12.00, and 4.80-10.70 (ppm) respectively while the average mean concentration of Copper (Cu)were 5.47, 7.90, and 7.13 (ppm) respectively. The copper values across the sample locations showed no significant difference ($p>0.05$).

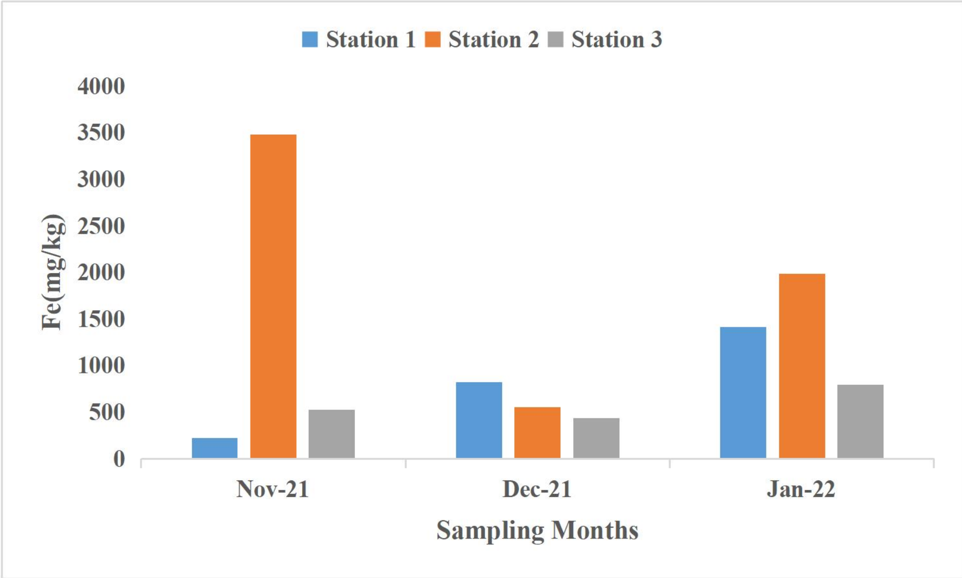

Figure 4.1: Spatial and temporal variation of Iron (Fe) in the sediments of Ossiomo River during the sampling period.

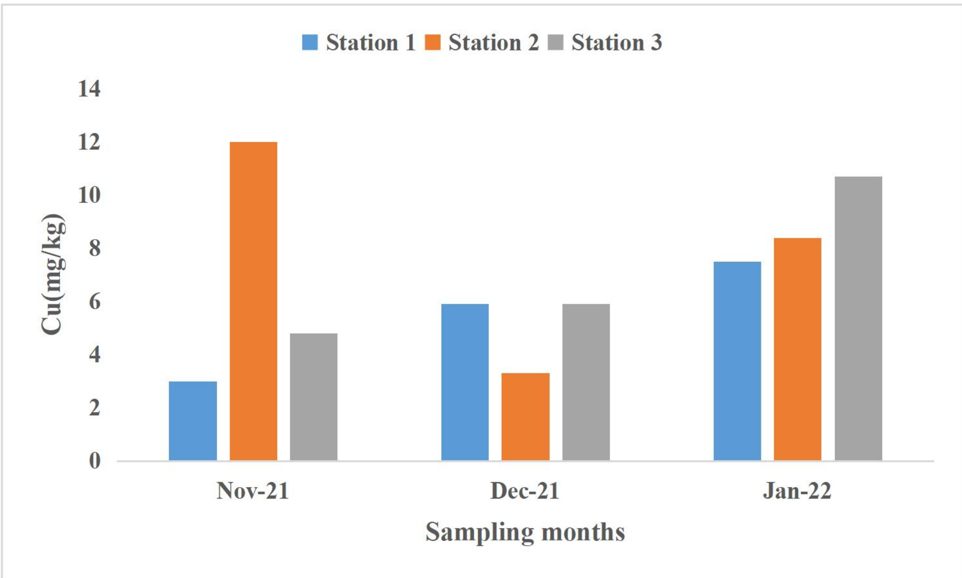

Figure 4.2: Spatial and temporal variation of Copper (Cu) in the sediments of Ossiomo River during the sampling period.

Figure 4.3 shows the spatial and temporal variations recorded for Zinc (Zn) in the sediment samples from the three stations of the study location from between November 2021 – January 2022. The trends observed across the various areas were relatively similar. The lowest and highest Zn values across the sites were recorded in station 1 and station 2 respectively. The concentration of Zn across station 1, station 2, and station 3 ranged from 9.70-30.20, 30.60-62.20 and 11.40-39.30 (ppm) respectively while the average mean concentration of Zinc (Zn) were 18.53, 41.97, and 26.33 (ppm) respectively. The Zinc values across the sample locations showed no significant difference ($p>0.05$).

Figure 4.4 shows the spatial and temporal variations recorded for Cadmium (Cd) in the sediment samples from the three stations of the study location from between November 2021 – January 2022. The trends observed across the various areas were different. However, it was observed that station 2 had the highest values of Cd across the study. The lowest and highest Cd values across the sites were recorded in station 2 and station 3 respectively. The concentration of Cd across station 1, station 2, and station 3 ranged from 0.10-0.10, 0.20-0.22, and 0.10-0.11 (ppm) respectively while the average mean concentration of Cd were 0.10, 0.21, and 0.11 (ppm) respectively. The Cadmium values across the sample locations exhibited a significant difference ($p<0.05$). Further DMR-test showed that there is no significant difference between stations 1 and 3 which exhibited a significant difference from station 2.

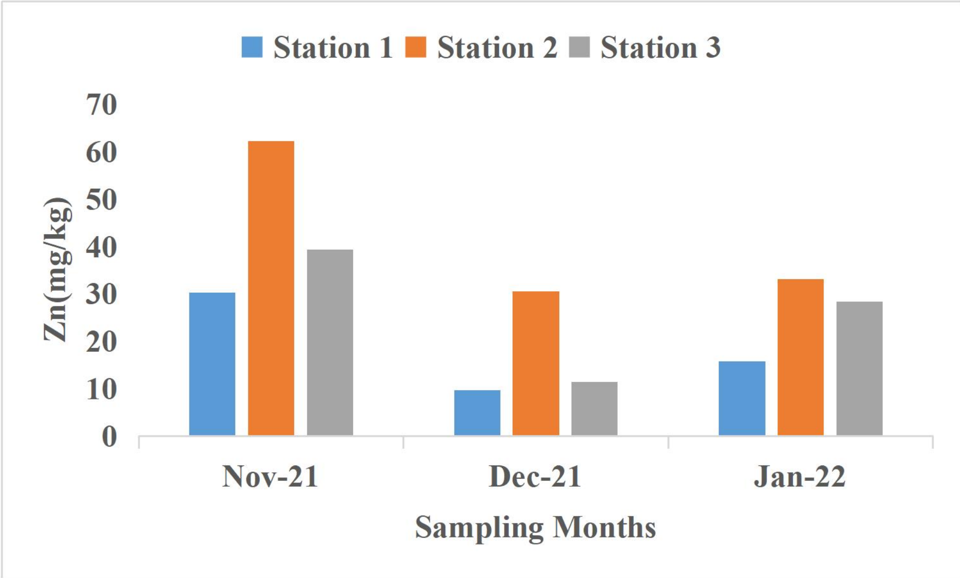

Figure 4.3: Spatial and temporal variation of Zinc (Zn) in the sediments of Ossiomo River during the sampling period.

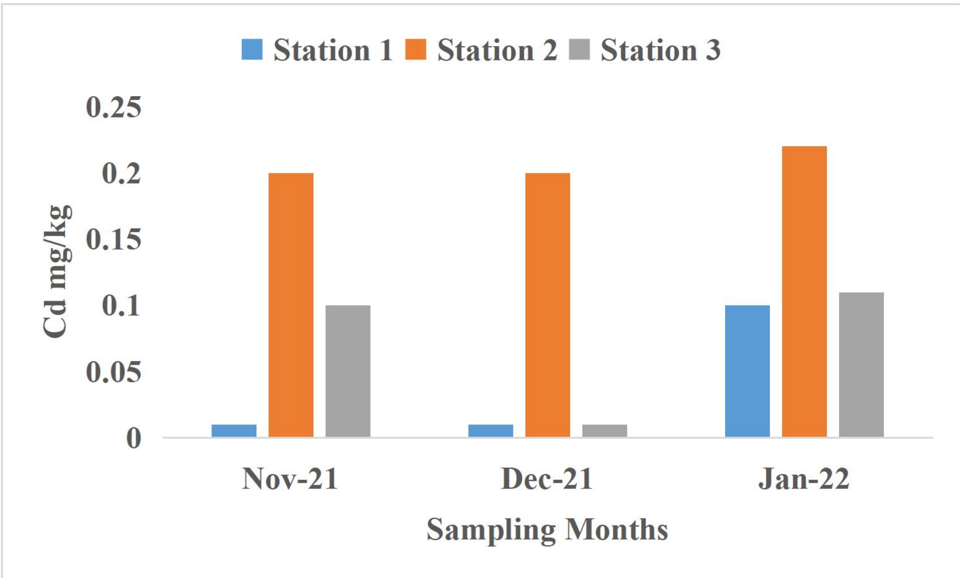

Figure 4.4: Spatial and temporal variation of Cadmium (Cd) in the sediments of Ossiomo River during the sampling period.

Figure 4.5 shows the spatial and temporal variations recorded for Lead (Pb) in the sediment samples from the three stations of the study location from between November 2021 – January 2022. The trends observed across the various areas were relatively similar for the December and January, while it was different for the month of November. The lowest and highest Pb values across the sites were recorded in station 1 and station 2 respectively. The concentration of Pb across station 1, station 2, and station 3 ranged from 3.00-4.00, 0.50-20.00, and 0.20-3.00 (ppm) respectively while the average mean concentration of lead (Pb) were 3.50, 11.83, and 2.07 (ppm) respectively. The lead values across the sample locations showed no significant difference ($p>0.05$).

Figure 4.6 shows the spatial and temporal variations recorded for Manganese (Mn) in the sediment samples from the three stations of the study location from between November 2021 – January 2022. The trends observed across the various areas were relatively similar for December and January while November was different. The lowest and highest Mn values across the sites were recorded in station 1 and station 2 respectively. The concentration of Mn across station 1, station 2, and station 3 ranged from 4.50-11.60, 6.30-20.10, and 4.90-6.30 (ppm) respectively while the average mean concentration of Manganese (Mn)were 8.40, 13.10 and 5.57 (ppm) respectively. The Manganese values across the sample locations showed no significant difference ($p>0.05$).

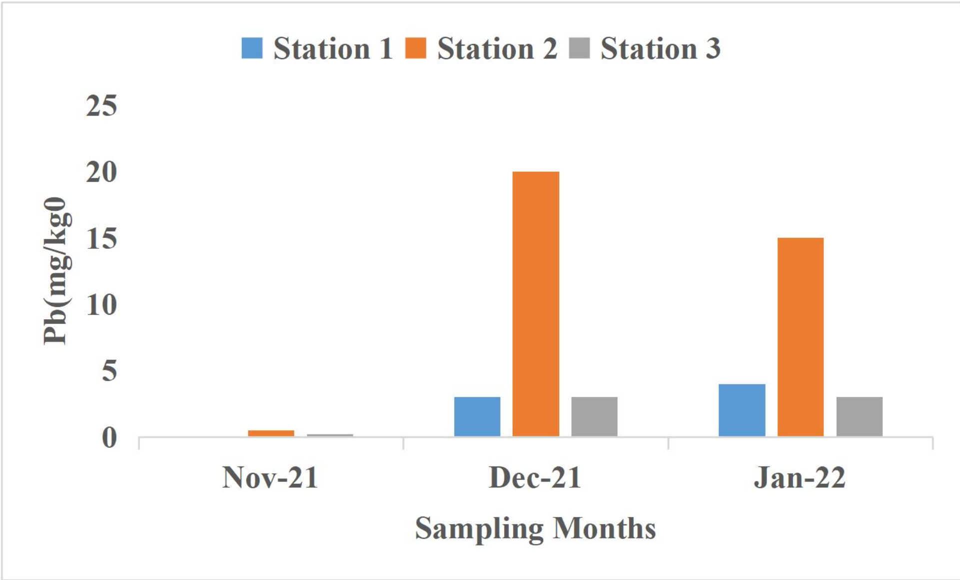

Figure 4.5: Spatial and temporal variation of Lead (Pb) in the sediments of Ossiomo River during the sampling period.

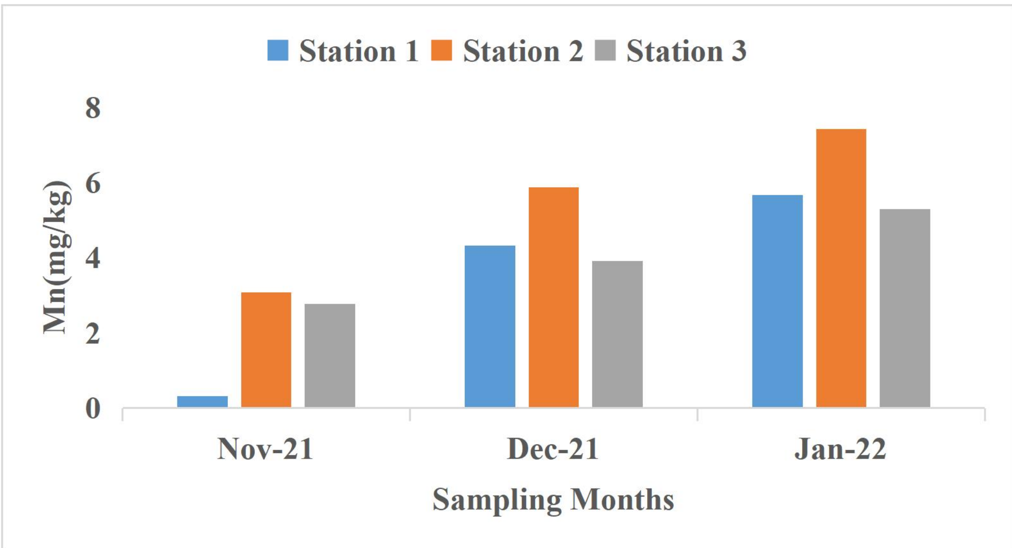

Figure 4.6: Spatial and temporal variation of Manganese (Mn) in the sediments of Ossiomo River during the sampling period.

Figure 4.7 shows the spatial and temporal variations recorded for Chromium (Cr) in the sediment samples from the three stations of the study location from between November 2021 – January 2022. The trends observed across the various areas were relatively similar for December and January but different in November. The lowest and highest Cr values across the sites were recorded in station 1 and station 2 respectively. The concentration of Cr across station 1, station 2, and station 3 ranged from 0.32-6.67, 3.08-7.42, and 2.77-5.29 (ppm) respectively while the average mean concentration of Chromium (Cr) was 3.44, 5.46, and 3.99 (ppm) respectively. The Chromium values across the sample locations showed no significant difference ($p>0.05$).

Figure 4.8 shows the spatial and temporal variations recorded for Total Hydrocarbon Content (THC) in the sediment samples from the three stations of the study location from between November 2021 – January 2022. The trends observed across the various areas were different. The lowest and highest THC values across the sites were recorded in station 2 and station 3 respectively. The concentration of THC across station 1, station 2, and station 3 ranged from 578.43-836.19, 31.11-945.25, and 741.11-2006.41 (ppm) respectively while the average mean concentration of THC were 700.49, 445.96, and 1333.94 (ppm) respectively. The THC values across the sample locations showed no significant difference ($p>0.05$).

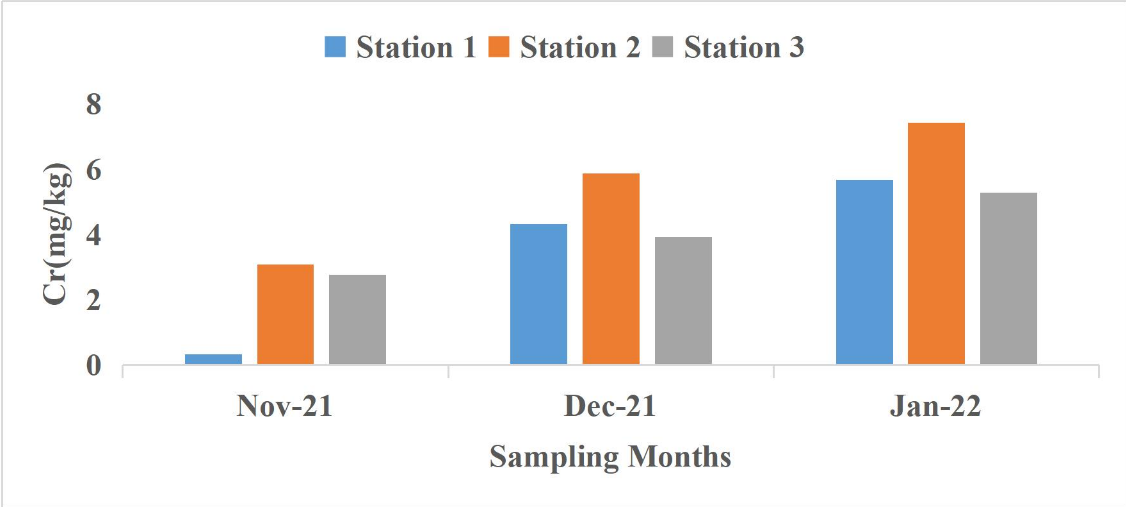

Figure 4.7: Spatial and temporal variation of Chromium (Cr) in the sediments of Ossiomo River during the sampling period.

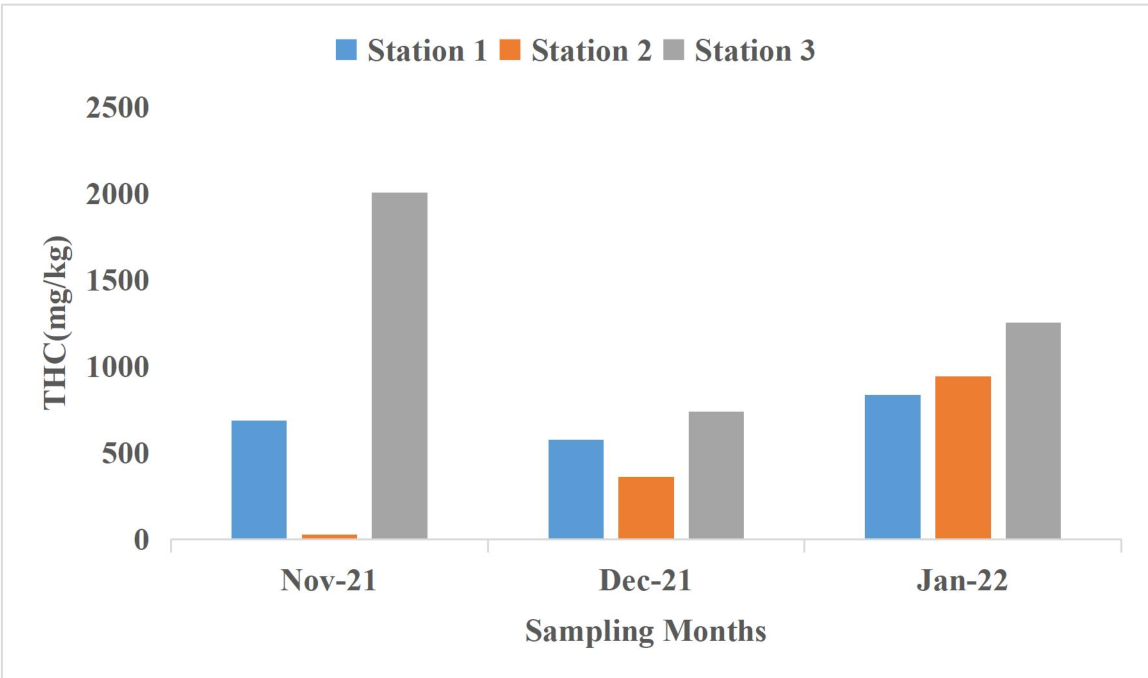

Figure 4.8: Spatial and temporal variation of Total Hydrocarbon Content (THC) in the sediments of Ossiomo River during the sampling period.

4.2 ASSESSMENT INDICES FOR SEDIMENTS FROM OSSIOMO RIVER

4.2.1 Enrichment Factor (EF)

Table 4.2 below shows the enrichment factor (EF) in the sediments across the three sample stations from Ossiomo River. The table indicates that there is a moderate enrichment of Fe in station 1 and 3 ($2 \leq EF < 5$) while there is a significant enrichment in station 2 ($5 \leq EF < 20$). Cr shows a significant enrichment across stations 1, 2, and 3 ($5 \leq EF < 20$). There is a significant enrichment of Cd in station 1 and 3 ($5 \leq EF < 20$), while station 2 shows a very high enrichment of Cd ($20 \leq EF < 40$). There is a moderate enrichment for Cu and Zn in stations 2 and 3 ($2 \leq EF < 5$), while no enrichment was recorded for Cu and Zn in station 1 ($EF < 2$). A depletion of mineral enrichment was recorded for Mn in stations 1 and 3 ($EF < 2$), while there was a moderate enrichment in station 2 ($2 \leq EF < 5$). There was very high enrichment for Pb in stations 1 and 3 ($20 \leq EF < 40$), and an extremely high enrichment in station 2 ($EF > 40$). The findings from this study indicated that there is a moderate enrichment for Fe and Zn, a significant enrichment for Fe, Cr, Cd and a very high enrichment for Pb in Ossiomo River. This is depicted by figure 4.9 which shows the values of EF variation of the three stations analyzed in the study location.

Table 4.2: Enrichment factor (EF) of sediments from Ossiomo River

	Station 1	Station 2	Station 3
Fe	3.622	8.846	2.587
Cr	10.707	16.999	12.440
Cd	10.000	20.667	10.500
Cu	1.822	2.633	2.378
Zn	1.911	4.326	2.715
Mn	1.867	2.911	1.237
Pb	35.000	118.333	20.667

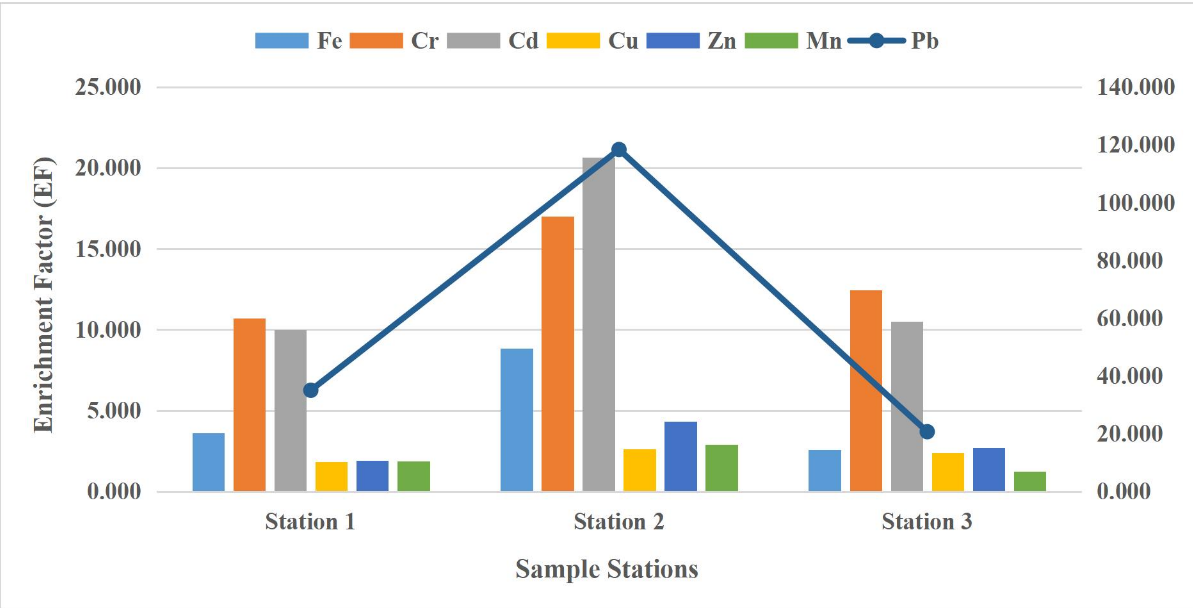

Figure 4.9: Enrichment Factor (EF) of the sediments from Ossiomo River

4.2.2 Geo-accumulation Index (*Igeo*)

Table 4.3 shows the summary of Geo-accumulation index (Igeo) values of heavy metal contamination in sediments across the three sampled stations from Ossiomo River. In relation to Fe, the sediment sample from station 1 was unpolluted to moderately polluted ($0<\text{Igeo}<1$), station 2 was moderately polluted ($1<\text{Igeo}<2$), while station 3 was practically unpolluted ($\text{Igeo}\leq 0$). In relation to Cr, the sediment from station 2 and 3 were moderately to heavily polluted ($2<\text{Igeo}<3$), while the sediment sample from station 1 was moderately polluted ($1<\text{Igeo}<2$). In relation to Cd, the sediment from station 1 and 3 were moderately polluted ($1<\text{Igeo}<2$), while the sediment from station 2 was moderately to heavily polluted ($2<\text{Igeo}<3$). In relation to Cu, the sediments across all three stations were practically unpolluted ($\text{Igeo}\leq 0$). In relation to Zn, the sediments from station 1 and 3 were practically unpolluted ($\text{Igeo}\leq 0$), while the sediment from station 2 was unpolluted to moderately polluted ($0<\text{Igeo}<1$). In relation to Mn, the sediments across all three stations were practically unpolluted ($\text{Igeo}\leq 0$). In relation to Pb, the sediment from station 1 was heavily polluted ($3<\text{Igeo}<4$), station 3 was moderately to heavily polluted ($2<\text{Igeo}<3$), while the sediment from station 2 was extremely polluted ($5>\text{Igeo}$). The findings using *Igeo* indicates Cu and Mn were practically unpolluted ($\text{Igeo}\leq 0$) across the sampled stations, Cr and Cd were moderately to heavily polluted ($2<\text{Igeo}<3$) in station 2, while Pb was heavily polluted in station 1 ($3<\text{Igeo}<4$) and extremely polluted ($5>\text{Igeo}$) in station 2. Figure 4.10 shows the Igeo values of the three stations analyzed in the study location.

Table 4.3: Igeo values of Sediments from Ossiomo River

	Station 1	Station 2	Station 3
Fe	1.272	2.560	0.786
Cr	2.836	3.502	3.052
Cd	2.737	3.784	2.807
Cu	0.281	0.812	0.665
Zn	0.349	1.528	0.856
Mn	0.316	0.957	-0.278
Pb	4.544	6.302	3.784

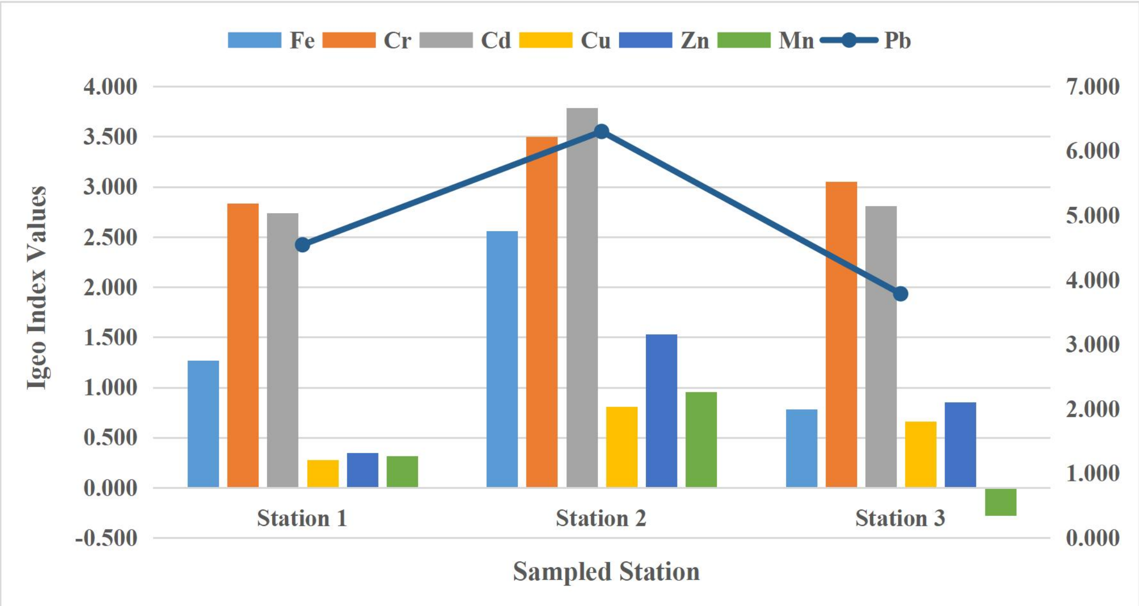

Figure 4.10: Igeo values of the sediments from Ossiomo River

4.2.3 Contamination factor (CF), Contamination Degree (CD) and Pollution Load Index (PLI)

The concentration factor is used as an indicator of the pollution level in sediment. The concentration factor and pollution load index explains the severity and variations of pollution in the sediments of the study location. In table 4.4 below, the samples indicate that there is moderate contamination of Fe in the sediments of station 3 (1<CF>3), considerable contamination of Fe in the sediments of station 1 (3<CF<6), and a very high contamination of Fe in the sediments of station 2 (CF>6). There is a very high contamination of Cr, Cd, and Pb across the three sample stations of the study location (CF>6). There is a moderate contamination of Cu across the three sample stations of the study area (1<CF>3). There is moderate contamination of Zn in stations 1 and 3 (1<CF>3), while there is a considerable contamination of Zn in station 2 (3<CF<6). There is a moderate contamination of Mn across the three sample stations of the study area (1<CF>3). The findings from this study shows a moderate contamination exist for Cu and Mn across the sampled stations from Ossiomo River, a very high contamination exist for Cr, Cd, and Pb across the three sample stations. Adopting Hakanson (1980), a very high degree of contamination (CD ≥ 24) exists across all the three sample stations.

Tomlinson *et al.,* (1980) described PLI which states that when PLI > 1, pollution exist; otherwise, if PLI < 1, there is no metal pollution. In respect to sampled stations from Ossiomo River, the PLI values across the three sample stations indicates that PLI > 1 which signifies that pollution of Ossiomo River. Figure 4.11 shows the spatial variation for the various heavy metals adopted for concentration factor (CF) while figure 4.13 shows the pollution load index (PLI) values.

Table 4.4: Contamination Factor, Contamination Degree and Pollution Load Index of sediments from Ossiomo River

	Fe	Cr	Cd	Cu	Zn	Mn	Pb	CD	PLI
Station 1	3.622	10.707	10.000	1.822	1.911	1.867	35.000	64.929	5.088
Station 2	8.846	16.999	20.667	2.633	4.326	2.911	118.333	174.716	10.288
Station 3	2.587	12.440	10.500	2.378	2.715	1.237	20.667	52.523	4.765

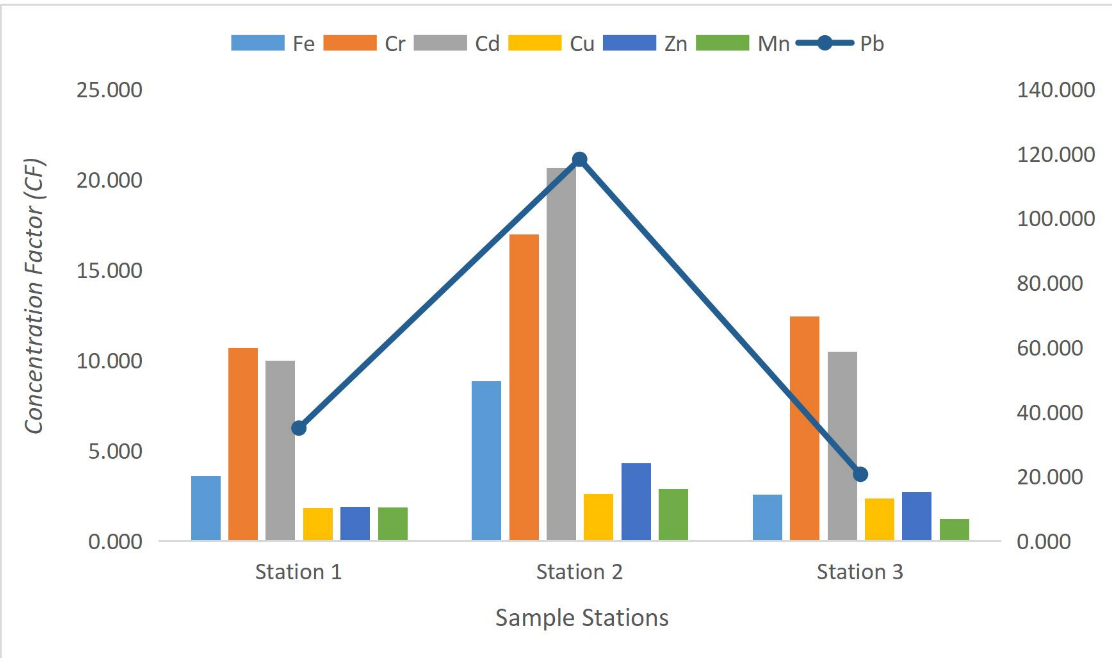

Figure 4.11: Contamination factor (CF) of heavy metals in sediments from Ossiomo River

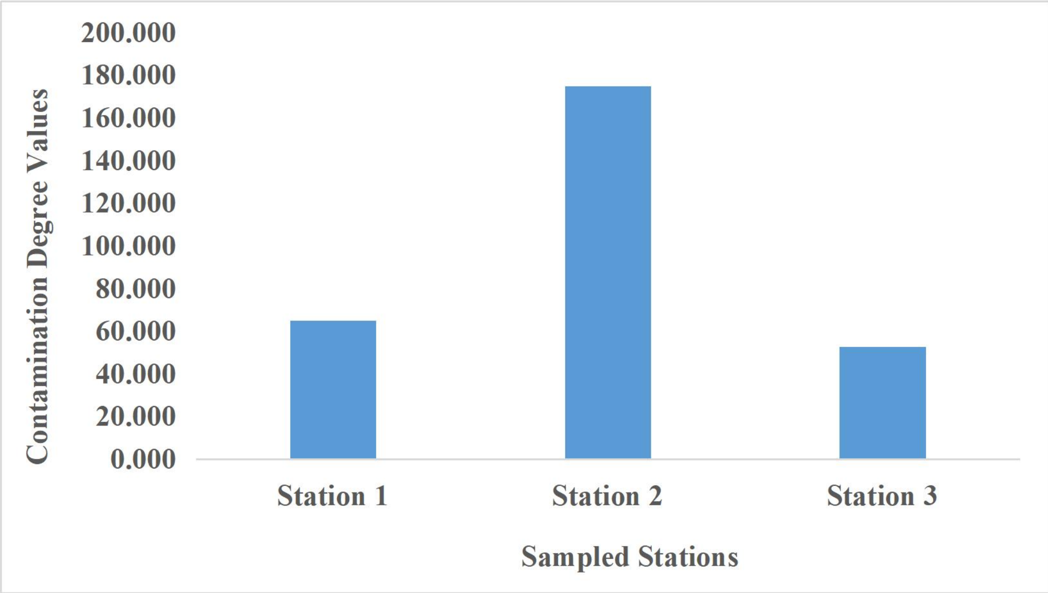

Figure 4.12: Contamination degree values in sediments from Ossiomo River

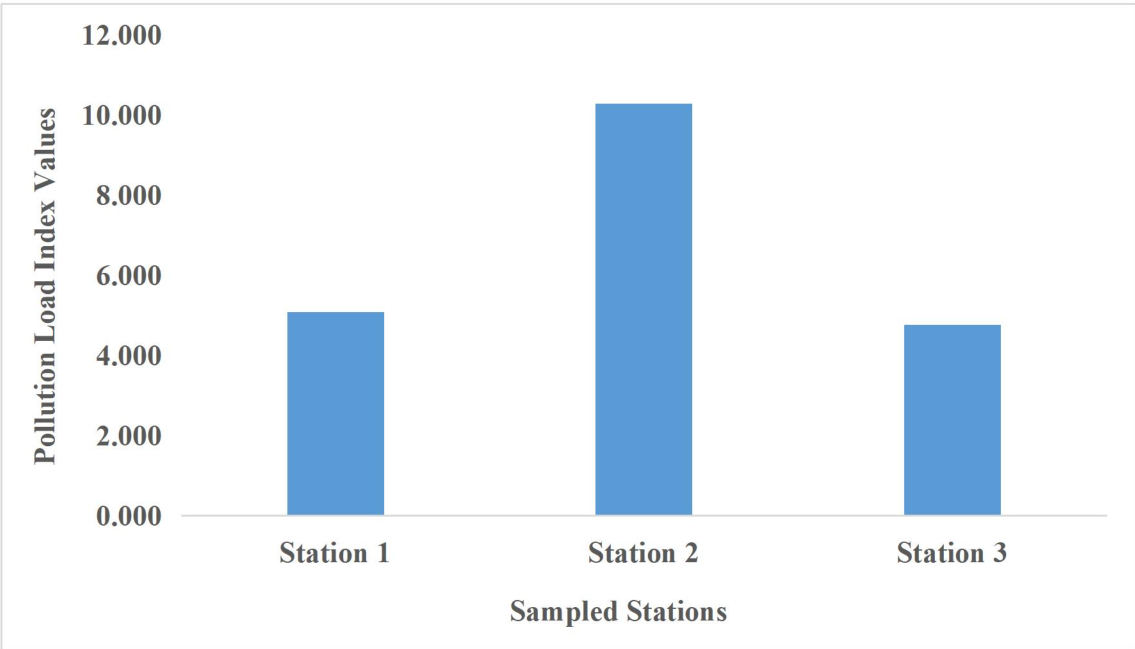

Figure 4.13: Pollution load index (PLI) values in sediments from Ossiomo River

4.2.4 Potential Ecological Risk Index (PERI)

Table 4.5 shows the Potential Ecological Risk Index (PERI) of heavy metal contamination in sediments across the three sampled stations from Ossiomo River. Interpreting the pollution degree for the sediments of the three sample stations of the study location, there was a slight pollution degree of Cr in station 1 and 3 (Ei_R<30), while there was medium pollution degree in station 2 (30≤ Ei_R<60). There was an extremely strong pollution degree of Cd across all the three sample stations of the study location (Ei_R≥240). There was a slight pollution degree of Cu, Zn, and Mn across all the three sample stations of the study location (Ei_R<30). There was a strong pollution degree of Pb in station 3 (60≤ Ei_R<120), a very strong pollution degree in station 1 (120≤ Ei_R<240), while an extremely strong pollution degree of Pb exist in station 2 (Ei_R≥240). Interpreting the risk level or risk degree, there is an extremely strong risk degree or level D across the sediments of the study location. When interpreting the potential ecological risk as explained by Hakanson (1980), station 1 and 3 indicates considerable ecological risk (300<RI≤600), while station 2 indicates a very high ecological risk (RI>600).

Table 4.5: Potential Ecological Risk Index (PERI) values of Sediments from Ossiomo River

	Station 1	Station 2	Station 3
Cr	21.414	33.998	24.881
Cd	300.000	620.000	315.000
Cu	9.111	13.167	11.889
Zn	1.911	4.326	2.715
Mn	1.867	2.911	1.237
Pb	175.000	591.667	103.333
Total	**509.303**	**1266.069**	**459.055**

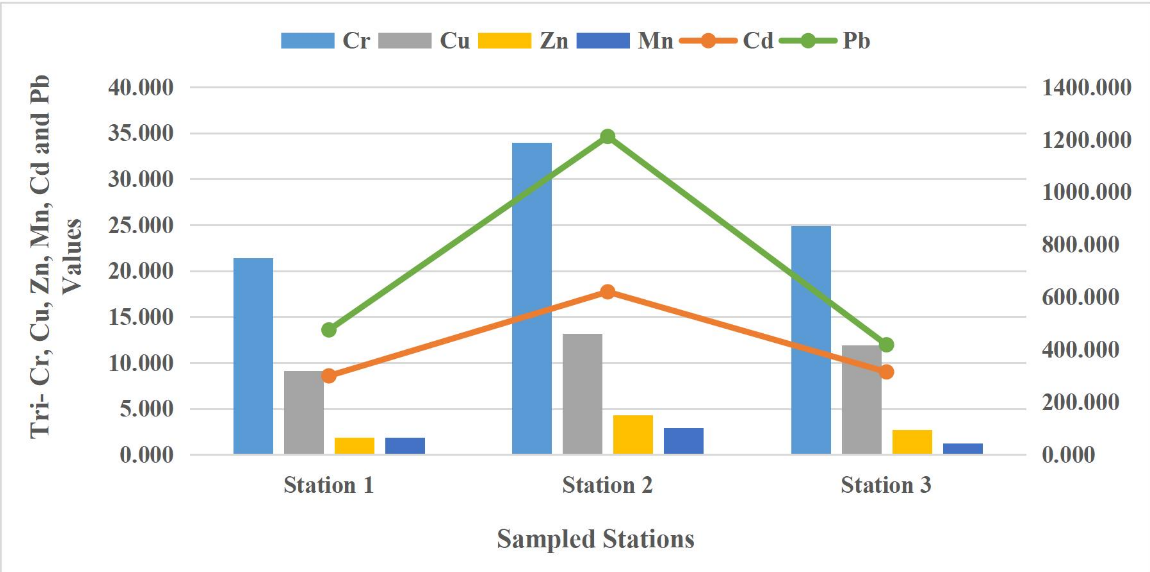

Figure 4.14: Potential Ecological Risk Index of heavy metals in sediments from Ossiomo River

4.3 CORRELATION MATRIX FOR HEAVY METALS IN SEDIMENT SAMPLES FROM OSSIOMO RIVER

The correlation analysis result expressed in table 4.6 reveals the correlation matrix for heavy metals in sediment from Ossiomo River. The table shows that Cu exhibited a positive and significant correlation with Fe. Zinc exhibited a positive and significant correlation with Fe. Cadmium showed a positive and significant correlation with Fe and Zn. Lead showed a positive and significant correlation with Cd. Manganese exhibited a positive and significant correlation with Fe and Cu while chromium showed a positive and significant correlation with Pb.

Table 4.6: Correlation matrix for heavy metals in sediment samples from Ossiomo River. Critical level of correlation coefficient for table 4.6 = 0.666 ($p<0.05$)df_2

	Fe	*Cu*	*Zn*	*Cd*	*Pb*	*Mn*	*Cr*	*THC*
Fe	1.000							
Cu	**0.779**	1.000						
Zn	**0.658**	0.421	1.000					
Cd	**0.634**	0.424	**0.650**	1.000				
Pb	-0.015	-0.205	-0.056	**0.620**	1.000			
Mn	**0.942**	**0.669**	0.501	0.482	-0.008	1.000		
Cr	0.217	0.317	-0.216	0.568	**0.714**	0.191	1.000	
THC	-0.450	-0.155	-0.121	-0.169	-0.231	-0.576	-0.019	1.000

CHAPTER FIVE

DISCUSSION

5.1.1 Heavy Metals in Sediments

The presence of heavy metals in the aquatic environment is an environmental and public health threat due to a number of their characteristics including biomagnification, bioaccumulation, persistence and toxicity (Ali *et al.,* 2019). These heavy metals come from a variety of natural and anthropogenic sources. In water bodies, sediments are the main sink for heavy metals and they play an important role in the cycling and transportation of these elements. Various processes which occur in water affect the resuspension of heavy metals from sediments in water (Cardoso *et al.,* 2019). Aquatic organisms especially those which live in proximity to or within sediments often accumulate high concentrations of heavy metals which then biomagnify in the food chain (Calmuc*et al.,* 2021).

Generally, the mean concentration of heavy metals in (mg/kg) in the sediments from Ossiomo River were in the following order Fe>Zn>Mn>Cu> Pb> Cr>Cd. Similar results have been by Ogbeibu et al., (2014) from Benin River and Anani and Olomukoro (2017) from Ossiomo River respectively. The mean variability of iron in the sediment samples were 821.17, 2005.33 and 586.43 mg/kg. Ayoade and Nathaniel (2018) recorded Fe concentrations of 11346.62mg/kg in sediments from a tropical manmade lake southwestern Nigeria while Emmanuel *et al.* (2018) higher iron concentrations ranging between 8928 – 13657 mg/kg for River Benue, North-Central Nigeria. However, the values exceeded those in a previous study on Ossiomo River by Anani and Olomukoro (2017) where iron concentrations ranged between 156.49 - 329.14mg/kg. Ogbeibu et al., (2014) recorded lower Fe concentrations of 1.88 -12.37 mg/kg in sediments from Benin River. There Fe concentration in this study exhibited no significant differences between the three sampled stations. However the value for Fe in this study were below the recommended limit of 5000 mg/kg by WHO, (2011) in Emmanuel et al., (2018).

The concentrations of copper in this study ranged from 5.47 mg/kg in station 1 to 7.90 mg/kg in station 2. Anani and Olomukoro (2017) recorded similar copper concentrations ranging from 4.52 - 10.73mg/kg from Ossiomo River, Edo State. Jabbi *et al.* (2018) with a mean sediment copper concentrations of 3.4mg/kg from Yardantsi Reservoir, Gusau, Nigeria. Lower concentration of Cu were by Ogbeibu *et al.* (2014) with mean values of 0.24 - 1.75 mg/kg from Benin River while higher concentrations of Cu with mean values of 4.0 - 17.5mg/kg were by Egbe and Ahunanya (2016) from River Gora, Kaduna. The Cu values obtained in this study showed no significantly different ($p>0.05$) across the three sampled station from Ossiomo River. However, Cu values in this study were below the recommended limit of 100mg/kg by WHO (2011) in Emmanuel *et al.* (2018).

The variability of Zn concentrations recorded in this study had an average mean value of 18.53, 41.97 and 26.33 mg/kg respectively from three sampled stations. Lower zinc values were obtained by Anani and Olomukoro, (2017) from Ossiomo River and Jabbi *et al.,* (2018) from of Yardantsi Reservoir, Gusau, Nigeria. However, higher values of 107.73 – 117.62 mg/kg were obtained for Zn by Okafor and Opuene (2007) in sediments. However, Zn values in this study were below the recommended limit of 300 mg/kg by WHO, (2011) in Emmanuel *et al.* (2018). The highest values for Zn in this study were recorded in station 2 as this can be attributed to anthropogenic activities that could have increased the concentration in Ossiomo River. While there were variations in the concentrations of zinc across the sampling stations, these variations showed no significantly different ($p>0.05$).

Cadmium values in this study recorded the least concentration of heavy metals from Ossiomo River. The mean values for Cd were 0.10, 0.21 and 0.11 mg/kg in stations 1, 2 and 3 respectively. The concentrations of cadmium in this study was lower than those from similar studies. Emmanuel *et al.* (2018) recorded higher values of cadmium (1.85 - 2.80mg/kg) from River Benue, North-Central Nigeria. Also, higher Cadmium concentrations values of 1.80 - 5.89mg/kg were obtaiend by Anani and Olomukoro (2017) in sediment from Ossiomo River. However, the values observed in this study is higher than the values of 0.09mg/kg obtained by Abata *et al.* (2013) in sediments from River Ala, Nigeria. Cadmium values across the stretch of Ossiomo River exhibited a significant difference ($p<0.05$) across the three sampling stations.

The variability of lead (Pb) in this study were higher in station 2 than stations 1 and 3. The mean values of lead in this study were 3.50, 11.83 and 2.07 mg/kg in stations 1, 2 and 3 respectively from Ossiomo River. However, Pb concentrations in this study were below the recommended value of 100 mg/kg in sediments by WHO, (20111) in Emmanuel *et al.,* (2018). There was an observed wide variation in the concentrations of lead obtained in station 2. Higher concentration of Pb were by Okafor and Opuene (2007) with values ranging from 112.02 - 119.3mg/kg in sediments from Taylor Creek, Bayelsa State, Nigeria and Egbe and Ahunanya (2016) with Pb values of 47.62 - 320mg/kg from River Gora, Kaduna. Emmanuel *et al.* (2018) obtained a higher value of 102mg/kg for Pb concentrations from River Benue, North-Central Nigeria. However, Ogbeibu *et al.* (2014) obtained lower values of 0.15 - 1.10mg/kg in sediments for Pb from Benin River. Anani and Olomukoro (2017) reported concentrations for lead in sediments from Ossiomo River in the range of 1.41 - 6.36mg/kg while Jabbi *et al.,* (2018) obtained a lower lead concentrations of 0.07 - 0.30mg/kg from of Yardantsi Reservoir, Gusau, Nigeria. Lead concentration in this study exhibited no significant difference ($p>0.05$) across the sampled stations from Ossiomo River.

Manganese concentrations in this study had average mean values of samples 8.40, 13.10 and 5.57 mg/kg in stations 1, 2 and 3 respectively. There was no significant differences ($p>0.05$)

in Mn values across all sampling stations. Higher manganese concentrations were observed by Emmanuel *et al.* (2018) with values of 75 - 253.5mg/kg in sediments of River Benue and 13.33 - 24.50mg/kg obtained by Anani and Olomukoro (2017) in sediments from Ossiomo River. Okafor and Opuene (2007) recorded very high Mn values of 177.51 - 266.9mg/kg from Taylor Creek, Nigeria and attributed the high value of manganese to the introduction of run-offs and other human activities from surrounding aquatic environment. Manganese values in this study were below the recommended limit of 750 mg/kg by WHO, (2011).

The lowest variability of chromium in this study fluctuated with a range of 0.32 mg/kg in while the highest level of variability was 7.42 mg/kg in station 2. These levels can be attributed to the presence of hydrocarbons and the use of additives such as detergents around the bank of Ossiomo River. The average mean of chromium in stations 1, 2 and 3 from Ossiomo River were 3.44, 5.46 and 3.99 mg/kg respectively. The result of this study is similar to the values of 2.26 - 3.71mg/kg obtained by Okafor and Opunene (2007) from Taylor Creek, Nigeria. Lower concentrations of 0.72 - 2.23mg/kg were reported by Jabbi *et al.* (2018) from of Yardantsi Reservoir, Gusau, Nigeria. Previous study by Ogbeibu *et al.* (2014) from Benin River and Anani and Olomukoro (2017) from Ossiomo River recorded very similar values of chromium concentrations ranging from 1.99 - 4.89mg/kg and 0.63 - 3.97mg/kg respectively. On the other hand, Abata *et al.,* (2013) obtained very high concentration of Cr (20.30mg/kg) from River Ala, which were higher than the values observed in this study. Chromium values in this study were below the maximum allowable limits of 100 mg/kg in sediments by WHO, (2011).

Hydrocarbon content of 3400 – 6800 mg/kg represents a high level of hydrocarbon contamination on the site (Osuji, and Nwoye, 2007). This assertion is different to the values of THC obtained in sediments samples from Ossiomo River. However, the concentrations of THC in sediments were high and showed a significant difference ($p<0.05$). The average mean values of THC in this study were 700.49, 445.96 and 1333.94 mg/kg in stations 1, 2 and 3 from Ossiomo River. A review of existing data on the Niger Delta by Niger Delta Environmental Survey (1999) and Osuji *et al.* (2004) confirms the effect of such high hydrocarbon levels on both above-ground and subterranean flora and fauna, which affects the availability of plant nutrients in the biogeochemical cycle (Osuji and Nwoye 2007). The high hydrocarbon levels in this study have provided proof of adverse contamination of the sediments by hydrocarbon content. An increase in the values of these contaminant indicators pose a serious threat to human health and environment. It is therefore crucial to pay immediate attention to it because most living organisms depend on the aquatic environment for survival and humans also depend on it for fishing purpose.

5.1.2 Enrichment Factor (EF)

The findings from this study indicated that there is a moderate enrichment for Fe and Zn, a significant enrichment for Fe, Cr, Cd and a very high enrichment for Pb in Ossiomo River. Similar values for enrichment factor of heavy metals in sediments were obtained in a study by Jiao *et al.* (2018). The result of this study is very similar to the study of Aiwekhoe *et al.*, (2019) who assessed heavy metal contamination of Otofure Dumpsite, near Benin City and showed high enrichment for Zinc (Zn), very high enrichment for chromium (Cr), lead (Pb) and nickel (Ni), an extremely high enrichment for chromium (Cr), lead (Pb), cadmium (Cd) and vanadium (V). This is likely to be influenced by the municipal waste that have emptied itself into Ossiomo River through runoffs which suggests androgenic origin that is always connected with surrounding environment that receives all kinds of waste ranging from domestic to commercial waste (Aboyade, 2004).

5.1.3 Geo-accumulation Index (*Igeo*)

The findings using *Igeo* indicates Cu and Mn were practically unpolluted ($Igeo \leq 0$) across the sampled stations, Cr and Cd were moderately to heavily polluted ($2 < Igeo < 3$) in station 2, while Pb was heavily polluted in station 1 (3<Igeo<4) and extremely polluted (5>Igeo) in station 2. Thus, it is possible to ascertain that the activities of man carried out in Ossiomo River are relatively detrimental to the aquatic environment which has shown to increase the level of metals in the sediments. Observations from various studies have revealed that heavy metals such as Zn, Pb, Cd and Ni, amongst others are associated to certain diseases that have lethal effects on man and animals, and their accumulation and long-time retention by plants and animals is very dangerous. Similar results have been reported by Ogbeibu *et al*., (2014) from Benin River.

5.1.4 Contamination factor (CF), Contamination Degree (CD) and Pollution Load Index (PLI)

The findings from this study shows a moderate contamination exist for Cu and Mn across the sampled stations from Ossiomo River, a very high contamination exist for Cr, Cd, and Pb across the three sample stations. Adopting Hakanson (1980), a very high degree of contamination (CD ≥ 24) exists across all the three sample stations. Tomlinson *et al.,* (1980) described PLI which states that when PLI > 1, pollution exist; otherwise, if PLI < 1, there is no metal pollution. In respect to sampled stations from Ossiomo River, the PLI values across the three sample stations indicates that PLI > 1 which signifies that pollution of Ossiomo River. Aiwekhoe et al., (2019) contamination values that exhibited a moderate contamination for iron (Fe), manganese (Mn) and copper (Cu), very high contamination for zinc (Zn), chromium (Cr), cadmium (Cd), lead (Pb), nickel (Ni) and vanadium (V). Also the Pollution load Index (PLI) showed that Otofure dumpsite is polluted (PLI > 1) by heavy metals which are similar to the results of this study where sediments from Ossiomo River were analysed. The PLI values obtained in this study were in the following order Station 3 > Station 1 > Station 2. The values for pollution load index in this present study were higher than those reported for heavy metals in sediments in the Benin river by Ogbeibu *et al.* (2014) who values of 0.0038 - 0.0221. These metals are used in our manufacturing industries in Nigeria and are commonly used in our homes as well as fungicides, pesticides and herbicides which are our house hold commodities before and after disposal that ends up in our surface water bodies (Dirisu et al., 2019)

5.1.5 Potential Ecological Risk Index (PERI)

The results of this study shows that there is a slight pollution degree of Cu, Zn, and Mn across all the three sample stations ($Ei_R<30$), a medium pollution degree of Cr in station 2 ($30\leq Ei_R<60$), a strong pollution degree of Pb in station 3 ($60\leq Ei_R<120$), a very strong pollution degree of Pb in station 1 ($120\leq Ei_R<240$) while Cd exhibited an extremely strong pollution degree ($Ei_R\geq240$) across all the three sampled stations from Ossiomo River. Interpreting the risk level or risk degree, there is an extremely strong risk degree or level D across the sediments of the study location. When interpreting the potential ecological risk as explained by Hakanson (1980), station 1 and 3 indicates considerable ecological risk ($300<RI\leq600$), while station 2 indicates a very high ecological risk ($RI>600$). Cadmium have been reported as one of the most eco-toxic metals with highly undesirable effects on aquatic health, humans, animal health and plant metabolism in Kabata-Pendias, (2000). Chronic exposure to very low cadmium concentrations can result to insomnia, cardiovascular diseases, anaemia and renal problems (Sharma *et al*., 2006). The values for PERI in this study are greater than those in previous studies (Simsek *et al.,* 2021). There is an urgent need to develop a soil and water monitoring programs in order to ascertain and prevent surface water and groundwater contamination; this is particularly significant in view of the location of Ossiomo River.

5.1.6 Correlation Matrix for Heavy Metals in Sediment

The variability of heavy metals as expressed using correlation coefficient showed that Cu exhibited a positive and significant correlation with Fe. Zinc exhibited a positive and significant correlation with Fe. Cadmium showed a positive and significant correlation with

Fe and Zn. Lead showed a positive and significant correlation with Cd. Manganese exhibited a positive and significant correlation with Fe and Cu while chromium showed a positive and significant correlation with Pb.

It can be observed in this study that the heavy metals content exhibited a positive and significant correlation between them and therefore may have originated from common sources, preferably from different industrial and commercial activities as well as contribution from oil spill pollution in Ossiomo River from vehicular traffic. These correlations can be explained by the fact that these elements have a common source (Otari and Dabiri, 2015) and therefore the pollution by heavy metals in sediments from Ossiomo River should not be ignored.

5.2 CONCLUSION

Heavy metal contamination in the aquatic environment is a source of concern for environmental and public health due to their adverse effects. Sediments are the main sink for heavy metals in the environment. This study was conducted to assess the ecological risk associated with selected heavy metals present in sediment from Ossiomo River, Nigeria. The results obtained showed that heavy metals concentration in the sediments did not exceed their respective reference values as prescribed by the WHO. However, ecological risk analysis via several indices including Geoaccumulation index, Contamination factor, Enrichment factor and Potential ecological risk index revealed that presence of heavy metals in the sediments were a potential threat to ecological health especially Cadmium, Lead and Chromium. The contamination of sediments by these three metals is of anthropogenic origin and measures should be implemented to arrest the release of these metals into Ossiomo River.

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