Evaluation of Heavy Metals in Water, Sediment, Fish and Flora from Six Selected Dams in Osun State, South-Western, Nigeria

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Certification

This thesis entitled “Evaluation of Heavy Metals in Water, Sediment, Fish and Flora from six Selected Dams in Osun State, South-Western, Nigeria.” Was carried out by Ishola, Abdul Dimeji with matriculation number LCU/PG/001032 in the Department of Chemical Sciences, (Chemistry Unit), Faculty of Natural and Applied Sciences, Lead City University, Ibadan, Nigeria under my supervision.

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Dedication

This research work is wholeheartedly dedicated to God Almighty the creator, the beneficent, the merciful, the supreme who created me and to my brothers, sisters, relatives, mentor, friends, and colleagues who shared their words of advice and encouragement to finish this study.

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Abstract

Heavy metals accumulation in consumables such as water, fish and plants are a threat to public health since their consumption is considered a primary route of human exposure to Potentially Toxic Elements (PTEs). This study investigated the physicochemical properties and concentrations of Cd, Cr, Cu, Fe, Ni, Pb Mn and Zn in a total of 204 samples comprising 60 Surface water, 60 sediments, 60 Tilapia (*Oreochromis niloticus*), 12 Okra (*Abelmoschus esculentus*) and 12 Bitter leaf (*Vernonia amygdalina*) samples collected from six dams in Osun State between October and November 2019. Values obtained were subjected to descriptive, bivariate and multivariate statistical analyses and also compared with WHO permissible standards. All physicochemical values for the surface water were below the WHO permissible limit except for BOD, COD and Turb which were above the WHO limit of 10, 4 and 5 mg L^{-1} respectively. Elemental concentrations in surface water were below the WHO limit except for Cd (0.006 mg L^{-1}) at one site and Ni (0.03 - 0.04 mg L^{-1}) for approximately 67% of the sites. Also, elemental concentrations in sediments were greater than the WHO limits except for Cu and Cr. Although the average concentrations of PTEs in plants were below WHO permissible limits, average concentrations of PTEs in fish exceeded the WHO maximum permissible levels of 0.7, 0.6, 0.3 and 0.3 mg kg^{-1} for Cr, Ni, Cd, and Pb respectively. Generally, PTEs concentrations in fish were in the decreasing order of Ni > Cd > Pb > Cr and the mean concentrations of Cr, Ni, Pb, and Cd ranged from 1.18 to 2.31, 3.15 to 3.92, 2.36 to 3.73 and 0.41 to 14.2 mg kg^{-1} respectively. Furthermore, human health risk assessment data revealed that the consumption of Tilapia, Okra and Bitter leaf from these dams are not safe for consumers.

Keywords: Trace metals, Edible vegetables, Fish, Hazard quotient, Dams.

Word Count: 299

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List of Acronyms

Abbreviation	**Meaning**
WHO	World Health Organization
LCU	Lead City University
BDATs	Best Demonstrated Available Technologies
CCA	Copper Chromium Arsenic
MeHg	Methyl Mercury
ICOLD	International Commission on Large Dams
ICID	International Commission on Irrigation and Drainage
IHA	International Hydropower Association
WCD	World Commission on Dams
LGAs	Local Government Areas
AAS	Atomic Absorption Spectrophotometer
COD	Chemical Oxygen Demand
BOD	Biochemical Oxygen Demand
DO	Dissolved Oxygen
TSS	Total Suspended Solid
TH	Total Hardness
TDS	Total Dissolved Solid
EDI	Estimated Daily Intake
CDI	Chronic Daily Intake
HQ	Hazard Quotient
RfD	Reference Dose
TCR	Target Carcinogenic Risk

PTE	Potentially Toxic Element
THQ	Target Hazard Quotient
NIMET	Nigerian Meteorological Agency
USEPA	United State Environmental Protection Agency
USEPA IRIS	United State Environmental Protection Agency Risk Information System
CSF	Cancer Slope Factor
APHA	America Public Health Association
ANOVA	Analysis of Variance
BW	Body Weight
CMA	Correlation Matrix Analysis

Chapter One

Introduction

1.1 Background to the Study

Heavy metals are a group of naturally occurring elements with a density greater than 5 g cm^{-3}. These metals are hazardous even in small quantities[1]. Chromium (Cr), arsenic (As), lead (Pb), manganese (Mn), cadmium (Cd), iron (Fe), copper (Cu), zinc (Zn), nickel (Ni) and mercury (Hg) are common examples of heavy metals. Heavy metals can be sorted into two fundamental groups: necessary for life (biologically essential) and not needed for living organisms (biologically non-essential). Copper (Cu), iron (Fe), zinc (Zn) and nickel (Ni) are biologically essential heavy metals that are beneficial to living systems when present in moderate amounts. However, if the concentration is too high, they become toxic. On the other hand, heavy metals such as lead (Pb) and cadmium (Cd) are not essential to life, and are harmful even at very low concentations[2]. Due to various domestic and industrial applications, heavy metals have been dispersed throughout the environment and this has caused concern over their whereabouts, toxicity, and potential consequences to the environment and human health. Unlike organic pollutants, heavy metals are unrelenting and can enter the food chain, resulting in a build-up in living creatures. Therefore, this is also an issue of public health. If the concentrations of these metals in water and food surpass the limits recommended by the World Health Organization, it could have a detrimental effect on the life forms that take it in. Although minor concentrations suggest that the health risks are low, there are still challenges that must be confronted[3,4].

Heavy metals can have a detrimental effect on metabolic activities in two key ways: by accumulating in and disrupting vital organs and glands such as the heart, brain, kidneys, bone, and liver. Additionally, prolonged exposure to multiple heavy metals has been linked to an increased risk of developing cancer, particularly through the ingestion of dust contaminated with

Nickel[5]. The particles of essential and non-essential heavy metals which are released into aquatic habitats from human activities such as industrial and agricultural practices interfere with the proper functioning of the ecosystem by pushing out the vital dietary components from their intended places[6]. Fish are commonly used as a source of protein for humans, making them ideal for measuring the level of heavy metal pollutants in the environment. By entering a water source, these pollutants accumulate in the tissues of fish, making them an effective indicator of contamination[7,8,9,10.] Studies have indicated that sediment has a greater uptake of heavy metals than water, as revealed by its higher concentrations of said metals[11]. Sediments that have been contaminated with heavy metals can act as a source of pollution that does not originate from one particular area[12]. This geochemical normalization technique can be utilized to evaluate the contamination level of heavy metals in sediments and the related risks to human health[13]. An assessment of the contamination level of heavy metals in sediment often involves the application of statistical techniques[14].

The examination of heavy metal levels in liquids, sediment, aquatic habitats, and vegetation is of substantial inquiry due to the hazardous nature of these metals and their capacity to amass in living things[15]. In addition, unregulated discharge of wastewater from residential and industrial sites, in conjunction with air pollutants from vehicle exhausts and commerce, may lead to large concentrations of heavy metals in surface water, such as lakes. Furthermore, the use of pesticides and fertilizers in agricultural processes may add to contamination in surface water. Both essential and nonessential metals can be hazardous if encountered in high concentrations, with their respective toxicity dependent on their type and bioavailability. Prolonged exposure to substantial levels of metals like nickel, and zinc, can cause respiratory issues, cardiac problems, pancreatic ailments, anemia, abdominal pain, and cancer[16]. Prolonged exposure to large amounts of copper can have damaging effects on the body's immunity, its organs - such as the liver and kidneys - as well as causing gastrointestinal problems, Wilson's disease, and heightened levels of anxiety[17].

Humans can be responsible for potentially devastating environmental degradation due to their actions. Contamination of damaging chemicals and heavy metals in sediment leads to major health woes, not to mention the ecological woes. This build-up of these toxins in sediment as an effect of human activities can be particularly damaging to the environment and its inhabitants[18]. Despite the potential benefits of certain levels of heavy metals, their presence beyond a certain amount can result in acute or chronic poisoning. Some plants can absorb heavy metals and concentrate them, resulting in a heightened chance of harm. Additionally, living organisms including insects, bacteria, fungi and nematodes, as well as abiotic influences, can create biological stress throughout the entire process of germination and maturation[19].

The damage caused by a buildup of heavy metals can be greater than what the body's processes of breaking down, storing and eliminating toxins can handle[20,21].

The quantities of potentially dangerous metals and metalloids need to be closely monitored in the environment and the results of those investigations studied in order to evaluate and reduce the risks of metals on human and wildlife health[22,23]. Environmental media such as sediments, soils, water and animal matter must be examined regularly in order to identify the sources, locations, and ultimate fate of these elements in the environment, as well as their potential for biomagnification in food chains. This data will be essential in conducting an accurate assessment of metal pollution and devising the necessary corrective actions.

1.2 Statement of the Problem

The increase in technology, accelerated industrialization, urbanization, population growth, and other types of human activity have caused serious pollution of the environment by heavy metals, especially in developing countries such as Nigeria. These pollutants are released into water sources which can be intensely accumulated and passed up aquatic food chains, causing lethal and nonlethal repercussions on flora and fauna. Such water contamination has been an issue of worry for many years due to its potential threat to public drinking water supplies and the danger to humans who consume aquatic life and other aquatic biotas. This contamination has caused considerable anxiety and the necessity for adequate information regarding it.

1.3 Justification of the Study

Dams in Osun State are a significant source of water and protein consumption for humans. They are second to groundwater in providing clean drinking water, and the raw materials they generate are used by the Water Board to supply domestic households with water in the area. Additionally, they provide a low-cost source of protein. To determine the cleanliness of these aquatic ecosystems, this study assesses the physical and chemical properties of the water and sediment in six selected dams as well as the quantity of elements found in the nearby fish, vegetables, and other organisms.

1.4 Aim and Objectives of the Study

The study aims to investigate the concentrations of selected heavy metals such as: iron (Fe), lead (Pb), zinc (Zn), Nickel (Ni), chromium (Cr), copper (Cu), cadmium (Cd) and manganese **(**Mn) in water, sediment, fish fauna and flora from six selected dams in Osun State, Nigeria.

The specific objectives were to:

(i) determine the selected physico-chemical parameters status of the six selected dams.

(ii) evaluate the daily human exposure to the studied heavy metals through the ingestion pathway

(iii) estimate the safety of the consumption of fish and commonly planted vegetables within the communities.

(iv) assess the elemental interaction in samples and identify possible sources of potentially toxic elements (PTEs) in fish samples using bivariate and multivariate statistical analyses respectively.

1.5 Research Questions

i. What are the levels of heavy metals in water, sediment, fish and flora from the six selected dams from Osun State?

ii. What are the levels of PTEs in water, sediment, fish and flora samples from six selected dams from Osun State?

iii. What are the environmental impacts of these heavy metals and PTEs?

1.6 Significance of the Study

In recent years, heavy metals have emerged as the primary pollutants of surface water, leading to significant detrimental effects, particularly on human health which depends on them as the source of potable water. In Osun State, the Water Board utilizes raw water from the dams to generate potable water for domestic water supply to households. Consequently, this study will provide baseline information about the concentrations of heavy metals in water, sediment, fish and plants as well as the human health risk involved in the consumption of fish and plants from the six selected dams in Osun State, South-Western, Nigeria.

1.7 Scope of the Study

This study assesses the concentrations of eight (8) heavy metals namely Fe, Pb, Zn, Ni, Cr, Cu, Cd and Mn, in water, sediment, fish and flora samples from six selected dams in Osun State, South-Western, Nigeria.

1.8 Limitation of the Study

This study considers the determination of selected heavy metals (Fe, Pb, Zn, Ni, Cr, Cu, Cd and Mn) concentrations in water, sediment, fish and flora only. The study also assesses the human health risk involved in the consumption of consumables such as water, fish and plants from the six selected dams in Osun State, South-Western, Nigeria.

1.9 Operational Definition of Terms

To ensure clarity and consistency, the study will use the following operational definitions:

a) **Heavy Metals:** For the purpose of this study, heavy metals refer to metallic elements with high atomic weights, such as lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), and other elements known for their potential toxicity and persistence in the environment.

b) **The Environment:** refers to the natural surroundings and conditions in which living organisms exist.

c) **Toxicity:** refers to the degree or extent to which a substance or agent can cause harm or damage to living organisms

d) **Dams:** are large structures built across rivers or streams to control and regulate the flow of water.

e) **Health Risk Assessment:** is the process of evaluating the potential adverse effects of a hazard or exposure on human health.

f) **Anthropogenic Activities:** are human actions that directly or indirectly affect the environment.

g) **Pollutant:** a pollutant is a substance or agent that contaminates the environment, causing harm to living organisms and ecosystems.

h) **Contamination:** contamination refers to the presence or introduction of unwanted substances into an environment. It can occur in various mediums such as air, water, soil, or food.

Endnotes

[1] Z. Fu & S. Xi, “*The Effects of Heavy Metals on Human Metabolism*”, **Journal of Toxicology mechanisms and methods**, 30(3), 2020,167-176.

[2] B. A. Joda, H. S. Alheloo, H. J. Al-Mankosh & S. A. Maitham, "*Determination of Heavy Metals Arsenic, Cadmium and Lead in Water, Sediments and Fish from Al Delmaj Marshes-Iraq*," InAIP Conference Proceedings, 2144(1), 2019,020012. AIP Publishing LLC.

[3] G. A. Engwa, P. U. Ferdinand, F. N. Nwalo, & M. N. Unachukwu, “*Mechanism and Health Effects of Heavy Metal Toxicity in Humans*”, Poisoning in the modern world-new tricks for an old dog. 10, 2019, 70-90.

[4] S. Sobhanardakani, L. Tayebi, & S. V. Hosseini, "*Health Risk Assessment of Arsenic and Heavy Metals (Cd, Cu, Co, Pb, and Sn) through Consumption of Caviar of Acipenser Persicus from Southern Caspian Sea*", **Environmental Science and Pollution Research,** 25(3),2018,2664–2671.

[5] S. Sobhanardakani, "*Ecological and Human Health Risk Assessment of Heavy Metal Content of Atmospheric Dry Deposition*, A Case Study: Kermanshah, Iran", **Biological Trace Element Research**, 187(2), 2019,602–610.

[6] D. Witkowska, J. Słowik, & K. Chilicka, “*Heavy Metals and Human Health*: *Possible Exposure Pathways and the Competition for Protein Binding Sites*”, **Molecules**, 26(19), 2021,6060.

[7] S. Rajeshkumar, Y. Liu, X. Zhang, B. Ravikumar, G. Bai & X. Li, "*Studies on Seasonal Pollution of Heavy Metals in Water, Sediment, Fish and Oyster from the Meiliang Bay of Taihu Lake in China*", **Chemosphere**, 191, 2018, 626-638.

[8] N. A. Alrabie, F. Mohamat-Yusuff, R. Hashim, Z. Zulkeflee, A. Arshad & M. N. Amal, "*Heavy Metals Concentrations in Stormwater and Tilapia Fish (Oreochromis Niloticus) in Kuala Lumpur Holding and Storage SMART Ponds, Pertanika*", **Journal of Tropical Agricultural Science**, 42(1), 2019,225- 236.

[9] S. Rajeshkumar, & X. Li, "*Bioaccumulation of Heavy Metals in Fish Species from The Meiliang Bay, Taihu Lake, China*", **Toxicology Reports**, 5, 2018, 288–295.

[10] R. Milacic, T. Zuliani, J. Vidmar, M. Bergant, E. Kalogianni, E. Smeti, N. Skoulikidis, & J. Scancar, "*Potentially Toxic Elements in Water, Sediments and Fish of The Evrotas River under Variable Water Discharges*, " **Science of the Total Environment,** 648, 2019, 1087–1096.

[11] Q. Liu, Y. Sheng, M. Jiang, G. Zhao, & C. Li, "*Attempt of Basin-Scale Sediment Quality Standard Establishment for Heavy Metals in Coastal Rivers*", **Chemosphere**, 245, 2020,125-596.

[12] Z. Huang, C. Liu, X. Zhao, J. Dong, & B. Zheng, “*Risk Assessment of Heavy Metals in The Surface Sediment at The Drinking Water Source of The Xiangjiang River in South China*”, **Environmental Sciences Europe**, 32, 2020,1-9.

[13] J. Feng, Y. Lin, M. Li, T. Ouyang, & M. Yu, “*Characterization and Risk Assessment of Heavy Metals in Surface Sediments from Jian and Moyang Rivers in Western Guangdong*”, **Frontiers in Environmental Science**, 2022, 1040.

[14] M. A. Salam, S. C. Paul, F.I. Shaari, A. E. Rak, R. B. Ahmad, & W. R. Kadir, "*Geostatistical Distribution and Contamination Status of Heavy Metals in the Sediment of Perak River, Malaysia*", **Hydrology**, 6(2), 2019,30.

[15] X. Miao, Y. Hao, H. Liu, Z. Xie, D. Miao, & X. He, “*Effects of Heavy Metals Speciations in Sediments on Their Bioaccumulation in Wild Fish in Rivers in Liuzhou—A Typical Karst Catchment in Southwest China*”, **Ecotoxicology and Environmental Safety**, 214, 2021,112099.

[16] T. Javed, N. Ahmad, & A. Mashiatullah, "*Heavy Metals Contamination and Ecological Risk Assessment in Surface Sediments of Namal Lake, Pakistan,* "Polish **Journal of Environmental Studies**, 27(2), 2018, 675–688.

[17] S. Buxton, E. Garman, K. E. Heim, T. Lyons-Darden, C. E. Schlekat, M. D. Taylor, & A. R. Oller, "*Concise Review of Nickel Human Health Toxicology and Ecotoxicology*", **Inorganics**, 7(7), 2019, 89.

[18] J. Briffa, E. Sinagra, & R. Blundell, "*Heavy Metal Pollution in the Environment and Their Toxicological Effects on Humans*", **Heliyon**, 6(9), 2020,6.

[19] Y. Al Naggar, M. S. Khalil, & M. A. Ghorab, "*Environmental Pollution by Heavy Metals in The Aquatic Ecosystems of Egypt*", **Open Access Journal of Toxicology,** 3(1), 2018, 555603.

[20] E. Giménez, M. Salinas & F. Manzano-Agugliaro, "*Worldwide Research on Plant Defense against Biotic Stresses as Improvement for Sustainable Agriculture*, **Sustainability**, 10(2), 2018, 391.

[21] M. Abdul Baki, M, M, Hossain, J. Akter, S. B. Quraishi, M. F. H. Shojib, A. K. M. Atique Ullah & M. F. Khan, " *Concentration of Heavy Metals in Seafood (Fishes, Shrimp, Lobster and Crabs) and Human Health Assessment in Saint Martin Island, Bangladesh*, **Ecotoxicology and Environmental Safety,** 159, 2018, 153–163.

[22] S. Rajeshkumar, & X. Li, " *Bioaccumulation of Heavy Metals in Fish Species from The Meiliang Bay, Taihu Lake, China*", **Toxicology Reports**, 5, 2018, 288-295.

[23] P. Garai, P. Banerjee, P. Mondal, & N.C. Saha, “*Effect of Heavy Metals on Fishes: Toxicity and Bioaccumulation*”, **Journal of Clinical Toxicology**, 18, 2021.

Chapter Two

Literature Review

2.1 The Environment

The surge of industrial and agricultural development has caused a notable upturn in the discharge of hazardous heavy metals into the environment, posing a grave danger to both vertebrate and invertebrate life forms. Low concentrations of these metals can interact with the soil and result in a nutrient shortage· In the last several decades, research has been conducted to quantify levels of contamination in public food sources, primarily in fish. Although heavy metal is a repetitive term, it applies to a variety of contaminants in both aquatic and terrestrial ecosystems, like lead (Pb), zinc (Zn), cadmium (Cd), copper (Cu), and manganese (Mn). All of them are dangerous to living organisms at lower concentrations. The presence of pollutants such as metals in aquatic ecosystems can cause serious harm to the environment and the health of humans, plants, and animals[1]. To understand their presence, it is necessary to monitor and identify the concentration of these elements in the water, sediments, fish and plants. Atomic Absorption Spectrophotometer was used for this purpose in order to study the levels of metals present in a dam and its surrounding areas. Different subsets of the population from different areas were sampled at varying distances from the source, and then analyzed for their pollutant content. Different metals such as Lithium (Li), Beryllium (Be), Boron (B) and those from element 91 to V in the periodic table were identified as potential contaminants. Their properties and associated environmental impacts had to be examined for their presence in the environment. The results of the sampling process with AAS will determine the overall impact of pollutants on the ecosystems as well as the measures required in order to reduce their concentration. Thus, regular monitoring of pollutants in aquatic ecosystems through AAS analysis provides valuable information to protect our environment and human health.

Heavy metals are entering the environment through natural causes and human activities. These sources can include natural erosion of the earth, mining, soil deterioration, industrial outputs, city drainage, sewage outpourings, illness or insect control products used on plants, and air pollution fallout. Most individuals are affected by the presence of these pollutants through their daily meals (food and water)[2]. Heavy metals are a family of minerals with a high atomic mass and relatively high density. Examples of these include lead, mercury, cadmium, arsenic, and chromium. Over time, the presence of heavy metals has increased in the atmosphere, through industrial and agricultural activities, due to their non-biodegradable nature. They can enter the food chain through the uptake of polluted water or soil, by consuming food grown in contaminated areas, or because of the presence of airborne particles. These metals can also enter the body directly through inhalation or skin contact.

When heavy metals enter the body, they are absorbed by organs such as the lungs, intestine, and skin and can gain access to the bloodstream and eventually reach various tissues. They spread throughout the body, affecting vital organs. Yet, their capacity to cause damage and toxicity depends on their concentration[3]. Even a low level of these metals can have a negative long-term effect, if the organism is continually exposed to them.

To evaluate the levels of exposure, it is essential to understand all the sources from which these metals may come, and to assess and quantify their presence in the environment and human. This is when biomarkers come into play. These molecules, proteins, and enzymes, which can be easily obtained from biological samples, can detect and measure the levels of metals in the body. Additionally, atomic emission spectroscopy (AES), inductively coupled plasma emission spectrometry (ICPES), and electrochemical systems or voltametry are the most widespread separation and detection techniques used to measure the concentrations of these metals found in the environment and foodstuffs.

2.2 Definition and Description of Pollution

In today's globalized and industrialized world, pollution has become an increasingly pressing issue due to the polluting activities of humans. More and more resources are used for energy production and industrial facilities, driving the emission of chemicals, toxins, and greenhouse gases into the atmosphere. This situation has been made worse by transportation, as cars, ships, and aircraft all expel pollutants into the environment. Moreover, improper waste management has been the cause of an increase in the emission of harmful substances that are poised to cause catastrophic damage to our health over time[4].

Furthermore, emissions from factories contribute to air pollution which is known to cause respiratory diseases, skin cancer, and asthma. Deforestation has caused the global warming of our world, due to the inability of trees to absorb carbon dioxide. Water pollution has caused a decline in marine life, hazardous chemicals being found in drinking water, and ocean acidification due to CO_2 emissions.

It is now clear that pollution causes grave damages to our planet and its inhabitants. Fortunately, governments and citizens all over the world are beginning to take necessary steps to deal with this issue. There is, for example, an increasing awareness of the importance of environmental sustainability, leading to an increase in the number of countries that have signed the Paris Agreement. Measures such as the introduction of renewable energy, recycling, and improved waste management, are helping to reduce the amount of pollutants that are released into the environment[5].

Soil pollution can have a wide range of deleterious effects on both the environment and human health. As the presence of pollutants can decrease soil fertility, crop yields may suffer. Furthermore, when exposed to toxic elements, soil organisms are vulnerable to bioaccumulation; making food more hazardous for human consumption. Pollutants can also operate by leaching;

whereby dangerous materials enter into groundwater and erode the organic matter of the soil. In certain environments, this can lead to an increased rate of water contamination, leading to increased instances of gastrointestinal distress or the spread of infected waterborne illnesses. Air pollution too can exacerbate soil pollution, containing particles which can remain in the soil and foster the spread of disease.

The significant threat posed by soil pollution necessitates the implementation of proactive steps to both prevent further contamination and purify existing damage. The principles of sustainable and regenerative agriculture can be applied in order to limit the amount of chemicals or waste used. Renewable sources of energy, such as solar and wind energy, can be utilized in order to reduce the amount of air pollutants which enter into soil environments. Furthermore, locally sourced materials can be used to return nutrients to the soil, appropriate waste management procedures can be enforced, and administrative policies can ensure that soil quality is monitored in areas of human activity.

Ultimately, soil pollution is a serious ecological and health hazard. Through the thoughtful implementation of preventative measures, the risk of contamination can be significantly reduced. By taking proactive steps to limit soil pollution, we can ensure a more sustainable environment for future generations[6].

The global population has increased exponentially over the last century, and with this increase in population, so too has a concomitant increase in human activities leading to the deposition of metals into aquatic environments. Recently, trace metal pollution has become a major problem, as even extremely low concentrations of metal can significantly affect biogeochemical processes and alter locally the equilibrium of trace metal concentrations in water systems. Metals can become concentrated in sediments due to gravitational settling, sedimentation or resuspension of sediment particles, or adsorption of metal to the surface of larger sediments. They can also be taken up by bacteria and other organisms via metal bio-transportation processes. In addition, metal-containing particles created by industrial processes can be deposited onto the sediments. The accumulation of metal in sediments can lead to a reduction of species diversity, affecting food webs, species spawning cycles, and bioavailability. High levels of metals can also decrease water clarity and the availability of oxygen and other nutrients by reducing the photosynthetic activity of aquatic plants.

Recently, many studies have been conducted to assess the levels of metal accumulation in sediment and the effects of these compounds on aquatic life. The levels of metal contamination of aquatic ecosystems vary depending on the type and concentration of metal, the availability of other materials for adsorption, and the rate at which it is deposited. Also, the impact of metals on the aquatic environment depends on the dose and duration of exposure, the presence of other pollutants, and the species of the aquatic organisms. Therefore, comprehensive studies that cover a wide range of geographic locations, footprints, and ecosystems are necessary to better understand and manage trace metal pollution[7]. Heavy metal pollution has become a major concern in many parts of the world due to its adverse impacts on the environments, human health and socio-economic activities. For example, high levels of lead and cadmium can affect nerve and immune system functionality as well as normal metabolic activities. Heavy metals can also disrupt the nitrogen cycle by interfering with the nitrogen fixation process. The accumulation of toxic levels of heavy metal in the soil can lead to a decrease in organic matter content and soil fertility. Additionally, heavy metal pollutants can be passed on through the food chain, leading to toxic effects in humans, animals, and aquatic life.

In response to the growing risk of heavy metal pollution, various governmental, non-governmental and scientific organizations have tried to research, mitigate and monitor its environmental impact. However, there is still a long way to go in this endeavor, as lack of facts, resources, and public awareness still present major impediments to progress in this critical field. Awareness and enforcement of existing regulations, long-term monitoring of the environment, public education, and periodic updating of policies and laws are some of the key strategies for reducing the likelihood of human and environmental exposure to heavy metal pollutants.

The spread of heavy metal pollution and toxicants are caused by a variety of causes such as air pollution, land erosion and waste management. Therefore, it is important to consider preventive measures in order to reduce the impact of heavy metal pollution on human health, aquatic ecosystems and the natural environment. Continuous monitoring, implementation of sustainable waste management practices and strict enforcement of environmental regulations are also essential if we wish to reduce the risk of heavy metal pollution.

Overall, heavy metal pollution is a serious environmental and public health concern with far-reaching impacts. It is essential to take both preventive and corrective measures in order to mitigate the risks posed by this growing and complex problem. We must establish effective laws, monitor the environment and raise public awareness to effectively manage and reduce the danger posed by heavy metal pollution.

In Nigeria, there is an urgent need to address the issue of pollution and contamination of rivers in order to secure safe food for human consumption and to preserve the ecosystem. Heavy metals are particularly dangerous, as they have been linked to a large array of negative health effects, and as a result, it is essential to minimize their accumulation in aquatic systems[8]. Moreover, the intensity of their buildup is accelerated by activities such as farming and dumping of refuse.

The Nigerian government has taken steps to combat the problem, such as introducing regulations and regulations that prohibit the disposal of industrial waste in rivers. However, this is only a small step in the right direction. It is essential that more effort is made to actively monitor and enforce these regulations, as well as take other measures, such as engaging in educational campaigns and appropriate land use management. Local authorities also have a role to play in educating the public about the potential health-related dangers associated with consuming contaminated fish, and in increasing monitoring in order to detect high levels of pollution.

Overall, it is essential that the Nigerian government, local authorities, and communities work together to address the problem of contamination of rivers in Nigeria. This can occur through a range of initiatives and regulations that aim to reduce the amount of pollutants entering rivers, as well as properly educate the public. If these steps are taken, it will help to ensure that the fish in these rivers remain safe to consume and will protect the environment and human health[9]. Toxic metals are a class of substances that can have detrimental effects on human health and the environment. These metals, while not essential to the functioning of the human body, can be ingested or absorbed into the bloodstream when exposed to them through industrial pollutants or naturally occurring sources. The most common toxic metals include arsenic, lead, mercury, and cadmium.

These metals tend to accumulate in the organs of the body, such as the liver and kidneys, increasing the risk of poisoning if these metals become too plentiful. For this reason, exposure to industrial pollutants like oil shale, fly ash, and water runoff can lead to heavy metal contamination in the environment. These pollutants can lead to 62% of all heavy metal pollution, including lead, nickel, cadmium, chromium, and manganese, and can accumulate in reservoirs and other aquatic species, leading to death due to direct physical contact as well as changes in behavior.

At high levels of contamination, toxic metals in the environment can also lead to ingestion of harmful substances through food, water, and air. While the long-term effects of metals ingested in this way may not be fully understood, it is likely that they can cause major health damage over time. Additionally, while these metals may not be essential to the functioning of the human body, they can interfere with metabolic processes, causing toxic build-up in cells, and leading to various medical problems[10]. When hazardous heavy metals are present, they can accumulate in the food chain, settling in living organisms such as fish. This can make aquatic creatures unsafe to eat, as their bodies are now polluted with contaminants. Ingestion and inhalation of those metals can be dangerous for aquatic wildlife.

Ultimately, understanding the complex nature of pollutants, such as heavy metals, is essential to providing effective and efficient controls on the environmental and public health risks that threaten Nigeria. It is up to the scientific community, governing bodies and the population of Nigeria to come together and put the necessary policy changes and safety guidelines in place to protect the nation's valuable resources and the welfare of its people from longstanding heavy metal pollution.

Heavy metal pollution in Nigeria is a growing concern. The lack of comprehensive studies, data collection and analysis have meant that the risks to both the environment and human health have been mostly overlooked. It is essential that the scientific community, governments and citizens come together to ensure safety measures are put in place to ensure the nation's resources and population are safeguarded. Research into contamination levels, uptake and accumulation of pollutants, toxicity and risk, and human health risks need to be evaluated in order to provide effective environmental and public health controls. In particular, data needs to be collected to document how pollutants accumulate in aquatic ecosystems and their effect on the environment, as well as the health of those exposed to toxins. These steps would enable informed decisions to be made on how to best protect against the ill-effects of heavy metal pollution in order to ensure a safe and healthy future for Nigeria[11]. Urban contaminants tend to be mainly organic substances, which can drastically increase the nutrient content for primary producers, leading to eutrophication and ultimately deoxygenation of water.

The water around Chikachi has been affected by toxic metals, due to the industrialization that has taken place in the area. Pollution from agricultural runoff, discharges from factories, and sewage from the local settlements have all contributed to the metals in the river[12]. The accumulation of these metals has caused serious damage on the local environment - they block the riverbed gravels which spawning fish rely on, reduce light penetration, and increase the growth of plants and algae, resulting in reduced oxygen levels. These metals are toxic to human health as well, and can cause a host of health issues. Soils can become contaminated with heavy metals through deposition of dust, fertilizers and runoff from high-traffic roads. Contamination can also come from production sites, incinerators and waste dumps. Copper and iron, while beneficial in moderation, can become toxic if they accumulate in high quantities. However, other heavy metals, including cadmium, mercury and lead, are dangerous even in tiny amounts[13].

The industrialization of Chikachi has caused immense damage to the local environment, with an abundance of toxic metals poisoning the waterways and soil. This has resulted in poor water quality, as well as other impediments to economic activities. These metals can be hazardous to both human and animal health, making it essential to take measures to reduce their spread in the area. Ways to lower heavy metal levels include better waste management systems, improved agricultural and industrial practices, and improved pollution control. Ultimately, the importance of protecting this local environment lies upon the community - and it is up to them to secure the bright future of Chikachi, free of toxic metals.

The Joint Food and Agriculture Organization of the United Nations /World Health Organization (FAO/WHO) Food Standards Programme Codex Committee on Contaminants in Foods, 13th

Session has established a provisional tolerable weekly intake (PTWI) for heavy metals to ensure that levels of exposure pose no potential harm to human health. Four of the most toxic heavy metals, including mercury (Hg), cadmium (Cd), lead (Pb), and arsenic (As), have been assigned safe levels, with the PTWI for mercury being the most stringent, at 0.0014 mg/week. This is because even the slightest intake of the metal can be dangerous to a person's health[14]. This indicates the impact of these four heavy metals, as well as the various sources of exposure.

2.3 Bioavailability of Heavy Metals in Soil

Bioavailability of heavy metals in soils depends on various physical, chemical, and biological factors. This complex process determines if an organism will be adversely affected when exposed to contaminants[15]. Investigations have discovered that the capacity of metals to organisms diminishes after time has passed since they were put in the soil. Metals found in soil may be split into five sections, bound to organic matter, adhered to carbonate components, tied to manganese oxides, transferable, and left-over metal. The greater part of metals is limited to organic matter or adsorbed to solids and thus not free and increasingly hard to access. The degree of metal bioavailability is dependent on its chemical form, which can influence its mobility and the degree to which it is accessible to the organism.

Zinc (Zn) is an essential element for all organisms due to its contribution to healthy and balanced growth. Zinc is necessary for a number of biological processes, and its deficiency can cause severe health issues in plants, animals and humans alike. A number of environmental factors affect the concentrations and availability of zinc (Zn) in soil, making it difficult to accurately assess zinc levels and determine its effects.

The total zinc content of soil is determined by the amount of zinc originally present in the soil, as well as any zinc that is added to the soil in the form of fertilizers or pesticides. Soil pH, cation exchange capacity, exchangeable cation, organic matter content, mineralogy and clay content also affect zinc levels. Adsorption, desorption, precipitation, dissolution and complexation processes have an effect on zinc concentrations, as they determine the amount of zinc that is dissolved in the soil solution and therefore available for uptake by plants.

Organic matter content typically plays a role in increasing the total zinc content, by helping to bind zinc molecules to soil particles and redistribute them throughout the soil. Clay particles in soil can also bind to zinc, while mineralogy can affect zinc solubility. Cation exchange capacity can reduce pH levels, which increases zinc solubility and therefore its availability for uptake by plants.

The total zinc content and bioavailability of zinc (Zn) in soil vary significantly due to the numerous factors influencing its concentration and availability. High zinc concentrations can be toxic to plants and animals and can cause health problems if it accumulates in food crops and water supplies. Therefore, it is important to accurately assess zinc levels in soil to avoid any potential problems[16].

2.3.1 Soil pH

Soil pH is an important environmental factor that affects the growth and development of plants, animals, and microorganisms. The range from acidic to alkaline soil is between 0 and 14. The optimal range for most plants is between 6.2 and 7.2, although certain crops prefer slightly different pH levels, for example, potatoes prefer higher pH (6.5-7.0). Soils with a pH below 5.5 may damage the roots of plants, while soils with a pH above 8.0 can also be detrimental to plant growth.

Soil pH is also an important factor in the availability of plant nutrients, such as phosphorus, potassium, and magnesium. Microbial activity, including nitrification and denitrification, is also affected by soil pH. For example, under acidic conditions, nitrification is inhibited, reducing the availability of nitrogen, a major macronutrient for plants. Similarly, in alkaline soils, certain bacterial species may not be able to survive and function efficiently.

Soil pH affects the chemical, physical, and biological properties of the soil and is an important parameter for understanding the chemical, biological, and physical properties of a soil system. It can also affect the availability of chemical elements, such as calcium, magnesium, and aluminum. As such, soil pH is a major factor in controlling the availability of nutritionally important chemical components and microorganisms. Soil pH can be altered by the addition of organic material, chemical fertilization, irrigation, liming, or other management practices, and can have a significant impact on soil fertility[17].

At lower pH levels, zinc (Zn) is more readily available for plant uptake. In contaminated soils, zinc (Zn) is typically released at low pH, which then subsequently increases its solubility. This makes zinc (Zn) more accessible and plant uptake increases. In alkaline soils, zinc (Zn) is normally absorbed to silicate clays and oxides and is less available for plant uptake because of reduced solubility. Additionally, zinc (Zn), cadmium (Cd) and nickel (Ni) were all reported to be released in soils from a mine in Togo at a low soil PH.

In contrast, high pH levels can cause zinc (Zn) precipitation of zinc carbonate and zincate compounds or $Zn(OH)_2$, leading to a decrease in the concentration of zinc available for plant uptake. In Australian laterite soils, zinc (Zn) solubility increased to 3000 mLg-1 when the soil pH was low. This highlights the importance of soil pH levels in controlling the solubility levels of zinc (Zn) for plant uptake. In general, for optimum plant uptake of zinc (Zn), it is recommended to maintain soil pH levels of 6.5 to 7.5[18].

2.3.2 Cation Exchange Capacity

It is understood that the Cation exchange capacity (CEC) of soil is an essential property affecting its behavior. The CEC refers to the power of the soil to store positively charged cations (Mg^{2+},

Ca^{2+}, Na^{+}, K^{+}, H^{+}, Al^{3+}, Mn^{2+}, Zn^{2+}), which are held in place on negatively charged sites. These mineral and organic particles are invariant when subjected to changes in pH, meaning that the cations contained within the soil can be replaced by other cations, making them exchangeable. The CEC depends on the mineralogy and organic matter content of the solid, with a higher clay particle and organic matter content associated with a higher CEC. Soils with a negative charge possess a significant CEC and low cation mobility. A higher CEC of the soil leads to a greater absorption and immobilization of metals[18].

2.3.3 Organic Matter Content

Organic matter serves as a key component of soil fertility as it adds nutrient elements to soil, making them available for plant uptake. It also acts as a source of energy for the growth and activities of micro-organisms, involved in nitrogen fertilization, and organic matter increases the retention of water and nutrients. Additionally, organic matter improves the structure, fertility and the ability to maintain pore space in the soil, thus improving the soil's resistance to erosion and facilitating water movement.

Organic matter affects many physical and chemical characteristics of soils, such as soil porosity, cation exchange capacity, microbial population, and activity. It increases aggregate stability and can be used as an indicator of soil health. Research shows that increasing organic matter in soil has positive effects, especially regarding increasing soil productivity and soil biodiversity. Industrial waste water contamination can reduce organic matter in soils and the success of any agricultural activity depends upon maintaining appropriate levels of organic matter in soils. Zinc is an essential mineral nutrient for plants, but it is less available to plants in high concentrations. In order to increase its availability, zinc can form more stable complexes with certain organic substances, such as humins, fluvics, humics, amino, and carboxylic acids. By combining itself with these organic molecules, zinc becomes less available to plant life and as a result, less damaging. It requires more energy for plants to break down the organic molecules in order for them to access and utilize zinc, resulting in better plant growth and higher tolerance to zinc-heavy soils. Additionally, the presence of these organic molecules shields the zinc from environmental factors, such as rainfall, which would otherwise leach it away. This makes zinc more persistent in the soil and creates an opportunity for multiple cycles of plant growth using the same source of mineral nutrition. In essence, the formation of zinc and organic complexes provides an efficient solution for sustaining healthy levels of zinc for healthy plants[19].

2.3.4 Clay and Hydrous Oxides

Weathering is a natural process that breaks down certain minerals over time. It is responsible for the formation of clay and hydroxyl, small substances with an enormous surface area which allows them to trap and remove heavy metals present in water and soils. Studies have proven its usefulness in decontamination of industrial and agricultural wastewater, where the agents of sorption, precipitation and liming are employed for this purpose.

Most clays used for this application have an incredibly small size, particles measuring no more than 2 micrometers in width. These are an important component of the soil, enriching it with minerals and other essential components. Overall, weathering has an important role in the environment, helping to improve soil fertility and reduce air, water and soil pollution. It is also responsible for the formation of clays with a multitude of applications areas, including the removal of heavy metals. Clay minerals are extremely small particles which are found in abundance in soils. These minerals have a high surface charge, which is due to their small size and high number of surface charges. This active surface enables cation adsorption and attraction. Clays and hydrous oxides (containing Al, Fe, and Mn) have a natural adsorptive capability when it comes to contaminants and can grab ions and cations through a process known as adsorption or ion exchange. When the level of clay and hydrous oxide increases in a soil, these particles act as sites for metal adsorption and decrease metal bioavailability within the soil. In this way, clay minerals are responsible for the regulation and management of contaminants within the soil[20].

2.3.5 Conditions of Redox

Redox potential is a measure of the tendency of certain substances to accept or donate electrons, or become oxidized or reduced. Since organic molecules are the main source of electrons to the soil, a low redox potential can negatively affect the microbial growth. It can reduce nutrient availability, as well as its capacity to retain water. Similarly, high redox potential may produce toxic products in the soil, affecting the germination rate of the vegetation.

It is therefore vital to determine how the redox potential of a soil influences microbial activity. In order to do so, researchers need to investigate the effects of the redox potential on the processes of molecular respiration, enzyme activity, growth regulation and yield of bioproducts.

By studying how redox potential affects microorganisms, scientists may be able to improve agriculture practices, as well as better understand the spatial and temporal variability of the redox potential of soils around the world. While much information is already available, further research is still necessary to make better use of the redox potential to improve soil fertility. Redox reactions in soils are largely determined by the solubility of metals and water molecules. Scientific studies have shown that zinc availability is improved with repeated, short-term waterlogging events and low redox potential. This could be due to the water creating a favorable environment that increases the solubility of zinc. On the other hand, some authors dispute this notion, claiming that the presence of standing water and low redox potential could actually reduce metal bioavailability in soils. This may be because standing water and low redox potential create a favorable environment for steel sulphide formation, which binds to metals and decreases solubility.

It is important to understand the effects that redox reactions can have on metal availability in soils. By fully comprehending the effects of waterlogging on metal solubility, it is possible to develop soil management plans that maximize metal availability in certain areas. To this end, further research is needed to clearly understand the role of waterlogging and low redox potential in metal solubility, as well as the development of steel sulphide[21].

2.3.6 Aging of Metals in Soil

Metal aging is a phenomenon that is important when it comes to reducing the risk of heavy metal soils to the environment. A process of transformation occurs over time where the metal is moved away from the surface of soil particles into areas that are less accessible. This time-dependent process is mostly decided by the uneven distribution of liquids and solids, resulting in a lower level of bioavailability.

One of the most significant effects of metal aging is the decrease in exposure levels to both animals and humans. Since the metal is less accessible, the risk of exposure to high levels of metals is reduced. This consequently reduces the negative consequences they can have on both the environment and the health of people and animals.

In addition, metal aging can also partly explain the decreasing contamination levels in a certain area, even though input rates remain largely constant. As the metals become less accessible over time and move further away from the surface of the soil particles, their concentration decreases. This can be beneficial to soil ecosystems and the environment as a whole.

Overall, metal aging is an important phenomenon that can help to reduce the environmental risks of heavy metal soils. Through the gradual process of decreasing accessibility, the exposure of animals and humans is reduced, and overall contamination levels can also lessen[22]. As the metal ages in soil and passes through processes such as binding to oxidized iron and aluminum minerals of low reactivity, its ability to desorb from the soil solid phase into the soil pore water is inhibited, resulting in a reduction of environmental risk.

2.3.7 Adsorption and Desorption

Sorption is a useful process in which substances are held on or near the surface of a solid material. In general, this process occurs by the physical forces of attraction between the particles of the two substances. Adsorption is specific in that the particles forming the interface between the two materials are not equally dispersed and the rate of sorption is influenced by the surface area of the absorbent. An example of adsorption is the dirt-sticking strength of clay minerals, which results from the attraction of dust particles to the surface of the clay.

The phenomenon of sorption is widely observed in industries such as petroleum, metal recovery processes, air filtration, waste water treatment and biotechnology. A popular example of sorption is the use of activated charcoal for air purification and odor removal. In this instance, the charcoal powder is spread throughout an air stream. As air passes through the powder, odors and gaseous molecules are trapped within the charcoal's highly porous structure.

Other scientific applications of sorption include chromatography and the separation of very small molecular scales. In chromatography, highly specialized sorbents are used to separate different types of molecules based on their size and polarity. To increase the accuracy of separation, a variety of solvents, temperature and pressures can be used to shift the adsorptive properties of the separation medium. The ability of immobilization agents to reduce the amount of bioavailable Cd in soil depends on many factors, such as natural soil pH, the particle size and structural stability of the immobilizing agent, and the degree of Cd contamination. A wide variety of immobilizing agents may be used, including natural organic compounds, such as humic and fulvic acids; inorganic compounds, such as hydroxides and oxides of iron, aluminum, and calcium; and clay-based materials, such as bentonite and zeolites.

Immobilization agents can be added to soil in several ways, including land-applied manures and composts or the conversion of contaminated soil phases to the form of cement or plaster. The effectiveness of immobilization agents in reducing Cd bioavailability is typically assessed by laboratory bioassays, including column and batch tests. Several chemical and physical characterization techniques, such as scanning electron microscopy, X-ray diffraction and chemical analyses (e.g., chemical extraction tests), are also used to evaluate the effectiveness of immobilization agents.

Immobilizing agents are an effective and simple way to reduce available Cd in soil. These agents bind to metals, preventing the plants from absorbing them, and the metals remain in the soil where they are not able to cause any further harm. By using immobilization agents to reduce the bioavailability of Cd in soil, negative environmental and health effects can be minimized. Humidity plays a major role in how trace metals interact and attach to soil particles. When the associated humidity is low, the soil particles are more likely to become dry and unable to absorb cations. As soil humidity increases, the soil particles will become saturated and more likely to absorb cations. The amount of trace metals that can be absorbed will depend on the charge of adsorption sites, the content of humic substances, phyllosilicates, and other variable-charge minerals, and the associated humidity in the soil. Low humidity results in low trace metal sorption, while high humidity will allow the soil to have an increased capacity for trace metal sorption. The charge of adsorption sites, the content of humic substances, phyllosilicates and other variable-charge minerals will also determine how much trace metal can be sorbed in the soil. Furthermore, by manipulating the humidity of the soil, it might be possible to adjust the trace metal sorption to achieve the desired outcome. In conclusion, humidity is an important factor which affects trace metal sorption by soil, influencing the capacity of trace metal sorption as well as the success of metals binding with the soil surface.

Soil composition affects the binding capacity of its colloidal surfaces, directly affecting the adsorption and desorption of Zinc in the soil. Clay minerals such as Kaolinite, Illite, Vermiculite and Chlorite possess high cation exchange capacity (CEC) and offer greater binding stability to trace metals. The pH of the soil is an important factor affecting the availability of Zinc to plants. If the pH of soil is too low or too high, Zinc bound to soil colloids become less available to plants. Hydrous oxide compounds like Aluminium, Iron and Manganese act as scavenger sites for Zinc in the soil by forming stable bonds with the metal. Further, organic matter also affects the adsorption of Zinc in soil by governing its surface charge, thereby affecting the binding of trace metals.

Overall, the composition of clay minerals, soil pH, hydrous oxides, and organic matter all influence the adsorption and desorption of Zinc in soil. This, in turn, affects the availability of Zinc for plant uptake. Thus, to ensure optimum availability of Zinc in soils, it is important to consider these factors[23].

2.3.8 Dissolution and Precipitation.

Agglomeration is the preferred technique when attempting to increase the size of individual particles. This process involves combining smaller particles together to form larger, more nearly spherical particles. This approach is often employed in precipitation and crystallization processes, as the larger particles tend to settle faster, yielding a higher purity product. Additionally, larger particles are more likely to adhere to each other than smaller, irregularly-shaped particles are, resulting in higher yields.

Dissolution and precipitation are essential stages in the presence of metals in soil. These processes involve the release and recapture of metals from the environment, respectively. During dissolution, the solubility product constant is exceeded such that the metal ions become available for uptake. The availability of these metal ions is determined by the pH and the concentration of the anions such as sulphate, phosphate, and carbonate. Immobilization of metals can also take place in the presence of these anions, especially at high pH and metal concentration.

Due to its capability to form large particle sizes quickly and efficiently, agglomeration is the only viable option for size enlargement in precipitation processes. This method is efficient and can yield higher purity products due to its ability to produce large and spherical particles which settle down faster and are more resistant to fragmentation. Hence, agglomeration remains the preferred option to increase the size of individual particles in precipitation and crystallization processes.

A large amount of Zinc (Zn) can be held by soil before it is precipitated. When metals combine with oxygen or hydrogen to form oxides or hydroxides, they become solid and will likely precipitate. Additionally, sulphides can be utilized to effectively remove high concentrations of toxic heavy metals. Reverse precipitation is the process by which solids are broken down into their separate soluble components. Many factors influence how available the soil is to plants and how soluble the metals in it are, including pH and the type of metal present. These factors are responsible for the precipitation and solution process[24].

2.3.9 Complexation

Metal complexes can form a vital part of numerous technologies such as in gas phase catalysis and corrosion protection. By forming these metal complexes in a solution, the metals can remain usable for a longer amount of time. This is due to an increase in the reactivity level of the metal, and allows for a much more efficient production.

Metal complexation also helps with various aspects in the environment. It allows for slowly released metals from solutions and aids in reducing the level of available toxic metals from permeating the environment. This is because some metals, such as Zinc (Zn) and Lead (Pb), have high levels of toxicity for humans and animals. So, complexation helps to minimize the amount of these metals reaching the environment, which helps protect human and animal health.

Besides the environmental impact, metal complexation also contributes to the potential of future technologies. Researchers have been able to create functional bio-complexes just by using naturally occurring ligands, forming a kind of "biomolecular spring-board" based on the coordination environment of the metal. This can allow for the production of more efficient catalysts and extend the ways we are able to use materials in different applications.

Metal complexation is a vital part of many different applications and technologies. It helps increase the solubility of metals and protects the environment from toxic metals. It also opens up a wide variety of opportunities for the production of more efficient catalysts. Complexation is an essential part of modern technologies and shows great promise for what can be done in the future.

Organic matter of a humic nature is present in many surface water sources, including lakes, rivers and streams. These substances have a heightened capacity for complexation, making them a great choice for many different applications. Natural ligands for complexation include citric acid, fulvic acids, humic acid fractions and oxalic acid. Meanwhile, synthetic ligands are often powerful molecules such as ethylenediaminetetraacetic acid (EDTA), diethylenetriaminepentaacetic acid (DTPA) and ethylenediaminedisuccinic acid (EDDS). These various ligands make for a great range of choice for applications such as water purification, ion exchange, waste management and more. By using these ligands, complexation is enhanced and many processes can be improved[25].

2.3.10 Chemical Speciation

The type of form in which an element appears in a solution is determined by its speciation. Some studies show that the free metal ion form is the most toxic type of metal. Metals can be present in soils in both soluble and solid phases. These metals exist in solution as complexes that are bound to either organic or inorganic compounds, or as free ions. Metal ions in a solid state may be held onto soil particles due to the processes of ion exchange or surface complexation, or as minerals mixed together with other metal particles. The form that a metal takes in a soil can affect its toxicity and availability for uptake[26].

2.4 Heavy Metals Toxicity

Heavy metals can be released into the environment as a result of industrial emissions, irresponsible disposal of certain chemical products and by-products, and overexploitation of natural resources. The health of both humans and other species is put at risk due to the high levels of toxicity of these metals. Multiple negative effects on organisms and ecosystems have been observed such as reduced reproductive success, impaired development, changes in populations, and genetic damage, along with the disruption of enzyme pathways.

Therefore, further research should be done to address the issues surrounding the release of heavy metals. A concerted effort among governments, industries and individuals is necessary in order to reduce its spread with containment and treatment practices and regulations, better air and water quality control, improved industrial waste management, and the support of responsible resource management. All these actions may have a chance at mitigating or eliminating the dangerous effects of heavy metals on the environment[27].

2.4.1 Lead (Pb)

Lead is an environmental pollutant that has a wide range of adverse health effects, particularly on the nervous system. Exposure to lead poisoning can cause a number of medical issues, including decreased kidney function, damage to the respiratory, urinary, and cardiovascular systems, and neurological impairments. Pregnant women exposed to lead have at a greater risk of experiencing negative outcomes such as stillbirths, low birth weight, and delays in neurodevelopment. In addition, crucial organs such as the brain and kidneys can experience long-term chronic damage due to even low-level lead exposure.

It's important to note that lead is one of the most widespread environmental pollutants, with multiple industries such as coal burning, cement production, metal smelting, and road transportation emitting large amounts of lead into the air. Heavy metal toxins such as lead finds its way into the earth's closest soil layer, making humans and wildlife alike susceptible to high levels of lead poisoning. Immediate steps need to be taken to contain the spread of lead and reduce its levels in the environment if we are to safeguard the health of populations and the environment.

Investigations into lead contamination suggest that the most significant emission sources are motor vehicle engines and industrial processes. The combustion of leaded gasoline, for instance, results in the release of lead into the atmosphere, leading to its presence in the soil. The majority of lead emissions are from the exhaust system of motor vehicles and from industrial processes.

Although the use of lead in the industrial sector has decreased considerably over recent decades, lead still exists in various products and finds its way into the environment. In residential areas, lead-based paint is a significant source of lead contamination. Inhalation of lead dust can lead to adverse health effects, especially in children and pregnant women.

Research has demonstrated that soil lead levels in environments that are heavily polluted with lead can reach 20 cm in depth. Lead is known to have a low reactivity, and therefore it does not disperse further than 20 cm into the soil. Lead contamination tends to be found in and around heavily trafficked areas and metropolitan areas due to the concentration of lead emitted by motor vehicles and industrial processes. Pre-industrial revolution levels of lead in the air were much lower than current levels, indicating that lead contamination has increased considerable in the last hundred years due to the increased use of lead-based products and motor vehicles.

The reduction in lead release into the environment has been significant, but it is still found in many places. Lead can be found in drinking water and soil, as it is toxic to most living organisms. It is also used in paints, batteries and many other products. As a result, the biggest source of environmental lead can be ingestion of lead-contaminated soil and dust.

Lead poisoning is linked to several health problems, such as delayed mental and physical development, hearing problems, anemia, problems with growth and development, and learning difficulties. Low levels of lead exposure can reduce IQ and cause attention problems, making it especially dangerous for pregnant women and children.

Fortunately, the amount of lead released into the environment has been decreasing for some time now. This means less lead will be ingested and less negative effects will result from exposure. Exposure to lead still has detrimental effects on physical and mental health, however new regulations and policies have largely been successful in reducing the amount of this hazardous metal in the environment. Lead is a toxic metal which is found in the environment, both in the air, soil and water supply. Even in small amounts, it can have potentially devastating health effects. It is particularly dangerous to infants, young children and pregnant women.

In infants and children, lead can lead to delayed physical and mental development, as it can interfere with the development of red blood cells and cause biochemical changes. In adults, lead can damage organs such as the kidneys, as well as cause high blood pressure. It is also associated with increased oxidative stress on placenta metabolism, increasing the risk of miscarriage in pregnant women.

Lead poisoning can be prevented through adequate ventilation, reducing lead in clothing and toys, controlling dust and soil lead contamination, and proper nutrition. All drinking water supply should also be tested for lead contamination regularly.

Medical treatment of lead poisoning also exists. This involves administering EDTA or dimercaptosuccinic acid (DMSA) to bind the lead in the digestive system and decrease toxic levels. However, prevention is the best approach to minimising lead poisoning. Therefore, awareness of lead safety should be increased, especially among those living in areas where lead contamination is likely.

The ingestion of lead can lead to serious health concerns, particularly for children. Long-term health repercussions are seen in the form of cognitive deficits, lower IQs, behavior and conduct issues and neuropsychiatric disorders. Other health concerns associated with lead ingestion include anemia, hearing and vision issues, as well as kidney and brain damage. Renal injury is seen in adults and increased blood pressure as lead affects the cells of the kidneys and vasculature.

Lead consumption through food, water, air and some consumer products has been examined and measured by different countries to regulate levels. Lead present in the environment is mostly due to the mining of lead and burning of fossil fuels, although contamination of soil and groundwater is also a cause. With the reduction of in-use lead in products such as paint and gasoline, levels of lead present in the environment have decreased, albeit slowly. In some countries, it is still used for manufacturing and for pipes in older domestic water systems, leading to contamination of drinking water. Monitoring lead ingestion and avoiding lead in products is key to avoiding the potential health risks it poses[27].

2.4.2 Cadmium (Cd)

Cadmium contains high levels of toxicity that can be detrimental to the ecological system and living organisms[28]. Not only is it naturally present in the environment, it also arises due to agricultural and industrial activities. The amount of cadmium permitted in drinking water is 5pgl- and the risk for contamination of soil and water is higher in areas with a concentration of copper (Cu), zinc (Zn) and lead (Pb). It is produced non-necessarily and emitted into the atmosphere from mines, metal smelting factories, alloys, batteries, pigments, and as an additive in plastics[29].

Cadmium (Cd) exposure from smoking is particularly significant and numerous studies have indicated that tobacco smoke is the greatest source of human exposure to this harmful compound. In fact, the World Health Organisation estimates that smokers may be willing to be exposed to levels up to 200 times higher than for non-smokers. This is due to multiple factors such as the direct inhalation of tobacco smoke, as well as metal contamination of cigarettes due to heavy use of cadmium in the metal parts that are employed in the manufacturing process. As such, it is essential for smokers to reduce their cadmium exposure, as well as reduce their overall Tobacco smoking in order to be vigilant of the dangerous levels of cadmium they are exposed to.

Moreover, it is widely accepted that the most effective way to reduce human exposure to cadmium (Cd) is by avoiding smoking and other activities that may put the individual at a greater risk of this element entering their bodies. The ingestion of foods, water and the inhalation of air pollution should also be restricted. Medical treatments, such as binding agents and chelating agents, may be used to treat large levels of Cd exposure. It is also important for people to use protective devices such as masks and air filters as a preventive measure to effectively reduce their exposure to cadmium.

Overall, humans are routinely exposed to cadmium (Cd) and the potential risk of harm from such exposure. The greatest source of exposure is likely via smoking, and in the face of this, it is important for smokers to reduce their tobacco smoking habits, limit direct contact with the smoke, and ensure that they are taking precautions to properly protect themselves. It is also essential that people are vigilant in monitoring their dietary habits and choosing foods that are low in cadmium content. Finally, proper treatments such as chelating agents may also be necessary in cases of high Cd exposure. In sum, avoiding smoking and using protective devices, as well as minimizing contact with polluted air and appropriately choosing items for our diet can go a long way in reducing our exposure to this dangerous element.

Mercury (Hg)

Mercury contamination of the environment is a serious risk to human, animal, and environmental health. It persists in the environment, is accumulative, and can disperse to new areas by water and snowmelt. Humans are primarily to blame for introducing mercury into the atmosphere through activities such as burning fossil fuels and hospital waste, and vaporizing ocean water. In response to this, an international strategy was created in 1998 with 40 recommendations to reduce mercury emissions associated with human activities. This strategy has driven an improvement in air quality standards and a reduction in mercury emission levels in many countries. It has also helped to redirect research and monitoring to understand how mercury binds to particles and transforms in the environment. The ultimate goal is to better manage and protect our environment from mercury contamination. The symptoms of ingesting poisonous inorganic mercury compounds include vomiting, salivation, bloody diarrhea, stomach aches, and a burning sensation in the mouth and throat. Additionally, long-term exposure to organic mercury compounds can cause degenerative changes in the central nervous system. Damage to the kidneys can lead to a severe form of uremia, called anuria. Black mercury may also be observed on the gums due to the presence of necrosis and ulcers in the mouth that appear as a result of opaque, gray residue[30].

2.4.4 Arsenic (As)

In response to this issue, many governments have established standards for the concentration of arsenic in water and soil, as well as for people handling and using arsenic. To reduce the prevalence, water infrastructures are being established to reduce levels of arsenic in drinking water. These infrastructures, such as filtration pumps and irrigation systems, can help lower concentrations in contaminated water sources. Additionally, measures such as avoiding consuming food and water from affected areas, proper hygiene, and improved sanitation are also being taken.

Overall, governments, NGOs, and organizations are working together to mitigate the risk posed by arsenic contamination. Improved water treatment technologies, active monitoring and extensive research can help decrease the public's exposure to this dangerous heavy metal. Long-term health programs must be set in place to make sure individuals are fully aware of the risks and of preventive steps that may be taken. With global efforts, we may soon generate more awareness and decrease the number of people affected.

Arsenic is a naturally occurring element which accumulates in the environment through various industrial and agricultural processes. When used in pesticides, it can be lethal to aquatic life such as fish and can seep into waterways. Industrial workers who frequently come into contact with arsenic through their occupation are at an increased risk of health issues, since arsenic can be absorbed through the skin or inhaled. There are also medications which may inadvertently contain arsenic, making it easy to become poisoned if taken in high doses. Finally, certain types of seafood can naturally contain significant amounts of organic arsenic, making it a potential health risk.

Overall, arsenic is a serious problem for humans, animals, and the environment. In terms of humans, it can cause a range of different health problems, from skin and respiratory irritation to cancer. To prevent its spread, it is important to be aware of products, medications and environment that contain arsenic, and to limit exposure to them by taking appropriate measures[31].

2.4.5 Chromium (Cr)

Chromium is both naturally and human-induced, leading to its accumulation in habitats. This can be especially detrimental for fish, as the heavy metal accumulates most markedly within their gills, livers, and kidneys. The level of chromium toxicity in aquatic ecosystems can differ between species and age, as well as the environment's pH, temperature, alkalinity, and water hardness. Hexavalent chromium (Cr+6), the type introduced to the environment by humans, is particularly hazardous. Elevated concentrations of this form in drinking water can lead to stomach tumors, damaging cellular integrity and impeding vital functions. Additionally, people may indirectly take in chromium through seafood, such as fish residing in contaminated waterways. It is necessary to restrict human activities that lead to chromium discharges, so as to protect both the environment and individuals from their adverse effects[32]. This has been linked to their irregular swimming patterns and sluggishness.

2.4.6 Iron (Fe)

Iron is required for a healthy body, but too much of it can be dangerous. The body needs 3-5 grams of iron, and normally 60-70% of that is found in red blood cells. An overload of iron can cause serious health risks, such as nausea, stomach irritation, vomiting, and diarrhoea, as well as damage to tissue and an increased risk of cancer, particularly breast cancer.

In order to regulate iron levels in the body, people should be careful when choosing dietary sources and supplements. It is important for people to understand the potential risks of consuming more iron in their diet than is necessary, and to take into consideration their particular health needs as well. In addition, it is important to speak to a doctor before taking any supplements with high amounts of iron, or other heavy metals, as they can be toxic in high concentrations.

Having the right amount of iron is essential for a healthy body, so it is important to be mindful of the amount of iron in your diet. Taking into account your body's individual needs, as well as speaking to a doctor before taking any supplements, are key to maintaining healthy levels of iron and avoiding any serious health risks. Iron is essential for proper functioning of the immune system and tackling inflammatory responses resultant from infection[33].

2.4.7 Zinc (Zn)

Zinc is naturally found in many foods such as oysters, red meat, and poultry, but is also added to processed foods. It can be found in toothpaste, baby formula, and many multivitamins. While it is important to have the right amount of zinc in your diet, too much of it can be harmful.

Excessive zinc consumption can cause nausea and vomiting, stomach cramps, upset stomach, headaches, and fatigue. In some severe cases, it can even cause anemia. Too much zinc intake can also cause problems with the blood pressure, as it can lead to increased levels of LDL (bad cholesterol). Additionally, an excess of zinc intake can also cause a decrease in HDL (good cholesterol), which affects the body's ability to process fats.

It is important to note that when consuming high levels of zinc, a person should take care to monitor the amount of zinc they are ingesting from both dietary sources and from supplements. Stick to the recommended daily allowances (RDA) for zinc and adjust intake depending on your specific circumstances. Always consult your healthcare provider before changing your dietary habits. Additionally, too little zinc can lead to weight loss, rough skin, oligospermia, and hyperammonemia[33,34]. In short, zinc is essential for many biochemical processes within the body, but must be taken in the correct amounts for optimal health.

2.4.8 Nickel (Ni)

Nickel poisoning can be an extremely serious condition for humans, with long-term exposure leading to potentially fatal consequences. Symptoms of Ni poisoning can range from mild to severe depending on the extent of exposure, with skin rash and aneamia among the mildest symptoms. Long-term Ni poisoning is also linked to a higher risk of developing various types of cancer. Even lower doses have been linked to negative impacts on the cardiovascular system, including disruption of normal heart rate and sudden drops in blood pressure.

As a result of the health risks associated with Ni poisoning, it is important to take precautions to reduce the risk of exposure. These include wearing protective clothing and using proper safety equipment when working with nickel, as well as avoiding contact with items and materials that may contain high levels of Ni. It is also recommended to limit intake of food sources that may contain Ni. This can include limiting the amount of canned and processed foods, as well as avoiding shellfish and drinking water from certain sources. However, for those with a known sensitivity to Ni, medical attention should be sought out immediately in cases of suspected poisoning.

Nickel poisoning can be a dangerous health condition if not properly addressed. It can lead to a wide range of negative health effects, from skin rash to developing cancer. If someone is suspected of having nickel poisoning, medical attention should be sought out immediately.

A group of employees who were exposed to nickel at levels of 7.1–35.7 mg kg^{-1} were investigated in detail. It was found that nickel chloride, nickel sulfate and boric acid-laced fountain water were the main sources of the contamination. The workers subsequently reported a range of symptoms such as stomach cramps, vomiting, diarrhea and nausea. Two studies in Pakistan have documented the varied presence of Ni in traditional medicines. The first employed FAAS (flame atomic absorption spectroscopy) to measure levels of heavy metals such as Ni in commercial herbal products; Ni concentrations were found to be in the range of 0.2 to 56.3 gg^{-1}. The other study utilized AAS (Atomic Absorption Spectroscopy) to detect the presence of eight heavy metals, including Ni, in a group of herbal items sold in local markets in Karachi. Nickel was detected in amounts between 0.4-76.97 gg^{-1} in the sampled materials[35].

2.4.9 Copper (Cu)

Copper is an important element found in both plants and animals. It is essential to the formation of human blood haemoglobin and is vital for seed production and disease prevention in plants. There are, however, some potential risks that we should be aware of. It has been linked to both short-term and long-term health issues when consumed in excess from certain plumbing systems, algae treatments, and other contaminations. Excessive copper can cause adverse effects on the liver, kidneys, and stomach, whereas deficits of this element can lead to Anemia and Neutropenia.

Luckily, evidence suggests that Copper is generally stable in the environment and has a low chance of multiplying or bio-accumulating, making it a relatively safe substance. Unfortunately, it can be easily dispersed in drinking water, and a precautionary approach should be taken to ensure the public's safety.

Overall, Copper is an important element necessary for human, plant and animal health, but it should be controlled when used in plumbing systems and some water treatments as it can be easily consumed and lead to health issues. Proactive measurements should be taken to guarantee the safety of consumers while still allowing us to benefit from the fruitful properties of Copper[36].

2.4.10 Manganese (Mn)

Manganese is an important mineral that we need in relatively small amounts to stay healthy. Without manganese, the body would not be able to make use of the nutrients that we consume like carbohydrates and proteins or to perform other crucial functions. Our bodies absorb manganese from the food we eat and the air we breathe. It's also important that we get the right amount of manganese in our diets, too much or too little can have negative effects. People aged

19 or over should aim for 2.3 mg of manganese per day (3.0 mg for males and 1.8 mg for females), but it's important to not exceed the safe upper limit of 11 mg each day[36]. It is essential to our biochemical processes and in helping the body make energy, protect against oxidative stress, and use vitamins and minerals properly. Food sources of manganese include green leafy vegetables, nuts, whole grains, and tea. It has been established that too much Manganese (Mn) can be harmful, with excessive levels found in the liver, pancreas, bone, kidney and brain leading to a decrease in IQ. Research suggests that the accumulation of Mn is linked to oxidative stress, mitochondrial dysfunction, protein misfolding, endoplasmic reticulum stress, autophagy dysregulation, apoptosis, and disruption of another metal homeostasis. Symptoms of Mn poisoning have been noted in patients over an extended period of time, including hepatic cirrhosis, polycythemia, hypermagnesemia, dystonia and Parkinsonism-like symptoms. Manganese deficiency, particularly in women, has been linked to the development of osteoporosis[36].

2.5 Assessing Exposure of Heavy Metals

Many heavy metals like arsenic and lead may be naturally present in soil, water and air, but those found in urban environments are more likely to originate from industrial and human activities. Vehicular emissions, agricultural runoff and improper disposal of industrial waste can easily contaminate our air, water, land and food. So, it is important to ensure proper waste management and also introduce stringent regulatory measures to limit industrial effluent. In order to prevent further contamination, it is also necessary to regulate the use of land for agricultural purposes and impose stronger control over livestock and fisheries.

At a broader level, we need to implement environmentally sound technologies including water treatment and soil remediation, while monitoring and assessing the quality of air, water, soil and food. A good public health policy should be in place that encourages the use of preventive and protective measures to reduce the potential health hazards from heavy metal contamination. Educating the public about the less hazardous use of chemicals and disposal of industrial wastes is also paramount. Finally, governments must create regulations for better toxic waste management and periodically review their safety and regulatory guidelines for effective enforcement and compliance. Environmental monitoring and biomonitoring are both vital components when it comes to assessing the true extent of exposure to environmental contaminants. Environmental monitoring provides a measure of ambient concentrations of contaminants while biomonitoring estimates the amount of the contaminant that has been taken up by the body and is currently in the body or has active metabolites in the body. Environmental monitoring is of particular importance when attempting to determine whether certain substances are found in a certain environment and at what concentrations. It is necessary to provide an initial assessment of potential exposures, as well as for trend analysis over time. Biomonitoring meanwhile, is a way to identify the extent of actual internal exposure to toxic substances and determine whether it is likely to have any impact on human health. Together, environmental monitoring and biomonitoring provide a comprehensive picture of the extent and type of exposures faced by members of the exposed population, which can help to understand the risks faced and what actions should be taken in response.

Finally, a way to straightforwardly determine the level of metal exposure in a population is the measurement of the relevant chemical or its metabolites from certain biological samples like urine or blood, with particular thresholds being indicative of the exposure. In another development, prolonged exposure to hazardous metals can have lasting impacts on the body, such as it being stored in keratinous tissues like nails, hair, and teeth for a significant amount of time. This means health professionals can use nail, teeth, and hair samples as indicators of chronic metal exposure, such as lead. As lead is frequently found in food sources, routine safety checks need to done to avoid long-term lead poisoning. Minerals such as lead and cadmium are also present in tooth matrix. Additionally, arsenic intake is quickly expelled through the kidneys, but can remain stored in the skin, hair, nails, and bones of a person exposed to it for an extended period of time. Results from studies show that inorganic arsenic and monomethylarsonic acid make up 10-15% in urine with dimethylarsonic acid making up the bulk of the metabolites at 60-80%. An examination of recent urines samples revealed small amounts of dimethylarsonous acid and monomethylarsonous acid. This review looks into three distinct types of biomarkers related to exposure, effects, and susceptibility. Examples of biomarkers of exposure include chemical assessment of DNA or protein adducts metabolites, and the parent chemical itself. Other biomarkers of effect are changes in cellular expression of metabolic enzymes, while biomarkers of susceptibility point to preneoplastic lesions, mutations, and other early indications of cell or subcellular disruption.

Together, this paints a picture of internal dosage and the level of biological activity that can occur in response to exposure. The ability of an individual to respond to certain exposures is demonstrated by susceptibility biomarkers. Researchers have explored these three types of biomarkers when studying the effect of heavy metals on the human heart. Genomics and proteomics are the two most common techniques used to identify current biomarkers to measure metal exposure. Recently, proteomics biomarkers were used to determine preclinical changes in individuals exposed to heavy metals. A comparison between two groups, one with no exposure to metals, the other with exposure, was conducted. Using serum samples, urinalysis, and biochemistry analysis of blood, three protein indicators of preclinical modification in the exposed metal group were identified. The effects of exposure to heavy metals on the skin and the body's response to stress are important indicators of potential damage. Cadmium toxicity can often be determined by measuring the amount of 2-microglobulin present in the urine. Abnormal levels of sugar, amino acids, and compound phenol have also been linked to nephron injury caused by cadmium. In addition, an increase in the excretion of proteins of both high and low molecular weight can indicate a decrease in glomerular filtration rate[36].

2.5.1 Effects on Soil

The implications of heavy metal contamination of soil cannot be ignored, as it poses a risk to both human and environmental health. It can cause severe health issues, including neurological disorders, digestive problems, skin problems, and even cancer. Moreover, it can contaminate the food chain and lead to the destruction of organisms such as earthworms and fish. Furthermore, heavy metal contamination can also disrupt essential soil processes such as nutrient cycling, water filtration, and carbon storage.

In order to tackle heavy metal contamination of soil, it is essential to implement effective strategies and regulatory frameworks. This can be done through proper disposal of hazardous material and by controlling effluent and emissions from industrial processes. Moreover, frequent monitoring of water and soil quality and regular assessment of heavy metal concentrations should be carried out, to prevent contamination and to protect both public and environmental health. It is also important to raise public awareness of the issue and to encourage individuals to reduce the use of fertilizers and pesticides.

Heavy metals in soils can be detrimental to soil health and quality by impacting the ecology of microbial communities. Long-term exposures to heavy metals lead to profound changes in the microbial diversity and abundance, in addition to decreasing the activity levels of these organisms. This has been evidenced through various research studies, which have shown that heavy metals can cause a decrease in the tolerance of bacterial communities and a decline in the presence of arbuscular mycorrhizal (AM) fungi in contaminated environments.

These findings are of great importance, as AM fungi are essential for the rehabilitation of soils that have been polluted by heavy metals. Research into the effects of chemicals on soil microorganisms must be pursued in order to properly address this issue and ensure that soils are preserved. With this knowledge, strategies can be put in place to support the development of microbes that are better able to tolerate heavy metals, thus helping to restore soil health and quality. The ability to preserve these microbes and rehabilitate contaminated soils is essential for sustaining proper soil function and fertility[37].

2.5.2 Plant Effects

Polluted soil not only affects the physical characteristics of the plant but can also damage the internal physiological processes within the plant. For instance, prolonged exposure of some heavy metals such as copper and zinc can lead to the inhibition of photosynthesis and other metabolic processes. Furthermore, the accumulation of these pollutants in the food chain from the polluted soil eventually causes adverse health effects on humans and wildlife.

It is important to note that growing plants in polluted soil will likely lead to an increase in the amount of heavy metals in the food chain. Therefore, strategies such as loam soil engineering and bioremediation should be adopted in order to reduce the levels of these pollutants in the soil. Loam soil engineering involves tracking the movement of the pollutants and ensuring that they do not enter the food chain, while bioremediation enables the plants or microorganisms to break down the pollutants into harmless by-products. These strategies could help solve the problem of heavy metal accumulation in the food chain and ensure the protection of human health. Using compost from waste can improve crop production; however, this should be done without neglecting the possible negative effects it can bring, since many vegetables have their edible parts. Heavy metals pose a great risk to animals and humans, as it is easy for them to enter the food chain through the roots of plants. As such, we must take great caution against their transfer from soil to humans.

The temperature, soil organic matter, moisture levels, pH, and nutrient content all had very important roles to play in the absorption of heavy metals and its subsequent overconcentration in plant tissues. Beta vulgaris (Spinach) accumulated more Cd, Zn, Cr, and Mn during the summer season, while the uptake of copper (Cu), nickel (Ni), and lead (Pb) were higher during the winter. During the summertime, the high decomposition rate of the organic matter caused a release of heavy metals which could then be taken in by plants. The increase in transpiration during the summer, due to higher ambient temperatures and less humidity, also enabled the plants to absorb more heavy metals than what was observed during the wintertime. The specific species of plant also influenced how much heavy metal buildup it contained, while the transfer factors of the metals from the soil to the plants determined how well they absorbed the heavy metals.

If the level of lead (Pb) in the soil rises, the level of soil production may be reduced. This is because lead can have a toxic effect on plants, causing symptoms like fading of old leaves, dark green leaves, stunted foliage, and brown, short roots. Other effects of heavy metals and phytotoxicity include slower growth, chlorosis, reduced yields, and reduced or hampered nutrient absorption and nitrogen fixation in leguminous plants. Furthermore, seed germination can sometimes be delayed due to lead, which may be the result of neutralizing the toxic effects via mechanisms like metal binding, micro-organism accumulation, leaching and chelation[38].

2.5.3 Consequences for The Aquatic Environment

Heavy metals enter the aquatic environment through multiple pathways such as industrial runoff, sewage from households, urban runoff, and in some cases through natural sources like volcano eruptions and weathering of rocks. Contaminated water from human activities can cause the most severe damage, as it contains a higher concentration of pollutants. These pollutants can find their way into the food chain, exposing a much broader scope of the population to their poisonous effects.

Heavy metals can cause significant damage to aquatic organisms, including death and mutations. They can also have long-term effects, such as changes in behaviour or growth rates, reproductive impairment, and increased sensitivity to other toxins. Contamination can lead to decreased biodiversity as some species may not be able to adapt and survive in a polluted environment.

It is up to us to mitigate the effects of heavy metal pollution in the aquatic environment. The most effective way is to prevent the entry of contaminants in the first place. This means reducing the use of hazardous materials, avoiding the dumping of toxic substances, and properly disposing of hazardous waste. People should also be more aware of the potential effects of pollution on the environment and take steps to preserve and protect our aquatic habitats from further damage. Heavy metals are usually attached to particulate matter that settles to the bed of an environment and become incorporated into the sediment.

Because of this, metal pollutants have sunk and settled into the sediment at the bottom of reservoirs and other aquatic habitats, as well as being taken up by both rooted and unrooted aquatic microphytes and other creatures. With such a high rate of trace metals entering and being associated with the lower sediments, environmental degradation caused by this can occur in locations where the components of suitable water quality are overlooked. This kind of contamination has the potential to result in serious damage to the organisms dwelling in, or near, the sediment. Metal can be seen in high concentration in rivers, and this could cause significant changes in the composition of the diatom communities. Aquatic organisms can accumulate heavy metals, and these can be transferred through the food chain to carnivores, including humans, at the top. These metals can have serious impacts on aquatic creatures and can even reach people who consume contaminated fish and other aquatic products, potentially posing a risk to public health. Mercury is one of these pollutants, the harmful compound of which is methylmercury and can form in aquatic sediments. All mercury found in fish muscles is a result of methylmercury formation.

Fish are important bioindicators of metal pollution in aquatic ecosystems. Metals in their bodies indicate the health of the water they inhabit. When fish absorb and transport metals, they become vulnerable to their potentially toxic effects. Many different tissues, organs and organ systems are affected by the presence of metals, such as the liver and kidneys, which can ultimately lead to decreased vigor, disequilibrium and mortality. Metals also accumulate in fatty tissues, and when these tissues are consumed by predators, the metals can be passed along the food chain, resulting in a build-up of toxic levels of metals in the environment. To monitor these effects, benthic macroinvertebrate assemblages are used to assess health in aquatic systems. The presence of metals in fish can be an indication of the level of contamination in their environment and the subsequent risk to their health and the environment as a whole. Invertebrates serve a crucial role in the food webs of flowing waters, bringing together primary producers and higher trophic levels, as well as moderating organic matter decomposition and nutrient cycling in lotic ecosystems. Many moving-water fish species rely on invertebrates as the main source of food, and the consequences of heavy metal contamination on drift-prone macro invertebrates has yet to be evaluated in terms of their value as food for fish. As many commercially or recreationally valuable salmonid species depend heavily on these invertebrates, this issue is of utmost concern[39].

2.5.4 Human Health Consequences

It is essential to be aware of the potential risks associated with the ingestion of edible vegetables that have been grown in contaminated soil. Consuming such vegetables can have a range of negative impacts on human health, such as physiological, morphological, and genetic abnormalities. Approximately 90% of our exposure to heavy metals comes from the consumption of these vegetables, while the remaining 10% derives from contact with polluted dust and air. As such, it is critical to monitor and inspect food crops that are grown in potentially contaminated soils closely and frequently to minimize the chances of heavy metal accumulation in the food cycle. Prolonged contact with these contaminants can lead to long-term health risks, such as cognitive and reproductive problems. Therefore, by deploying strict and consistent inspection systems, it is possible to reduce the health risks associated with consuming vegetables that contain high levels of heavy metals.

Cadmium (Cd) contamination of air, water and soil is a major environmental and health concern, especially for those living in areas where there is industrial activity. Cd can enter the food chain through contaminated soil, water and air, and through occupational and environmental exposure. Cd accumulates in the body with time, leading to an increased risk of adverse health effects. Research has shown a broad range of effects including increased risk of cancer, genotoxicity, damage to the nervous, immunological and reproductive systems, while long-term exposures can create pulmonary dysfunction and emphysema. Numerous pathways may be involved in Cd contamination, including release from single point sources and diffuse sources, volatilization from contaminated surfaces, contamination of agricultural crops and food, leaching from soils, and atmospheric transport and depositions.

Cd exposure can have a wide range of adverse health outcomes and governments are increasingly focused on the prevention and risk reduction of environmental exposures to Cd. Prevention efforts should focus on reducing the release of Cd into the environment, and on areas of dietary exposure from contaminated soils, food, and water. The World Health Organization (WHO) has endorsed the Guideline for Cadmium in Drinking-water that sets an upper limit for

Cd in drinking-water of 0.01 mg L^{-1}. Implementing these preventative strategies is crucial if we are to reduce the risk of Cd poisoning and its associated health consequences. Exposure to cadmium, zinc, and copper can cause a variety of negative health effects. Consumption of these materials in high doses has been linked to cardiac failure, cancer, anosmia, cerebrovascular infarction, emphysema, osteoporosis, proteinuria, and cataract formation. Excessive intake of zinc and copper can produce symptoms such as nausea, diarrhea, discolored urine, jaundice, liver deficiencies, kidney problems, and anemia. Copper is a significant part of the mammal nutritional system, playing a critical role as an acceptor and donor in metalloenzymes. The right balance of zinc and copper is necessary for good health and any excess can lead to many illnesses. It is important to regulate the amount of these materials being consumed so as not to risk ill health. Studying the links between environment exposures and health outcomes can be difficult. There are often too many confounding factors that make it hard to confidently make the link. Research has established, however, that with increased levels of certain environmental toxins, there are associated morbidity and/or mortality risks. This includes things such as copper (Cu) and nickel (Ni). Overconsumption of these substances can lead to poisoning or other negative health impacts, such as skin and mucous membrane damage, respiratory issues, neurological disorders and gastrointestinal distress. Genetic or pre-existing illnesses can make individuals more vulnerable and thus it is important to monitor the levels of toxins in food and water in order to protect the health of those who consume them. Lead poisoning is a serious health hazard since it can lead to a range of physical issues, including death. Low levels of lead poisoning may cause headaches, abdominal pain, weakness, irritability, and anorexia, while high levels can affect the central nervous system, nerves, bones, teeth and hair. It can also disrupt normal functioning of the gastrointestinal tract and urinary system, cause anaemia and reduce haemoglobin production. Acute lead poisoning may result in abdominal pain, nausea, vomiting, seizures and paralysis. The effects can be even more severe in children, as their bodies are still developing and therefore more vulnerable.

Long-term exposure to lead can cause permanent damage, such as poor memory, inability to concentrate, hyperactivity, learning difficulties, hearing loss, vision problems, and slowed growth. Chronic exposure to lead can lead to kidney damage, damage to the reproductive system, and an increased risk of cancer.

Lead poisoning is a worrying health risk, especially for children, as even low levels of exposure can have devastating long-term consequences. Therefore, it is essential to be aware of the potential health hazards of lead poisoning, and to take preventive steps to reduce exposure to lead in the home. These measures include reducing dust exposure, keeping lead-based paints and contaminated soil away from children, and cleaning surfaces often, paying particular attention to toys, furniture, and other objects that children may come into contact with. Additionally, a deficiency of calcium and zinc can increase the absorption of lead into the body. The tenth most common component found in the Earth's crust is Chromium (Cr), appearing as Cr^{3+} or Cr^{4+} in the environment. Although it is poisonous and can potentially be carcinogenic to both animals and plants, its toxicity is caused by Cr^{+6} and its ability to penetrate cell membranes and oxidize biological molecules.

Mercury is a toxic, naturally occurring element that has no known role in biological processes. It can enter the environment from several sources and is especially dangerous in water sources due to its ability to accumulate in organisms. Ingesting this element can cause immediate gastrointestinal issues, as well as more long-term health effects such as neurological damage, erethism, and acrodynia. Even short-term exposure to mercury can lead to spontaneous abortions. When present in combination with arsenic, the type of metals consumed and the associated concentrations will determine how severe the health effects are. Although mercury occurs naturally, all efforts should be made to eliminate human-caused sources of mercury to protect human health. Arsenic poisonings can take many forms, causing confusion, headaches, and long-term physical, behavioral, and psychological damage. It is especially dangerous to children, as it interferes with neurological and brain development, leading to learning disabilities and behavior problems. Chronic arsenic poisoning can lead to cardiovascular and muscular disease, harmful absorption and excretion of cellular components, and even coma or death.

When arsenic enters the body, it quickly takes over essential enzymes, disturbs metabolic functions, and can cause damage to DNA. Over time, the toxins remain in fatty tissues such as the liver, causing enzyme functions to be disrupted and leading to organ dysfunction. Chronic arsenic exposure can cause severe physical, cognitive, and emotional effects that negatively alter a person's quality of life. Awareness, limited exposure, and medical attention are necessary to maintain good health in areas where arsenic contamination is an issue[40].

2.5.5 Effects on Composting Process

Heavy metal contamination of soils can affect human health, plants, and soil organism activity. The most serious health concern from heavy metals lies in the contamination of drinking water caused by polluted soils. Heavy metals can accumulate in plants and result in decreased food safety for humans. When taken up, heavy metals can interfere with metabolic pathways, reduce growth and yield, and alter the composition and availability of nutrients. In terrestrial ecosystems, heavy metals can suppress the activity of soil microorganisms and arthropods, resulting in soil toxicity.

In order to reduce the impacts of heavy metal contamination, soil should be managed sustainably, utilizing methods such as composting. Composting reduces the amount of organic waste, and simultaneously adds organic material to the soil in form of humus, which can act as a chelating agent binding to heavy metals and reducing their toxicity. Additionally, composting can reduce the mobility of the heavy metals, thereby decreasing the risk of human and environmental exposure. Heavy metals such as copper and zinc can be toxic for both humans and the environment. To protect against their harmful effects, it is important to limit their exposure as much as possible. The physiological and morphological effect of heavy metal exposure can be illustrated by a study that applied three different doses of copper and zinc to a substrate. The study aimed to evaluate how this exposure impacted enzymatic activities during vermicomposting. The results showed that the presence of Cu and Zn reduced phosphate production, inhibited enzymatic reactions, and inhibited the metabolic processes of microbial enzymes. It is clear that heavy metal contamination must be minimized to protect human and environmental health. Therefore, appropriate environmental management strategies should be employed for the control of heavy metal inputs and retention in soils, sediment and water bodies. The study demonstrated that increasing doses of copper and zinc led to decreased levels of dehydrogenase activity. Resulting trends highlighted the importance of the dose and type of metal present in the substrate. Heavy metals can have a negative effect on the functioning of organisms by interfering with metabolic processes[41]. In this experiment, the concentration of copper and zinc disrupted the ability of naturally occurring enzymes to catalyze redox reactions. This finding further underscores the potential adverse effects of heavy metals on organisms and environment through decreased enzyme activity.

By studying the impact of copper and zinc on enzyme activity, this research has shown how environmental pollutants can degrade biochemical processes. Long-term accumulation of certain pollutants in soil can lead to disruption of the native microbial communities. This may lead to a decrease in water and nutrient cycling, thereby reducing the productivity of the soil. Moreover, the transfer of pollutants to plants and other organisms may present a health risk. Overall, results from this study point out the dangers posed by the heavy metals copper and zinc and the need to monitor and restrict usage to minimize their impact on the broader environment.

High copper and zinc levels have been found to disrupt the vermicomposting process and hinder the growth of the *Eisenia fetida* earthworm. To ensure the survival of the earthworm species and avoid any inactivation of the enzyme processes, it is necessary to regulate the levels of copper and zinc in the system[41]. In the control group, the levels of dehydrogenase were relatively higher due to the lack of heavy metals, yet decreased as the dosage of heavy metal increased. Additionally, heavy metals can affect hormonal activity by altering the microbial community and its reaction with the enzyme-substrate complex.

2.6 Heavy Metal Removal Using Conventional Methods

2.6.1 Precipitation of Chemicals

Chemical precipitation is a commonly used water treatment process for industrial wastewater and sewage. It involves introducing a variety of chemical compounds into the mix, encouraging the formation of a solid that can be removed from the other material. Coagulants such as aluminum, calcium, iron and organic polymers work to precipitate metals, and can remove up to 80% of zinc, copper, and lead from industrial effluents, and up to 96.2% of oil through a combination of hydroxide precipitation and air flotation.

Unfortunately, chemical precipitation is not all that successful in removing heavy metals at low concentrations, and is best used for highlighting BOD (Biochemical Oxygen Demand). Applications are generally non-specific, and it is often combined with other treatment processes to achieve the desired results. This strategy is seen in both industrial and municipal waste processes, where chemical precipitation helps to purify the water[42].

2.6.2 Electrodialysis (ED)

Electro Dialysis (ED) is an ideal solution for water treatment due to its simplicity and cost-effectiveness. This method uses electrolysis, where an electric current is used to pass chargeable ions through a membrane. This process leads to positive and negative ions being transferred while the rest of the polluted particles stay trapped on the opposite side of the membrane. It can be used to separate different ions from water, allowing for the removal of pollutants in the wastewater. It is very efficient, with a removal rate of 94-98%, making it an environmentally friendly wastewater treatment technology. Moreover, it is cost-effective and easy to maintain so it does not require much maintenance and requires small amounts of electricity to operate.

Overall, Electro Dialysis (ED) is an effective and economical method for treating wastewater. Its simplicity, high removal rate, low cost, and small maintenance requirements make it a great choice for water treatment. It is an environmentally friendly process that can help protect our natural resources[42]. Research studies have revealed the potential of ED in wastewater treatment and its application has since been expanded.

2.6.3 Coagulation and Flocculation

Coagulation and flocculation are two important components of drinking water and wastewater treatment, both of which involve the charge neutralization and agglomeration of colloids, as well as the formation of larger particles which can then be removed through sedimentation. Coagulation is initiated when a chemical or coagulant is applied to the water, causing the colloidal particles to form aggregates called floc. Commonly used coagulants are aluminum, lime, iron, calcium salts, and other organic polymers, while poly-aluminum chloride, polyacrylamide, and poly ferric sulphate are typical flocculants used to help metals precipitate. Flocculation involves stirring the water in a gentle, slow manner to create flocs of particles which can ultimately settle out. It is not effective at removing all heavy metals[42].

2.6.4 Ultrafiltration

Ultrafiltration is a widely used process for the removal of dissolved and colloidal particles from water. This method is highly effective for getting rid of pyrogens from the water. Separation is done using filtration membranes with pore sizes ranging from 0.1 to 0.001 microns. During ultrafiltration, high molecular weight solids and large organic and inorganic polymeric molecules are trapped in the pressure-driven filtering process, leaving low molecular weight substances like water and small molecules to pass through. The success of the separation, however, can be affected by the electrical charge and surface chemistry of the particles and the membrane[42].

2.6.5 Reverse Osmosis (RO)

Reverse osmosis is a water treatment technique which uses pressure to separate lighter particles from water. This process helps to eliminate waterborne contaminants, including heavy metals. In simple terms, a pressure is created by pumping water through a filtering membrane - only allowing the smaller particles to pass through, while trapping the heavier molecules on the other side. Therefore, the wastewater coming out is much cleaner and can be reused in various ways. This process has been successful in treating wastewater with low levels of heavy metals. By using reverse osmosis, wastewater can be recycled and reused for various purposes, such as irrigating crops or other industrial purposes. Utilizing reverse osmosis can help improve water conservation and reduce the use of fresh water, creating a more sustainable environment. This procedure helps to separate wanted molecules from undesired ones by moving a liquid from a place of higher concentration to a place of lower concentration. Reverse osmosis is widely used for wastewater treatment for a variety of industries, such as electroplating and metal finishing, mining and petrochemicals, pulp and paper, textiles, and food processing, as well as for the treatment of radioactive wastewater, contaminated groundwater, and municipal wastewater[42].

2.6.6 Adsorption

Adsorption is an important process that can be used in a variety of applications. It is a process of binding molecules to a surface. This can be done through either physical or chemical interaction. The interaction of the molecules and the surface are determined by the parameters of the adsorbent and adsorbate. At a physical level, adsorption is capable of tackling various forms of pollution, such as heavy metals and organic pollutants, through the capture and binding of these contaminants to the surface of the adsorbent. With the addition of appropriate chemicals, it is possible to create a layer that contains a high concentration of reactive sites, effectively enhancing the adsorption capacity of the surface. At a chemical level, some of the main applications of adsorption include water treatment, gas separation, filtration, and adsorption chillers. Adsorption can also be used in molecular biology, as it is capable of capturing and binding molecules or cells while they are in solution. In essence, adsorption is a powerful and inexpensive tool that can be successfully employed in various situations. It is a mix of microscopic crystals that has a graphite lattice, and is available in either small pellets or powder form. The most commonly employed adsorbents for removing metals are activated carbon, biomaterials, zeolites, clay minerals and industrial solid wastes. By-products from industrial and agricultural production or natural materials are a common source of low-cost adsorbents. These materials tend to be locally available in large quantities, resulting in their typically low cost. Several studies have been conducted about different types of sorbents, including bark, tannins, lignin, dead biomass, chitin/chitosan, xanthate, clay, ash, peat moss, leaf mold, zeolite, moss, iron-oxide-coated sand, bone gelatin beads, modified wool, modified cotton, and seaweed/algae/alginate[42].

2.6.7 Ion Exchange

Ion exchange is an effective and efficient means of removing heavy metals from wastewater. Resins can be used for this purpose, and examples include AMBERJET 1200 Na and INDION

225H high-density resins. When implemented, AMBERJET 1200 Na resin was able to capture lead and nickel with a removal rate of 99% and 98%, respectively. INDION 225H high-density resin, meanwhile, was applied in an expanded bed adsorption context as a means of extracting copper from the wastewater.

The use of ion exchange resins has many benefits. In addition to removing heavy metals effectively, this process reduces the volume of sludge produced and enables water to meet stringent release requirements. The resins utilized also possess characteristics that make them well-suited to this purpose, such as strength in solid phase mixing and isothermal properties. This makes them highly efficient and effective for heavy metal removal from wastewater. The researchers employed a high-strength acidic cation exchange resin in a stationary bed to extract nickel from the wastewater. The resin was beneficial as it could treat large volumes of effluent simultaneously and was more efficient at extracting heavy metals from wastewater. Ultimately, they managed to remove 97% of the nickel present in the wastewater[42].

2.6.8 Activated Carbon

Activated carbon is a type of product created from substances with high carbon content, such as industrial byproducts. To produce activated carbon, substances like coconut shell buttons are recycled and subsequently subjected to temperature and pressure processes. Through these processes, the carbon obtains an incredibly high porosity, allowing it to absorb incredibly complex compounds. A study was recently conducted to determine the absorption capabilities of activated carbon created from coconut buttons. It was found that copper (II), lead (II), and mercury (II) can all be effectively removed from wastewater when taken through the process of adsorption. The study also determined that the levels of pH in which each substance is absorbed most successfully is dependent on the chemical. It was found that copper adsorption was highest at pH 6.0, while mercury absorption was most effective when the pH level rose to 7.0. The absorption rates for the three pollutants were found to be in this order: copper (II) < mercury (II) < lead (II); with the latter having an absorption rate of greater than 90%, and copper and mercury being higher than 95%[42]. Other sources of agricultural waste used for this purpose include moso and bamboo, olive and grape stones, and lignin.

2.6.9 Carbon Nanotubes

In recent years, carbon nanotubes have been intensely studied due to their robustness, remarkable adsorption potential, large surface area, and remarkable electric and mechanical properties. To analyze the elimination of cadmium, copper, lead and zinc, 8-hydroxyquinoline was combined with tailored multiwalled carbon nanotubes. It was noted that cadmium had more than 80% elimination efficiency[42].

2.6.9.1. Photocatalysis

Non-toxic semiconductors can be used in photocatalysis to rapidly and effectively disintegrate ecological contaminants. The semiconductor moves, collects contaminants on its surface, a photochemical reaction occur, and the substances are let loose and eradicated from the vicinity.

In an effort to reduce and dispose of heavy metals found in pharmaceutical waste, researchers trialed a selenium-laced ZnO nanocomposite semiconductor, finding a disposal capacity of 0.211, 0.421, 0.097, and 0.147 for Cr, Cu, Cd, and Pb, respectively, per 0.5g of the material[42].

2.7 Heavy Metals in Volcanic Soils

Although the impacts of volcanic eruptions are typically transient, the deposited ash and pyroclastic material can linger in the environment for months, decades, or even millions of years and extend for hundreds of miles from the original eruption site. Soil is a central component of the biogeochemical system, acting as a source and sink for pollutants. Metals from the soil are absorbed into the body via three main routes - ingestion, inhalation, and dermal contact - and can be magnified, entering the food chain and reaching levels that pose significant health risks. As metals accumulate within human tissues, the nervous and reproductive systems, as well as the kidneys, can be adversely impacted.

Research has indicated that ash which is released from volcanic eruptions can be transported by wind and eventually settle and become embedded in the soil. To study the implications of this, several studies have conducted tests to analyze the quantities of heavy metals present in soil originating from various volcanic areas around the world. One such example is the Nigerian Biu Volcanic Province soil that was found to contain large concentrations of nickel (Ni), chromium (Cr), manganese (Mn), zinc (Zn), lead (Pb) and cobalt (Co). Furthermore, researchers from southern Turkey conducted detailed analyses on soil from volcanically-active regions and were able to detect high levels of chromium (Cr), zinc (Zn), copper (Cu), cadmium (Cd), iron (Fe), lead (Pb) and manganese (Mn). The levels of cadmium (Cd) and lead (Pb) present were significantly higher than the 57th percentile. These studies demonstrate how volcanic activity can drastically impact the composition of a region's soil[43].

2.8 Dams in Nigeria

More recently, there has been a resurgence of dam activity in Nigeria, with over 323 currently operational. The majority of them (about 250) are earth dams, sand dams, and rock-filled dams – all non-structural designs. These dams are typically lower, shorter and often upgradable, making them cheaper and more efficient for municipal and agricultural use. Some of the other dams include overflow (45), gravity (8), sluices (2) and multiple arch (1). Many of the dams are used to generate hydroelectric power and control flooding, while the overflow and gravity dams are used for irrigation and drinking water[44].

The construction of a dam requires careful consideration, particularly in areas prone to extreme weather phenomena, such as drought and flooding. In democracies, dams often face greater legal challenges, as they restrict traditional use of land and can lead to displacement of people and agricultural disruption. Nevertheless, dams remain a powerful tool for managing water resources, such as providing clean drinking water, regulating stream flows, fighting agricultural pests, and providing hydroelectric power. Currently, the Nigerian government is investing heavily in more dam construction and improvements in order to ensure continuous supply of water for the country's growing population. A dam is a structure designed to manage and control the flow of a river by blocking and storing its water[45]. This is done by constructing a wall made of concrete, steel, or other materials across a stream or river. Dams are able to control the level of the resulting reservoir, divert water for human consumption and energy production, and reduce the risk of flooding (Water Technology.net).

2.8.1 Economic Importance of Dams

1. **Hydropower:** Operation and use of generating facilities and/or equipment for producing power by the sole source of water.

2. **Flood Control:** Dams that facilitate the prevention and/or lessen the severity of flood damage to valuable resources within a flood basin.

3. **Navigation:** The operation and control of locks to facilitate the transportation of goods via inland waterways.

4. **Recreation:** The use of water bodies (reservoirs or rivers) for physical and recreational activities (boating, fishing, swimming, etc.).

5. **Water Supply:** Public and private withdrawals of water used for consumption, municipal, and industrial needs.

6. **Irrigation:** The primary purpose of a dam is to hold water in a reservoir so that it can be used to meet the needs and requirements of crop and plant irrigation, thereby supporting growth and production[46]. For this to be effective, the structure of the dam must be able to withstand any pressure it is under without being shifted or crushed. Additionally, the reservoir must be sealed so that minimal leakage from the dam foundation can occur. Nevertheless, it is the situation that demand the type of dam to be built and a proper broad classification based on the construction material must be made in dividing the tides of dam that have been commonly constructed in Nigeria as;

(a) Embarkment dams, which are built of rack fill or earth fill (b) Concrete dams, which are built of mass concrete. Some dams are built using rubble masonry but majorly embarkment dams are more common for both economic and technical purposes all over the globe and they take nearly 80% of all the large dams which have been constructed in modern times. The building of dams across the world has benefitted communities and economics by allowing them to make use of water resources, yet it has also come with consequences. The true extent of how dams have impacted people, their social systems, health, and cultures must be taken into consideration when evaluating the objectives and costs of dams. According to the World Commission on Dams Report of 2000, 60% of the world's rivers have been affected by dams and their diversion. They have caused displacement for somewhere between 40 and 80 million people around the world (World Commission on Dams, 2000). Nigeria serves as a good example, with many communities losing their homes and land due to hydroelectric flooding each year. Another case of study is Tiga and Challawa dams in Niger and Jigawa, respectively. In August of 2001, many people were displaced due to the collapse of the two dams[47].

2.8.2 Classification of Dams

Dams can be classified in number of ways. But most usual ways of classification of dams are mentioned below:

Based on the functions of dams, it can be classified as follows:

1. **Storage dams**: Storage dams are designed to hold surplus water from a river when there is an excessive amount being released due to heavy rain. The water behind the dam can then be released when the river lacks a sufficient supply. This helps meet the demand for water for domestic, industrial and agricultural purposes. Additionally, storage dams serve to create habitats for aquatic animals and wildlife, provide a source of hydroelectric power, and act as a form of flood control.

2. **Diversion Dams**: The use of these structures does not involve creating a water-holding basin, but instead raises the water level so that it can be diverted into a canal system. The dams are made to be low, as compared to a conventional reservoir, since they are only meant to direct water towards the canals and not store it. Whenever the river water is overflowing due to breaching floodgates or unusually high waves, it will spill over or through the dam and continue downstream. In normal flow situations, it is completely or partially diverted into the irrigation channels. Weir and barrages are notable examples of these kind of dams.

3. **Detention Dams**: Detention dams are created to regulate flood water and retain it in a controlled fashion until the flooding has subsided. The water is gradually released when conditions return to normal, and it seeps into the soil and foundations around it, which raises the area's groundwater levels, potentially facilitating crops growth with only minimal irrigation. In addition, detention dams can also be employed on smaller tributaries and streams to contain silt and debris before they reach a larger reservoir. This type of dam is typically referred to as a debris dam.

4. **Debris Dams**: Debris dams are structures placed across a stream's channel which capture sand, stones, driftwood, and other debris and prevent them from accumulating in areas that may be harmed by sediment buildup. They serve as a kind of detention dam, keeping potentially damaging sediment from downstream.

5. **Coffer Dams**: A coffer dam is a structure that is used to create a dry working space in a body of water so tasks can be carried out safely. It is built by enclosing an area and then pumping the water out. This type of structure is used to help construct or repair permanent dams, oil platforms, bridge piers, and more. Typically, the coffer dam is composed of welded steel components such as sheet piles, wales, and cross bracing. Once the work is completed, the dam is then dismantled[48].

B. Classification of Dams Based on Structure and Design, Dams can be Classified as Follows:

1. **Gravity Dams**: A gravity dam is a type of dam that is constructed from concrete or masonry and specially designed to hold back water by using only its own weight and resisting the outward force of the water pressing against it. This type of dam is structured so that each section is reinforcing and independent of the other sections. Building a gravity dam requires carving out a portion of the riverbank, allowing water to fill the opening and be contained. Once the area is cleared, the ground is tested to ensure it can successfully support the weight of the dam and the water it holds. This testing process is needed to ensure the soil does not erode over time, which would weaken the structure and allow some of the water to pass through. Some notable gravity dams include the Ground Crulee Dam (United States), the Nagarjuna Sagar in India, and the Itaipu Dam, located between Brazil and Paraguay.

2. **Earth Dams**: An earth fill dam, commonly referred to as an embankment dam, is built from natural materials like soil, rocks, clay and gravel. This is the oldest type of dam, and one which

can be constructed with basic, primitive equipment. Unlike gravity and arch dams, which require a solid foundation and more complex materials, earth dams can be created on regular soil, though they haven't proven as reliable under certain conditions as other types of dams. The great advantage of earth fill dams is that they are able to be built on unfavorable sites, such as open rock or weak, permeable clay. The seepage water that could potentially weaken the downstream portion of a dam must be monitored and drained if necessary to prevent extreme failure in the case of a dam. There are different methods available for counteracting the issue including grouting the foundation, digging a cutoff trench and backfilling it with an impermeable material, instating a drainage structure at the base of the dam, or extending the seepage paths with an impermeable blanket and adding a free-draining fill at the downstream end. Examples of such dams are the New Cornelia Dam in the USA and the Rongunsky dam in Russia.

3. **Rockfill Dams**: Rockfill dams are typically constructed from rock deposited and compressed at the dam site, and are relatively permeable. To prevent water seepage, some areas of the dam feature an impenetrable material like reinforced concrete, asphaltic concrete, or clay. These dams are an ideal solution at sites where suitable rock is within or near the dam area and the foundation is able to adequately handle the load or any potential erosion resulting from seepage beneath the dam. A water barrier must also be included in the design of the dam, which is often situated in the middle of the dam or on the upstream side. Early concrete-faced rockfill dams had embankment inclines of 1 or 1.5 and were satisfactory for lower heights, like up to 75 meters. Above that, however, there were problems with cracking and excessive water seepage due to the compressibility of the rockfill. This concern was addressed when people discovered they could improve compaction by wetting the rockfill, though the introduction of vibratory rollers in the 1960s made the process more widespread. Two examples of this type of structure are Chicoasan Dam in Mexico and Mica Dam in Canada.

4. Arch Dams: An arch dam is a curved structure, with its convexity directed towards the upstream side. This shape helps it to efficiently transfer the water pressure and other forces to its abutments. Arch dams are an excellent choice for narrow canyons with strong flanks that can take the pressure from the arch action. Their sections are usually in the shape of a triangle, much like a gravity dam, but much thinner. They may have one or two curvatures in the vertical plane, and double curvature is more cost efficient and used more often in practice. Examples of arch dams are the Hoover Dam in the United States and the Idukki Dam in India.

5. **Buttress Dams**: Buttress dams are of three types: A buttress dam is made up of three parts: a deck type, a multiple-arch type, and a massive-head type. The deck type is made up of a reinforced concrete slab supported by triangular concrete walls, known as buttresses, that transfer the water pressure from the slab to the foundation. The buttresses are spaced at intervals of 6 to 30 m, depending on the size and design of the dam. The multiple-arch type features several arches connected to the same deck and buttresses while the massive-head type has a solid stone wall spanning the river valley. The deck type buttress dam does not form a continuous wall, making it simpler to build and requiring less materials than other buttress dams.

In a multiple-arch buttress dam, the traditional deck slab is removed and the space between the buttresses is instead filled with horizontal arches made of concrete. This design necessitates less concrete than gravity dams, while the curved upstream faces of the buttresses form massive heads to bridge the distances between each buttress. Although this design doesn't require as much concrete, it may be more expensive in terms of formwork, reinforcement and labor due to the increased precision required. Foundation requirements for this sort of dam are usually less demanding than those for gravity dams. Some notable examples of buttress dam design are the Bartlett dam in the United States, and the Daniel-Johnson Dam in Canada.

6. **Steel Dams**: A steel dam is composed of metal framework with metal skin placed on the face upriver. Generally, there are two types of steel dams: direct strutted and cantilever. For direct strutted dams, the water pressure is directed straight at the base through angled struts. With the latter though, a bent sustains the top deck which is built into a cantilever truss. This presence of tensile force prods the need to attach the deck girder to the base at the upstream toe in order to sustain itself. Hovey proposed that by flattening the slants of the lower struts within the bent, the tension at the upstream toe could be lowered. However, heavier struts would be essential for this to occur.

Another way to lessen the tension is to place the embattled curve rigidly together so the downward force from the water on the lower part of the deck can nullify the power induced in the cantilever. This setup is more costly than other methods since it needs bracing. Steel dams, though more expensive and vulnerable to corrosion, are sometimes used during the construction of permanent dams where they serve as temporary coffer dams. These dam structures come with timber or earth fill on the inside walls to make them impermeable, enabling the area between the dams to be dewatered so work can be done on assembling the permanent dam. Examples of steel type dams include the Redridge Steel Dam of the USA and the Ashfork-Bainbridge Steel Dam of the USA.

7. **Timber Dams**: The main structures of a timber dam are constructed out of wood, typically coniferous varieties, such as pine and fir. These dams are designed for heads of up to 8m typically, with the apron featuring a pile, crib, pile-crib, or buttressed design. When the sluices are particularly long, they are divided into multiple openings by intermediate supports, such as piers, buttresses, and posts. For these openings, wooden shields are placed, often in multiple rows, and can be raised and lowered with either permanent or mobile winches.

8. **Rubber Dams:** Rubber dams provide a sophisticated and efficient solution to many projects due to their ease of construction, operation and decommissioning in tight timelines. These dams are constructed out of large cylindrical shells that are made of a special synthetic rubber and inflated with either compressed air or pressurized water. The inflated shell allows the crest level to be easily adjusted by releasing pressure and any surplus water will overflow. However, due to the delicate nature of rubber dams, they are only suitable for small projects, requiring extreme caution when constructing and erecting them. An example of this type of dam is the Janjhavathi Rubber Dam in India[49].

2.8.3 Different Parts and Terminologies of Dams

A. **Crest**: The top of the dam structure. These may in some cases be used for providing a roadway or walkway over the dam.

B. **Parapet Walls**: Low Protective walls on either side of the roadway or walkway on the crest.

C. **Heel**: Portion of structure in contact with ground or river-bed at the upstream side.

D. **Toe**: Portion of structure in contact with ground or river-bed at the downstream side.

E. **Spillway**: It is the arrangement made (kind of passage) near the top of the structure for the passage of surplus/ excessive water from the reservoir.

F. **Abutments**: The valley slopes on either side of the dam wall to which the left and right end of dam are fixed to.

G. **Gallery**: A tunnel-like area with a shallow gradient, located inside a dam either longitudinally or transversely, with a sunken flooring to allow for water seepage. These sections are generally used for drilling grout holes, drainage holes and accommodating instrumentation to measure the efficiency of the dam.

H. **Sluice Way**: Opening in the structure near the base, provided to clear the silt accumulation in the reservoir.

I. **Free Board**: The space between the highest level of water in the reservoir and the top of the structure.

J. **Dead Storage Level**: Level of permanent storage below which the water will not be withdrawn.

K. **Diversion Tunnel**: Tunnel constructed to divert or change the direction of water to bypass the dam construction site. The hydraulic structures are built while the river flows through the diversion tunnel[50].

2.8.4 Dam Builders, Funding Agencies and Professionals

The International Commission on Large Dams (ICOLD) has been a driving force since its inception in 1928 in disseminating knowledge, best practices, and research relating to the design, construction, and maintenance of large dams. Additionally, the International Commission on Irrigation and Drainage (ICID) was founded in 1950 and the World Commission on Dams examine the environmental, social, and economic repercussions of building large dams all over the world[51]. This commission was active from April 1997 to 2001.

2.8.5 Historical Overview of Dams

In this research, six dams located in the Osun Metropolitan area of southwest Nigeria were studied. These dams were within the three Federal Constituencies of Osun Central (Eko-Ende and Iba), Osun East (Ilesa and Esa-Odo), and Osun West (Ede and Ikire-Asejire) and lie in close proximity to residential neighborhoods. For the purpose of this research, these dams were categorized according to their International Commission on Large Dams (ICOLD) criteria, with those taller than 15 meters, and significant in terms of storage volume, population density, or other factors, up to 10 m high, being considered as major dams. This type of classification is used across all Nigerian states[52].

2.8.6 Size and Choice

The desire for a consistent water supply throughout human history has necessitated the construction of dams. From large-scale mega-dams to smaller micro-dams, these water storage structures have provided relief from droughts and floods. Through open canals, tunnels, or closed pipes, water stored in dams can be transported to areas in need[53]. To ensure water is delivered with the shortest possible route, dam water should be properly transferred to the needed river basin. When deciding on the most suitable location for the construction of a dam, a thorough feasibility study should be conducted to determine the size and potential usefulness of the dam[54].

2.9. Physical Factors Governing Selection of Type of Dams

In order to ensure that the project is cost-effective, proper analysis must be done before settling on a dam site and the type of dam it will require. Generally, this means looking into multiple dam designs and possible structures to assess feasibility and the final cost. Exceptional circumstances may require only one type, but it is imperative to look into all the options and pick the most suitable and economical option.

The cooperation of various specialists is necessary to ensure efficient and appropriate designs when deciding on the kind of dam to be constructed. Professionals such as planners, hydrologists, structural engineers, engineering geologists and geotechnical engineers must work in concert to develop an understanding of the available material, hydrology, seismic activity and terrain. Other issues impacting the type of dam include spillway protection, outlet works, labor and equipment availability, accessibility, purpose and safety. In the end, a cost analysis is often conducted to decide which type of dam is most appropriate. Collaboration among experts is critical in the selection of the optimal dam for physical factors, such as geography and foundation conditions.

Topography - The topography of the area in which the dam is to be constructed has a big impact on the type of dam that should be used. For example, if the area features a narrow stretch of land with high, rocky walls, then a rock-fill or concrete overflow dam would be the best choice. On the other hand, if the area is characterized by low, rolling plains, then an earth-fill dam would work best. Where the landscape features neither of these conditions, then a composite dam structure may be the most suitable option. It is therefore clear that topography is extremely important when selecting the type of dam.

Topography can be a significant factor when choosing the type of ancillary structures for a project. For example, if there are hills or depressions in the landscape, using a spillway through them may become an option. If the height of the reservoir compared to the dam is substantial, then a chute or tunnel spillway might be necessary. These spillway considerations can have an effect on the construction of the dam. In cases of a deep, steep-walled canyon, building a concrete dam with a natural overflow might be a better financial decision than installing a spillway for a rock-fill dam.

Geology and Foundation Conditions

Geological questions about the different rocks and soils found in the area of a dam site must be asked and answered in order to assess which type of material would be the best for the construction of the dam. Particular attention should be paid to the properties of the rock and soil, such as strength, thickness, permeability, and faulting, to determine what type of dam would be suitable for the chosen location. The various foundations commonly seen in dam sites will be considered in the following discussion.

(a) Rock Foundations

Having a rock foundation free from geological flaws generally leads to greater shear strength, resistance to erosion and infiltration, thus allowing for the building of any desired dam. The most important factor should be to limit material expenses. In the case of rocks such weak as clay shales, sandstones, and weathered basalt, issues regarding the design and building of a dam may arise, which can dictate the selection of the dam's type.

(b) Gravel Foundations

Gravel foundations that have been sufficiently compressed are appropriate for earth-fill or rock-fill dams. Nevertheless, due to the high rate of water infiltration on these substrates, special measures must be taken to ensure the implementation of appropriate seepage control, water cut-offs, or seals.

(c) Silt or Fine Sand Foundations

Foundations for low concrete gravity and earth-fill dams can be effectively constructed using silt or fine sand, as long as appropriate design considerations are taken into account; however, this is not recommended for rock-fill dams. Issues such as uneven settlement, soil collapse when fully saturated, uplift pressure, prevention of water drainage from the soil, limiting losses due to seepage, and protecting the base of the downstream embankment from erosion must be addressed in the design of the dam.

(d) Clay Foundations

Clay foundations are not an ideal choice when it comes to building dams due to their lower foundation shear strength and large tendency to consolidate when under load. This requires flatter embankment slopes, which can become cost prohibitive, making clay foundations mainly suitable for earth-fill dams. Additionally, due to the consolidation, tests are usually required to investigate how well the clay foundation can handle a superimposed load. As such, it is usually not cost effective to build a rock-fill dam on a clay foundation, or a concrete gravity dam[55].

(e) Non-Uniform Foundations

Sometimes, constructing a dam in a location with uneven foundations of rock and soft material is unavoidable. Special designs or treatments might be used to compensate for this and make the structure structurally sound. Even in sites without particularly unusual conditions, problems can arise which require knowledgeable engineers to determine the best solution based on factors like the height of the crest and the distance between the crest and surrounding water. The elevation of the top of the dam for smaller structures is generally less than or equal to fifteen meters (15 m) while that for larger dams tends to be higher (H > 15 m). These dams can be constructed for single or multiple purposes; for example, the Shiroro dam in Niger State generates hydroelectricity and the Tura Dam in Katsina State provides potable water to local communities and villages. Other advantages of having dams are providing water for drinking, industrial uses, and irrigating crops, regulating flooding, offering recreational sites, navigation, and hydroelectric power generation. The construction of dams in Nigeria has been done for a single purpose; however, there are numerous potential benefits in building multipurpose dams. These include providing water for industry and municipalities, controlling floods, generating electricity, producing livestock and fish, supporting tourism, and irrigation. In 1973, Nigerian River Basin (RB) areas were split into eleven, each of which is directly overseen by the Federal Ministry of Water Resources. These River Basins supply potable water to towns and villages, with examples such as the Bakolori Dam in the Sokoto-Rima Basin Development Authority in Northern Nigeria, the Tiga, Challawa Gorge and KafinZaki Dams in the Hadejia - Jama Area River Basin, and the Kainji, Shiroro and Jebba Amss in the Niger Basin.

In the South Western part of Nigeria, the Ogun-Osun River Basin is home to a number of dams, such as Asejire, Eleyele, Erinle, Oyan, Ikere-Gorge, Egbe, Ero, Erelu and Ejigbo. Not only have dams such as Kainji, Shiroro and Jebba successfully generated electricity in Nigeria, as Kainji can generate up to 960 Megawatts, but they have also provided power to many of the country's cities. The River Basin's 135 km length and 30 km width further serve humanity through the promotion of domestic fish production. Moreover, dams have had a positive effect on food production and the alleviation of poverty, both through fisheries and agricultural irrigation. The dams on the Bakolori, Kafin-zaki, and Tiga rivers were designed to irrigate an estimated total of 220,000 hectares of farmland. However, these dams have been linked to severe consequences such as loss of life and displacement of persons, as well as destruction of villages, due to dam failures in recent years[56]. This lack of adequate information on the design and operational status of these dams has posed a major threat to safety, performance, and longevity in regard to concrete gravity dams installed in the last century.

2.9.1 Effectiveness of Dams for Development

No matter the size of the dam, it is essential to plan its construction in such a way that any negative effects on the surrounding community are minimized. Prior to starting the process, experts should be consulted and a proper feasibility study should be done. In order to have an effective dam for development, the right methods and resources must be used. In the planning stages, consideration should be given to economic and social needs such as food, energy, drought protection and flood protection. Ultimately, dams provide regular water supplies for drinking, growing food, generating hydro power at a lower cost, and reduce flooding. Factors like the amount of available water help determine the size of the dam. Constructing large dams can help increase energy, food, and fish production, as well as the development of other aquatic organisms. It also provides potable water, proper sanitation, and other necessities to rapidly evolving regions across the globe when possible. In spite of this, many impoverished regions still have unmet demands, despite the long-term development efforts in creating dams. From farmers generate food to businesses, to even individuals, everybody requires dam water for their various functions[57]. In turn, the reliance of these dams for basic survivorship necessitates those that depend on them to be prioritized highly among stakeholders.

2.9.2 Quantities and Storage for Beneficial Use

The water trapped behind a dam does not completely get allocated for human consumption. A certain amount of it is lost by evaporating, which ranges from one to two meters of water per year, depending upon the climate. Moreover, when the inflows are combined in the pool, some silt gathers in the upper part and slowly forms sediment deltas. It is possible to attenuate this loss of storage by having gates that open whenever there is an inflow of high levels of silt. The remaining portion of the liquid can be dispersed and employed for several usable requirements, except for which seeps away from the bed of the structure and its base[58]. The size of dead storage fluctuates, dependent on the catchment region's parameters, and is more prominent in a more diminutive reservoir. This goes for evaporation losses as well.

Storing water in reservoirs can lessen the variability of river flow during different times of the year, thereby preventing economic damage that can be caused by inundations and dry periods[59].

Endnotes

[1] P. Nyiramigisha, “*Harmful Impacts of Heavy Metal Contamination in The Soil and Crops Grown around Dumpsites*”, **Reviews in Agricultural Science**. 9, 2021, 271-282.

[2] H. Ali, & E. Khan, "*What are Heavy Metals? Long-Standing Controversy over The Scientific Use of The Term ‘Heavy Metals’*—Proposal of a comprehensive definition", **Toxicological and Environmental Chemistry,** 100(1), 2018, 6-19.

[3] D. Witkowska, J. Słowik, & K. Chilicka, "*Heavy Metals and Human Health*: Possible exposure pathways and the competition for protein binding sites", **Molecules**, 26(19), 2021,6060.

[4] I. Manisalidis, E. Stavropoulou, A. Stavropoulos & E. Bezirtzoglou, "*Environmental and Health Impacts of Air Pollution*: A review", **Frontiers in Public Health**, 14,2020.

[5] O. Akinnifesi, F. Adesina, G. Ogunwole, & S. Abiya, “*Occurrence and Impact of Heavy Metals on Some Water, Land, Flora and Fauna Resources across Southwestern Nigeria*”. In Heavy Metals-Their Environmental Impacts and Mitigation, 3,2021.

[6] J. J. Steffan, E. C. Brevik, L. C. Burgess, & A. Cerdà, *"The Effect of Soil on Human Health: an Overview"*, **European journal of soil science**, 69(1), 2018,159-171.

[7] M. Mokarram, A. Saber, & V. Sheykhi, “*Effects of Heavy Metal Contamination on River Water Quality Due to Release of Industrial Effluents*”, **Journal of Cleaner Production**, 277, 2020,123380.

[8] S. Kulkarni & A. Goswami, *"Effect of Excess Fertilizers and Nutrients: A Review on Impact on Plants and Human Population"*, International Conference on Sustainable Computing in Science, Technology and Management (SUSCOM), 2019, 1-4.

[9] E. David & C. Cosio, *"New Insights into Impacts of Toxic Metals in Aquatic Environments"*, **Environmental Journal,** 8(1), 2020,1.

[10] M. A. Ahsan, M. A. Siddique, M. A. Munni, M. A. Akbor, U. H. Bithi, M. Y. Mia, & M. Siddique. *"Analysis of M#ajor Heavy Metals in the Available Fish Species of The Dhaleshwari River, Tangail, Bangladesh"*, **International Journal of Fisheries and Aquatic Studies,** 6(4), 2018, 349-354.

[11] E. S. Chinemelu & G. I. Nwankwor, *"Seasonal Variations of Heavy Metals in Groundwater of Warri And Environs, Southwestern Nigeria"*, **International Journal of Advanced Academic Research | Sciences, Technology and Engineering**, 5(6), 2019, 2-5.

[12] M. Balali-Mood, K. Naseri, Z. Tahergorabi, M. R. Khazdair, & M. Sadeghi, "*Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium, and Arsenic*", **Frontiers in pharmacology**, 2021, 227.

[13] J. Bielecka, R. Markiewicz-Zukowska, P. Nowakowski, M. Grabia, A. Puscion-Jakubik, K. Mielcarek, K. J. Gromkowska-Kepka, J. Soroczynska & K. Socha, *"Content of Toxic Elements in 12 Groups of Rice Products Available on Polish Market"*, **Human Health Risk Assessment**, **Foods**, 9(12), 2020,1906.

[14] D. Agrelli, A. G. Caporale & P. Adamo, *"Assessment of the Bioavailability and Speciation of Heavy Metal(loid)s and Hydrocarbons for Risk-Based Soil Remediation",* **Journal of Agronomy,** 10(9), 2020,1440.

[15] H. Barman, S. K. Das & A. Roy, *"Zinc in Soil Environment for Plant Health and Management Strategy"*, **Universal Journal of Agricultural Research,** 6(5), 2018,149-154.

[16] D. Neina, *"The Role of Soil pH in Plant Nutrition and Soil Remediation",* **Journal of Applied and Environmental Soil Science,** 2019, 1-9.

[17] M. Jalali & S. Najafi, "*Effect of pH on Potentially Toxic Trace Elements (Cd, Cu, Ni, and Zn) Solubility in Two Native and Spiked Calcareous Soils",* **Experimental and Modeling. Communications in Soil Science and Plant Analysis,** 49(7), 2018,814-827.

[18] Q. Zhao, J. Tang, Z. Li, W. Yang & Y. Duan, "*The Influence of Soil Physico-Chemical Properties and Enzyme Activities on Soil Quality of Saline-Alkali Agroecosystems in Western Jilin Province, China",* **Sustainability,** 10(5), 2018,1529.

[19] I. M. Ugwu & O. A. Igbokwe, *"Sorption of Heavy Metals on Clay Minerals and Oxides*: A Review, **Advanced Sorption Process Applications,** 2019, 1-23.

[20] G. O. Dayo-Olagbende, S. A. Adejoro, B. S. Ewulo & M. A. Awodun, *“Effects of Oxidation-Reduction Potentials on Soil Microbes"*, **Agricultural,** 16(1-2), 2019,35-42.

[21] G. Liu, Z. Yu, X. Liu, W. Xue, L. Dong, & Y. Liu, *"Aging Process of Cadmium, Copper, and Lead under Different Temperatures and Water Contents in Two Typical Soils of China”,* **Journal of Chemistry,** 2020, 1-10.

[22] S. Li, M. Wang, Z. Zhao, C. Ma, & S. Chen, *" Adsorption and Desorption of Cd by Soil Amendment - Mechanisms and Environmental Implications in Field-Soil Remediation",* **Sustainability**, 10(7), 2018,2337.

[23] U. Azhar, H. Ahmad, H. Shafqat, M. Babar, H. M. Munir, M. Sagir, M. M. Arif, A. Hassan, N. Rachmadona, S. Rajendran, & M. Mubashir, “*Remediation Techniques for Elimination of Heavy Metal Pollutants from Soil: A Review*”, **Environmental research**, 2022,113918.

[24] M. I. Dinu & V. M. Shkinev, *"Complexation of Metal Ions with Organic Substances of Humus Nature: Methods of Study and Structural Features of Ligands, and Distribution of Elements between Species”,* **Geochemistry International**, 58, 2020,200-211.

[25] J. E. Emurotu, *"Chemical Speciation and Potential Mobility of some Metals of Selected Farmland in Kogi State, North Central Nigeria",* **Nigerian Journal of Basic and Applied Science,** 28(1), 2020, 48-55.

[26] M. Balali-Mood, K. Naseri, Z. Tahergorabi, M. R. Khazdair, & M. Sadeghi, “*Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium, and Arsenic*", **Frontiers in Pharmacology**, 2021, 227.

[27] G. A. Engwa, P.U. Ferdinand, F. N. Nwalo & M. N. Unachukwu, *"Mechanism and Health Effects of Heavy Metal Toxicity in Humans",* **Archives of Biological Sciences**, 10, 2019,70-90.

[28] N. E. Shaari, M. T. Tajudin, M. M. Khandaker, A. Majrashi, M. M. Alenazi, U. A. Abdullahi & K. S. Mohd, *"Cadmium Toxicity Symptoms and Uptake Mechanism in Plants*: A Review", **Brazilian Journal of Biology,** 2022, 84.

[29] United States Environmental Protection Agency, *"Factors Affecting the Environment", Retrieved from*. https://www.epa.gov/environmental-factors-affecting-health, 2019.

[30] S. Prakash & A. K. Verma, *"Arsenic: It's Toxicity and Impact on Human Health"*, **International Journal of Biological Innovations,** 3(1), 2021, 38-47.

[31] S. M. Islam, M. F. Rohani, S. A. Zabed, M. T. Islam, R. Jannat, Y. Akter, & M. Shahjahan, “*Acute Effects of Chromium on Hemato-Biochemical Parameters and Morphology of Erythrocytes in Striped Catfish Pangasianodon Hypophthalmus*”, **Toxicology Reports**, 7, 2020, 664-670.

[32] C. S. Silva, C. Moutinho, A. Ferreira da Vinha, & C. Matos, *"Trace Minerals in Human Health: Iron, Zinc, Copper, Manganese and Fluorine",* **International Journal of Science and Research Methodology**, 13(3), 2019,57-80.

[33] V. Delahaut, B. Rašković, M. S. Salvado, L. Bervoets, R. Blust, & G. De Boeck, "*Toxicity and bioaccumulation of Cadmium, Copper and Zinc in a direct comparison at equitoxic concentrations in common carp (Cyprinus carpio) juveniles*", **PLoS One**, 2020 15(4), e0220485.

[34] S. Buxton, E. Garman, K. E. Heim, T. Lyons-Darden, C. E. Schlekat, M. D. Taylor, & A. R. Oller, *"Concise Review of Nickel Human Health Toxicology and Ecotoxicology"*, **Journal of Inorganic Chemistry,** 2019, 7(7), 89.

[35] B. A. Fonge, M. T. Larissa, A. M. Egbe, Y. A. Afanga, N. G. Fru & V. M. Ngole-Jeme, *"An Assessment of Heavy Metal Exposure Risk Associated with Consumption of Cabbage and Carrot Grown in a Tropical Savannah Region. Sustainable Environment",* **An International Journal of Environmental Health and Sustainability**, 7(1), 2021,1909860.

[36] L. Stofejova, J. Fazekas & D. Fazekasova, *"Analysis of Heavy Metal Content in Soil and Plants in the Dumping Ground of Magnesite Mining Factory",* **Journal of Sustainability,** 13(8), 2021, 4508.

[37] O. B. Akintan, J. A. Olusola & A. M. Azeez, *"Heavy Metals Loads in Soil, Farmlands and Plant Crop at Open Dumpsite",* **Global Journal of Environmental Science and Management**, 5(4), 2019, 449-460.

[38] I. Bashir, F. A. Lone, R. A. Bhat, S. A. Mir, Z. A. Dar, & S. A. Dar, *"Concerns and Threats of Contamination on Aquatic Ecosystems",* **Journal of Bioremediation and Biotechnology,** 2020, 1-26.

[39] S. Mitra, A. J. Chakroborty, A. M. Tareq, T. B. Emran, F. Nainu, A. Khusro, A. M. Idris, M. U. Khandaker, H. Osman, F. A. Alhumaydhi & J. Simal-Gandara, *"Impact of Heavy Metals on the Environment and Human Health: Novel Therapeutic Insight to Counter The Toxicity",* **Journal of King Saud University Science**, 2022, 101865.

[40] C. Tibu, T. Y. Annang, N. Solomon, & D. Yirenya- Tawiah, *Effect of The Composting Process on Physic-Chemical Properties and Concentration of Heavy Metals in Market Waste with Additive Materials in The Ga West Municipaliity, Ghana",* **International Journal of Recycling of Organic Waste in Agriculture**, 8, 2019,393-403.

[41] I. Sylwan & E. Thorin, *"Removal of Heavy Metals during Primary Treatment of Municipal Wastewater and Possibilities of Enhanced Removal: A Review"*, **Journal of water**, 13(08), 2021, 1121.

[42] S. A. Razzak, M. O. Farooque, Z. Alsheikhd, L. Alsheikhmohamadc, D. Alkuroudd, A. Alfayez, S. Z. Hossain, & M. M. Hossain, *"A Comprehensive Review on Conventional and Biological-Driven Heavy Metals Removal from Industrial Wastewater"*, **Environmental Advances**, 2022, 100168.

[43] Q. Ma, L. Han, J. Zhang, Y. Zhang, Q. Lang, F. Li, A. Han, Y. Bao, K. Li, & S. Alu, *"Environmental Risk Assessment of Metals in The Volcanic Soil of Changba Mountain",* **International Journal of Environmental Research and Public Health**, 16(11), 2019,2047.

[44] S. I. Khassaf, *Dams and Reservoir, University of Bashra College of Engineering, Civil Engineering Department, Iraq*, 2020.

[45] G. Mengistu, G. Sahilu, L. Alakangas, W. Mulat, & H. Kloos, "*Assessment of Heavy Metal Pollution Associated with Tailing Dam in Gold Mining Area, Southern Ethiopia*". **Geosystem Engineering**, 26, 2022,1-1.

[46] P. Fan, M. S. Cho, Z. Lin, Z. Ouyang, J. Qi, J. Chen J & E. F. Moran, "*Recently Constructed Hydropower Dams were Associated with Reduced Economic Production, Population, and Greenness in nearby Areas*", **Science of The Total Environment**, 119(8), 2022, e2108038119.

[47] G. A. Speckhann, H. Kreibich, & B. Merz, "*Inventory of Dams in Germany*," **Earth System Science Data**, 13(2), 2021, 731–740.

[48] N. Adamo, N. Al-Ansari, V. Sissakian, J. Laue & S. Knutsson, *"Dam Safety: General Consideration*", **Journal of Earth Sciences and Geotechnical Engineering**, 10(6), 2020, 1-21.

[49] P. O. Youdeowei, H. O. Nwankwoala, & D. D. Desai, *"Review Article: Dam Structures and Types in Nigeria: Sustainability and Effectiveness",* **Water Conservation and Management**, 3(1), 2019,20-26.

[50] K. He, J. Wang, Q. Chen, F. Wu, X. Yang, & J. Chen, "*Effects of Cascade Dams on The Occurrence and Distribution of Microplastics in Surface Sediments of Wujiang River Basin, Southwestern China*", **Ecotoxicology and Environmental Safety**, 240, 2022, 113715.

[51]X. Fan, A. Dufresne, S. S. Subramanian, A. Strom, R. Hermanns, C. T. Stefanelli, K. Hewitt, A. Yunus, S. Dunning, L. Capra, & M. Geertsema, "*The Formation and Impact of Landslide Dams: State of The Art*", **Earth-Science Reviews**, 203, 2020,103116.

[52] T. Lavers & B. Dye, "*Theorising The Political Economy of Dams*, *Towards a Research Agenda,"* Working Paper 001. Manchester: The University of Manchester, Future **Dams**, 2019, Available at SSRN 3538193.

[53] Y. Wang, Y. Tian & Y. Cao, *"Review: Dam Siting: A Review*", **Water**, 13, 2021, 2080.

[54] O. Y. Ababio, "*New School Chemistry*,", Africana First Publishers PLC, Sixth Edition, 2016, 298-315.

[55] G. A. Adebisi, "*Basic Chemistry Laboratory Techniques*,", Iyiola Printing Press, Third Edition, 2020, 28-30.

[56] E. U. Akusoba & G. O. *Ewelukwa,* "*Calculation in Chemistry*,", Africana First Publishers PLC, 2018, 49-50.

[57] R. K. Dhir, J. De Brito, R. Mangabhai, C. Q. Lye, "*Sustainable Construction Materials*,", *Copper Slag*, Woodhead Publishing, 2016.

[58] I. A. Odesina, "*Essential Chemistry*,", Tonad Publishers Limited, Ninth Edition, 2020: 230-262.

[59] G. O. Ojokuku, "*Understanding Chemistry for Schools and Colleges*," PRESS-ON CHEMBOOKS, Third Edition, 2019, 119-127.

Chapter Three

Methodology

3.1 Description of the Study Areas

Osun State is located in southwest Nigeria and its capital is Osogbo. Most of Osun's population are members of the Yoruba ethnic group, who are known for their entrepreneurial spirit, hospitality, and agricultural lifestyle. There are three Federal Senatorial Districts and it is divided into two zones. The state has thirty Local Government Areas. Osun was created in 1991 when Oyo State was divided and takes its name from the Yoruba goddess River Osun[1]. According to the 2006 census, its population is 3.4 million[2]. It is home to several heavily populated urban areas, such as Osogbo, Ile-Ife, Ilesa, Ikirun, Iba, Iwo, Ede, Ila-Orangun and Ikire. In addition to having the second-highest literacy rate in Nigeria, Osun State is also home to some of the highest-profile landmarks, including Obafemi Awolowo University's campuses in Ile- Ife and Osogbo, Redeemer's University Ede, Oduduwa University in Ile- Ife, and Erin-Ijesa Waterfall. Other prominent sites, such as Osun-Osogbo Grove and Oduduwa Staff Grove can also be found in the state. The population in Osun State is largely composed of members of the Yoruba tribe, including Ife, Ijesha, Oyo, Ibolo, and Igbomina. Other states in the region are Oyo in the West, Ondo and Ekiti in the East, Kwara in the North, and Ogun in the South[3]. Osun is a state in southwest Nigeria where the official languages are Yoruba and English. The state's inhabitants are diversely spiritual, following Islamic, Christian, and pagan beliefs known collectively as traditional faith. Most of the residents are farmers, artisans, and traders. They have a tradition of creating handwoven fabrics, traditional tie-dyeing, leatherwork, calabash carving, mat-making and basket weaving. Osun has a strong cultural history, as well as a diverse range of tourist attractions, including an annual Osun Osogbo cultural festival held along the banks of the Osun

River, which dedicates itself to Yemoja, the goddess of fertility. Each year, devotees from across the nation and from overseas attend the event to celebrate culture, tradition and faith. People from the United States, Brazil, Cuba, Trinidad, Grenada, and other countries who have a heavy Yoruba cultural background are drawn to the yearly event at the Osun-Osogbo Grove which is a celebrated sanctuary and artist's haven. In 2005, the United Nations Educational, Scientific and Cultural Organization (UNESCO) declared it a World Heritage Site[4].

3.2 Description of Sampling Sites

For a period of twelve months, beginning in February 2018 to January 2019, samples of water, sediments, fish life, and vegetation were collected from six dams located in the Osun Central, East and West divisions of Osun State. These dams included Eko-Ende and Iba (Osun Central), Ilesa and Esa-Odo (Osun East), and Ede and Ikire-Asejire (Osun West). (Figure 3.3).

3.2.1 Eko-Ende Dam

The Eko–Ende Dam on the Otin River was completed in 1973, bringing a 5.5 million cubic metre (MCM) reservoir to the region. The surrounding environs are semi-rural to rural with rocky surfaces and ranging heights of 35 to 400 m above sea level. It is situated between 7^{o}54'30"N and 7^{o}57'0"N, and 4^{o}33'30"E and 4^{o}35'30"E. People in the nearby settlements greatly benefit from its presence as they are able to use the dam's water for drinking, agriculture, and fishing. The earthen construction of the dam has a capacity of 910,000 cubic metres (32 million square feet) and was finished in 1979. Eko-Ende is a small village in Ifelodun Local Government Area of Osun State, Nigeria, having an estimated population of 96,748. There is an area of about 114 km^{2} in the hamlet and it features a tropical climate with an average temperature of 26°C (79°F).

Figure 3.1: Map of Nigeria showing Osun State

Source: National Bureau of Statistics, 2020, Map of Nigeria, (https://nigerianstat.gov.ng/view/state_district_lg_map).

Figure 3.2: Map of Osun State showing the Local Government

Source: Environmental Baseline Database for Osun State. (2011)

The agricultural settlement lies in the midst of Eko-Ajala village and Ore on the Ikirun-Ogbomoso highway and typically experiences 1254 mm (49.4 inches) of rainfall annually, with the wettest months being July and September, and the driest being November and February[5].

3.2.2 Iba Dam

The community of Iba is located 35km northeast of Ikirun, east of Inisa, and southeast of Okuku in the Ifelodun Local Government Area of Osun State. Its coordinates are Lat. 7°58'09"N and 4°42'1"E long. 7.9690510N 4.703880E and it has an average annual temperature of 37°C. It has two health centers, one secondary school and four primary schools, but due to its rural nature, transportation, power, hospitals and water are difficult to come by. The total length of the dam in Iba is 36 kilometers (22 miles), with a basin size of 475 kilometers (183 sqmi). The wet season there is hot and muggy, while the dry season is much the same. The temperature fluctuates between 64°F and 92°F and only rises above 97°F or drops to below 57°F occasionally. The area receives an average of 54.6 inches of rain a year[6].

3.2.3 Esa-Odo Dam

The Esa-Odo dam is situated in Osun State, Nigeria, in the Obokun Local Government Area, between Lat. 7°45'0"N and Long. 4°49'0"E, and Long. 7°47'18"N and 4°50'12"E, located 458 meters above sea level. Built in 1971 and completed six years later in 1977, the dam was made mainly to serve as a drinking water reservoir for the villages located on its riversides, as well as to provide nearby industry (in particular Nigeria Breweries at Ilesa) and for fishing and tourism prospects. Esa-Odo is a mixture of earth-fill and concrete, featuring a crest length of 677 m, and 11.3 m of initial height; its catchment area is 120 square kilometers, and it is inhabited by 116,511 people, according to the 2006 census. With an average temperature of 35°C, an average annual precipitation of 502 mm, 205 days of dry weather and a UV index of 747, Esa-Odo has an average of 55% relative humidity[7].

3.2.4 Ilesa Dam

The Ilesa Dam is in Osun State, Nigeria, in the Ilesa East Local Government Area, by the junction of highways arriving from the cities of Ile-Ife, Osogbo and Akure. Located halfway between Lat.7°36'0"N, 4°40'0"E, and Long.7°42'0"N, 4°46'0"E, the Dam is an ancient structure with a total area of 63 km^2. Daytime temperatures in Ilesa usually stay between 65 and 92°F throughout the year. Even in the driest and hottest months the temperature usually doesn't fall below 59°F or exceed 97°F. The hot season in this location runs from January 22 to April 4, with an average daily high temperature in excess of 90°F and with February 19 as the warmest day of the year, with a maximum of 92°F and a minimum of 70°F. The chilly season carries on for 3.8 months, from June 15 to October 8, and typically has average daily temperatures below 83°F with December 30th the coolest day, high of 88°F and a low of 65°F. Lastly, the rainy season is the longest at 9.3 months, occurring from February 10 to November 21, and is typically defined as having at least 31 days of rainfall and an average of 0.5 inches across those days. The heaviest rainfall takes place leading up to September 11th, with a total average accumulation of 9.0 inches[8].

3.2.5 Asejire Dam

The Ikire – Asejire Dam is located 30-33.8 kilometers east of Ibadan city in Osun State. Construction commenced in the late 1960s, with the Dam opening on November 17, 1972. The Dam has a total capacity of 80 million litres, with the majority being used for domestic purposes. The catchment area immediately surrounding the Dam has had farming and other extractive activities prohibited, with trees planted along the banks to help reduce siltation and erosion. As a result, the Dam is able to remain consistently full throughout the year. Water from the Dam is treated at Asejire and Osegere water treatment plants and is distributed to Ibadan. The geographical coordinates of the dam are 7°21'45"N and 4°07'0"E, with an altitude of 137m above sea level and a length of 19.5km. The weather in Ikire is generally hot and humid all year round, but the wet season is often significantly more overcast than the dry season. The temperature normally fluctuates between 67°F and 94°F across the year. The temperature range throughout the year is quite limited, rarely dipping below 6°F or exceeding 98°F. The hot season starts on January 20 and ends on April 9, with a peak daily temperature of 94°F occurring on February 20. Conversely, the cold season begins on June 15 and concludes on October 4, with the coldest day on December 30, where the average daily low is 67°F and the high is 91°F. For most of the year, from February 2 to November 29, the wet season is in effect, with over 9.3 inches of rain falling on average within the 31 days surrounding 15 of September[9].

3.2.6 Ede Dam

The Ede dam is situated 12 kilometers upstream of Okinni town on the Erinle River and is a part of the Osogbo-Ede water supply extension system. It is bounded by Lat. 07°29'28" and 07°45'37" and Long. 004°31'41" and 004°27'9", with its terrain ranging from 250 m to 400 m above sea level. The climate in the area is classified as tropical, with the average annual rainfall being approximately 1400 mm and an eight-month rainy season (April to November). The Ede dam is an enlargement of the earlier Ede dam and Eko-Ende dam on the Otin River. It supplies water to cities such as Osogbo, Ede, Ife, Gbongan, Erinle-Osun, Ilobu, and Ifon, and also to small towns and villages in central, west, and Ife of Osun, to enhance their water distribution systems. This extends from Ede dam northwards along the Erinle River and its tributary, the Otin River for 112 kilometers, with a maximum breadth of 3.5 kilometers. Ede is located next to a substantial expanse of water and has a daily average high temperature of approximately 41°F, with temperatures rarely going below 30°F or exceeding 51°F. On January 12, the minimum daily high temperature was 41°F while an average low temperature of 33°F is typical, and it doesn't usually go below 19°F or over 44°F. The reservoir that encompasses the area covers roughly 14 km^2 at its normal water levels and 16 km^2 at maximum.

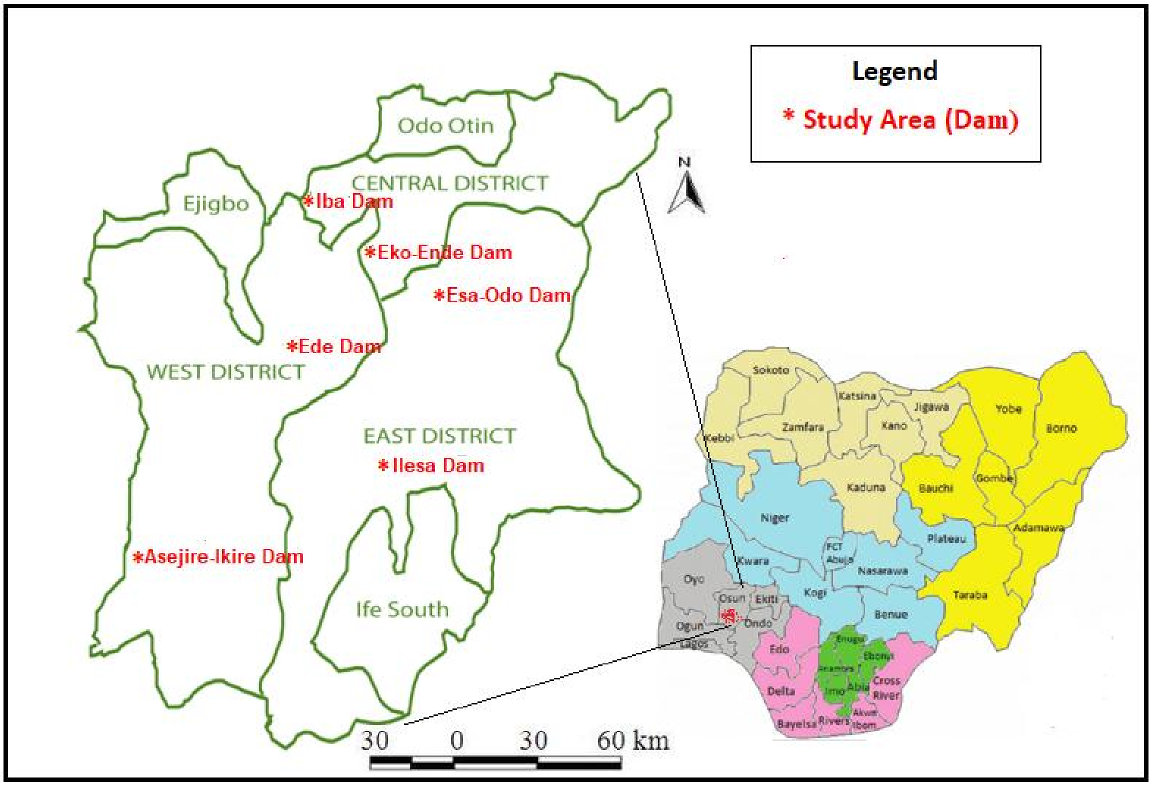

Figure 3.3: Map of the study area
Source: Author's Fieldwork, 2023

The first 31 days of September generally have decreasing amounts of rain in Ede, starting from 2.3 inches and usually not exceeding 3.9 inches or going below 0.8 inches, and ending up around 1.8 inches with maximums of 3.4 inches and minimums of 0.5 inches. The most precipitation is usually surveyed on the last day of the period, with totals normally amounting to 9.0 inches[10].

3.3 Sample Collection

Water, sediment, fish fauna, and plant samples were randomly collected from six selected Dams in Osun State between October and November, 2019.

3.3.1 Water Sample Collection

Water samples from the six selected Osun State dams were stored for analysis after being drawn with a Van Dorn sampler from the 10 spaces at each of the dams in a 1 L jar, which was then stored at a cooled temperature of 4°C.

3.3.2 Sediment Sample Collection

Sediment samples from the dams were carefully taken using a stainless-steel grab sampler from ten distinct places per dam. The samples were taken at a depth of 0 - 5 cm, with any loose particles and plant material removed by hand. They were then placed into a black polythene bag and clearly labeled.

3.3.3. Fish Sample Collection

The results of a six-dam mini-survey revealed Tilapia (*Oreochromis niloticus*) to be the most prevalent fish in the sample. Small catches of ten specimens per dam were obtained from local fishermen and transported in a thermos flask with ice chips, then stored at -30°C in an electric fridge for subsequent testing[13].

3.3.4. Plant Sample Collection

Okra (*Hibiscus esculentus*) and bitter leaf (*Verononia amygdalina*), the two most popularly cultivated vegetables in the area near the chosen reservoirs, were gathered and washed with tap water and then rinsed thoroughly with deionized water before being dried in the sunlight and placed in cellophane bags. Once in the lab, they were dehydrated in an oven. A Hammer mill was used to grind up the plant material, which was then stored in airtight polyethylene bags and kept in the refrigerator[14].

3.4 Samples Preparation

3.4.1 Preparations of water samples

Samples for elemental analysis were kept in plastic containers and preserved with the addition of 5 mL of concentrated HNO_3[11].

3.4.2 Preparations of Sediment Samples

Nearly 2 kg of sediment was collected from each dam, and heated for three days in an oven of 60°C until it reached a constant weight[12]. It was then broken down into small pieces with a mortar made from agate.

3.4.3 Preparations of Fish Samples

The fish specimens were cleaned with distilled water and then put in a 105°C oven for 24 hours to reach a consistent weight. The scales and bones were removed from the dried samples and discarded, leaving only the head, tail, gills, eyes and muscle. These remaining parts were crushed with a mortar and pestle and placed in labeled zipper bags until they could be digested[17].

3.4.4 Preparations of Plant Samples

The two samples were heated in an oven at 105°C until they held a constant weight. They were then ground into a fine powder in a laboratory grinder and stored in labeled polythene bags and kept in desiccators[18].

3.5 Samples Digestion

3.5.1 Digestion of The Water Samples

A sample of 50 mL of acid-preserved water was added to a 125 mL conical flask with 10 mL of 70% HNO3. The flask was covered with a watch glass and allowed to evaporate until nearly dry, making sure the bottom of the beaker was not dried out. Then, 1 mL of HNO_3 and distilled water was used to wash the residue, which was then passed through a Whatman No. 42 filter paper into a 25 mL volumetric flask. The remaining matter in the beaker was diluted with deionized water to the mark and stored in polyethene bottles for elemental analysis[15,19].

3.5.2 Digestion of the Sediment Samples

The sediment samples were processed using open vessel digestion. Initial digestion started with 1 g dried sediment and 5 mL of pure Merck nitric acid (99.99 %). This mixture was heated to 80°C until the sample was nearly dry. This process was repeated twice. Afterward, a small amount of water was added to the leftover substance. It was then filtered with a 0.45µm Whatman filter Merck and the filtrate was diluted to a final volume of 50 mL with deionized water[16,20].

3.5.3 Digestion of the Fish Samples

To prevent any contamination of the samples, all of the materials used in the preparation were first soaked in nitric acid for 15 minutes and then rinsed with deionized water. The sample was then left sitting at room temperature overnight. The aqua regia technique was used for the digestion process; 2 grams of the ground material were mixed with hydrochloric acid and nitric acid in a 3:1 ratio and heated up to 180°C. Once the digestion was completed, the residue was cooled and filtered into a 25 mL volumetric flask. Distilled water was used to fill the flask up to the required level. The sample vial was previously sanitized and the filtrate was placed in it and stored in the refrigerator until it was tested. An atomic absorption spectrophotometer was utilized to determine the concentration of heavy metals inside the fish tissue[21].

3.5.4 Digestion of the Plant Samples

The samples of the plant were digested employing aqua regia, 2g of each sample was carefully weighed and placed in a digesting tube. Distilled water was included in a few drops to moisten and spread it. Afterwards, 20 mL of aqua regia (15 mL HCl and 5 mL HNO_3) was incorporated, and the mixture was agitated thoroughly and cooked at 80-90°C for nearly 30 minutes prior to transferring to a 50 mL volumetric flask. Analysis of the specimens for their heavy metal content was accomplished thrice using an Atomic Absorption Spectrophotometer (AAS) to measure the heavy metals in compliance with the standard operating procedure[22].

3.6 Elemental Analysis

An Atomic Absorption Spectrophotometer (AAS) (Shimadzu AA-630) was utilized to analyze all digested water, sediment, fish and plant samples in triplicate for Fe, Cu, Zn, Mn, Ni, Cr, Cd, and Pb. Standards solutions that contain known quantities of heavy metals were used to calibrate the AAS before every three analyses, and the results were reported in mg L^{-1} [17].

3.7 Physico-chemical Analysis

3.7.1 Temperature, pH and Electrical Conductivity

For this study, three water sample variables were measured in situ - water temperature, pH and Electrical Conductivity with the aid of a multiparameter meter (YSI). Data were taken in triplicate for each sample[23].

3.7.2 Determination of Sulphate and Nitrate

Each dam was tested using bottles that were previously washed with dam water for sampling. The samples were placed in plastic containers and accurately labeled for identification. These samples were kept chilled at 4°C in an ice box during the transportation phase and analyzed within 24 hours as per the standard regulations. The portable turbidimeter (Hach 2100Q) was employed[24].

3.7.3 Determination of Phosphate

The colorimetric method (Hach DR3900) was applied to measure phosphorus. In a 25mL volumetric flask, two milliliters of the water sample were added along with one drop of phenolphthalein indicator, two milliliters of ammonium molybdate, and one milliliter of up-to-date diluted stannous chloride solution that was adjusted to the capacity of 25 mL with distilled water, which was then totally stirred. Five to six minutes later and prior to twenty minutes, a spectrophotometer with a wavelength at 660 nm was employed to evaluate the color intensity (absorbance)[25].

3.7.4 Total Dissolved Solids (TDS), Total Hardness, Turbidity, TSS, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD)

The water depth was calculated using a meter measure, while Total Hardness (TH) was established by titration with EDTA and Eriochrome BlackT as an indicator. Total Alkalinity (TA) was determined by titration with bromocresol green-methyl red as a detector. Turbidity and DO were determined using a turbidity meter (Lovibond TB 210 IR) and a DO meter (HI9819X Series) with a luminescent DO probe, following the standard process. Total Suspended Solid (TSS) concentration was calculated gravimetrically by filtration, dried in an oven and later averaged. Total Dissolved Solid (TDS) was immediately calculated using a TDS meter (YSI ProDSS). Biochemical Oxygen Demand (BOD) was determined utilizing the five-day dilution method. COD was calculated using the United States Environmental Protection Agency (USEPA) micro-digestion reactor along with the colorimetric technique. Results of all readings were taken as the mean of triplicate observations[24,25].

3.8 Quality Control and Quality Assurance

Analytical reagent grade chemicals such HNO_3 and HCl were supplied by Sigma Aldrich (St. Louis, USA) and Merck (Kenilworth, USA) chemical companies were used for samples, while spectroscopic grades were used for standards. Elemental calibration standards were prepared from spectroscopic grade stock standard solutions of 1000 mg L^{-1}. To prevent contamination all glassware and containers were washed with deionized water and then soaked overnight in 1 M HNO_3. Quality control procedures were implemented, which included reagent blanks, triplicate samples and recovery studies. The correctness of the analytical technique was established through simultaneous examination of certified reference material.

Endnotes

[1] A. N. G. Onyeakagbu, “Pulse”., **Journal of Experimental and Applied Mathematics,** 15(3), 2020, 233-237.

[2] National Population Commission, "2006 PHC Priority Tables". population.gov.ng. 2017, 10-10.

[3] B. A. Owolabi, A. Adewumi, O. S. Odewumi, E. F. Okosodo & J. O. Orimaye, "*Survey of Avifauna Species of a Degraded Environment*, Case Study of Osun State University, College of Agriculture, Ejigbo, Nigeria", **Merit Research Journal of Environmental Science and Toxicology**, 6 (2), 2018, 1-7.

[4] Z. Agu, "When will Osun Osogbo Festival be this Year?". Legit.ng-Nigeria News. 2019, 8-19.

[5] K. T. Ogundele, E. A. Oluyemi, J. A. Oyekunle, O.W. Makinde & S. T. Gbenu, "*An Evaluation of Health Hazards Indices of Natural Radioactivity of the Sediments from Eko-Ende Dam, Osun State, Nigeria*", **Open Journal of Ecology**, 8, (11), 2018,607-621.

[6] A. S. Olalekan, S. O. Adewoye, O. H. Sawyerr, & M. O. Raimi, “*Comparative Assessment of Seasonal Variations in the Quality of Surface Water and Its Associated Health Hazards in Gold Mining Areas of Osun State, South-West Nigeria*”, **Advance Environmental Engineering Research**, 4(1), 2023, 11.

[7] O. Obayemi, O. O. Komolafe, & E. E. Onana. "*Limnological Variables as a Determinant of Fish Parasites Abundance in The Esa-Odo Reservoir, Esa-Odo Southwestern Nigeria*", **Journal of Water and Health,** 2023.

[8] E. D. Ashaolu, J. F. Olorunfemi, & I. P. Ifabiyi, "*Effect of Land-use /Land Cover Change On Groundwater Recharge in Osun Drainage Basin, Nigeria,* **Journal of Geology, Geography & Geoecology**, 28 (3), 2019,381-394.

[9] B. Utete, & B. T. Fregene, "*Assessing the Spatial and Temporal Variability and Related Environmental Risks of Toxic Metals in Lake Asejire, South-Western Nigeria*", **Scientific African Journal**, 7, 2020, e00259.

[10] T. A. Oyewale, & T. Adesakin. "*Mycotoxigenic Fungi Distribution and Water Quality of Raw and Treated Water from Ede-Erinle and Opa Waterworks Systems, Osun State Nigeria,"* Preprint In Review Research-Article, Science Open Preprints, 2020.

[11] M. Ghaderpoori, A. Jafari, A. Ghaderpoury, & M. Karami, "*Heavy Metals Analysis and Quality Assessment in Drinking Water – Khorramabad City, Iran*", **Data in Brief**, 16, 2018, 685-692.

[12] I. K. Doamekpor, Y. Abusa, H. K. Ketemepi, R. K. Klake, M. E. Doamekpor, P. A. Anom, & J. Obeng, "*Assessment of Heavy Metals in Water and Sediments of Sakumo II, Chemu and Kpeshie Lagoons – Ghana*", **West African Journal of Applied Ecology**, 26(2), 2018,56–71.

[13] M. Mensoor, & A. Said, "*Determination of Heavy Metals in Freshwater Fishes of the Tigris River in Baghdad",* **Fishes**, 2018, 3(2), 23.

[14] K. Khan, G. M. Shah, A. Shah, Z. Saqib, M. Hussain & I. U. Rahman. "*Elemental Composition and Heavy Metals Determination of Some Wetland Plants of Family Polygonaceae*", **International Journal of Biosciences**, 15(3), 2019,483–488.

[15] H. Flefel, D. Nokhrin, & I. Donnik, "*Determine Heavy Metals in Water, Aquatic Plants, and Sediment in Water Systems*", Web of Conferences 222, 2020, 02028.

[16] M. S. Nkinda, M. J. Rwiza, J. N. Ijumba & K. N. Njau, "*Heavy Metals Risk Assessment of Water and Sediments Collected from Selected River Tributaries of the Mara River in Tanzania*", **Discover Water**, 1(1), 2021,3.

[17] D. A. Almashhadany, H. S. Khalid & H. S. Ali. "*Determination of Heavy Metals and Selenium Contents in Fish Meat Sold at Erbil City, Kurdistan Region*", **Journal of Food Safety**, 9 (3), 2020, 8753.

[18] P. H. Bukar & M. A. Onoja, *"Assessment of Heavy Metals in Okra (Abelmoschus esculentus) Cultivated through Irrigation in Maiduguri, Nigeria",* **Open Journals of Environmental Research**, 1(1), 2020,59–70.

[19] O. O. Olubanjo & E. B. Adeleke, *"Assessment of Physico-Chemical Properties and Water Quality of River Osse, Kogi State",* **Applied Research Journal of Environmental Engineering**, 3(1), 2020,21–30.

[20] T. Sawidis, M. K. Chettri, G. A. Zachariadis, & J. A. Stratis, "*Heavy Metals in Aquatic Plants and Sediments from Water Systems in Macedonia, Greece*". **Ecotoxicology and environmental safety**, 32(1), 1995,73-80.

[21] M. Krivokapić, "*Study on the Evaluation of (Heavy) Metals in Water and Sediment of Skadar Lake (Montenegro), with BCF Assessment and Translocation Ability (TA) by Trapa Natans and a Review of SDGs*", **Water**. 3(6), 2021,876.

[22] E. N. Vaikosen & G.O. Alade, *"Determination of Heavy Metals in Medicinal Plants from the Wild and Cultivated Garden in Wilberforce Island, Niger Delta Region, Nigeria",* **Journal of Pharmacy and Pharmacognosy Research**, 5(2), 2017,129–143.

[23] A. Rahman, I. Jahanara & Y. N. Jolly, *"Assessment of Physicochemical Properties of Water and Their Seasonal Variation in an Urban River in Bangladesh",* **Water Science and Engineering**, 14(2), 2021, 139–148.

[24] A. S. Thangiah, *"Spectrophotometric Determination of Sulphate and Nitrate in Drinking Water at Asia-Pacific International University Campus",* **Rasayan Journal of Chemistry,** 12(03), 2019,1503–1508.

[25] Z. Pan, X. Nong, Y. Xie, Y. Li, H. Zeng, Y. Liang & M. Zhang, *"Field Determination of Phosphate in Environmental Water by Using a Hand-Powered Paper Centrifuge for Preconcentration and Digital Image Colorimetric Sensing"*, **Journal of Analytical Methods in Chemistry**, 2022, 1–7.

Chapter Four

Results and Discussion of Findings

4.1 Physico-Chemical Parameters of Dams

Temperature and pH were measured on the field, while other parameters were fixed and measured afterward in the laboratory. Therefore, Table 4.1 summarized the results of Temp, EC, TDS, Alk., TH, Turb, TSS, pH, DO, BOD, COD, NO_3^-, SO_4^{2-} and PO_4^{3-} of water samples collected from six (6) dams in Osun State. The results show that the highest temperature of 23.3°C was recorded at Ede dam while Ilesha dam recorded the lowest temperature of 19.1°C (Table 4.1). This temperature fluctuation across the sampling sites could be due to the presence of certain industrial effluents which may impact species' biodiversity-associated problems in the surface water of the studied dams. This result is consistent with the findings reported in literature[1]. The pH of the surface water samples ranged from 6.45 to 6.84 (slightly acidic) and was similar to those reported for other dams in Nigeria[2]. Ikire dam had the highest pH value of 6.84, while Eko-Ende dam had the lowest pH value of 6.45. This study has found that the levels of pH are suitable for aquatic organisms, including fish. Metals in surface water are readily available at lower pH values. Reformat

Also, the EC obtained in this study ranged from 195 to 232 µs cm^{-1}, and is higher than the range of values reported which ranged between 67.1 and 79.1 µscm^{-1} in their study[3]. Contamination develops in the dam when conductivity surpasses 1000 µs cm^{-1}. For potable water, an EC of 1000 µscm^{-1} is recommended by World Health Organization[4]. Total Dissolve Solid (TDS) shows the general nature of the salinity of the water. Water with high TDS produces scales on cooking vessels and boilers. The TDS values from the surface water from this study ranged from 86.2 to 166 mg L^{-1}, and are significantly lower than those reported which ranged from 425 to 832 mg L^{-1}

[5]. Water with high TDS concentrations may have a laxative effect and may add an unpleasant mineral taste to drinking water[6]. Also, high total dissolved solids concentration can affect water clarity, which can lead to a decrease in photosynthesis and an increase in water temperature. Similarly, alkalinity ranged from 26.5 to 29.2 mg L^{-1}. The turbidity of the surface water samples ranged from 1 to 30 NTU and mean turbidity of 6.00 ± 0.01, 10.0 ± 0.02, 30.55 ± 0.00, 21.0 ± 0.01 and 6.00 ± 0.02 NTU for Eko-Ende, Iba, Ilesa, Esa-Odo, Ede and Ikire were observed in this study respectively (Table 4.1). High turbidity was observed in approximately 83% of the surface water which may be due to suspended particles and colored material in the water scattering light and making the water appear cloudy or murky. Sediment, particularly clay and silt, fine organic and inorganic materials, soluble colored organic compounds, algae, and other microscopic organisms are examples of particulate matter. The cost of water treatment for drinking and food processing can be increased if the turbidity is high. Because suspended particles absorb more heat, turbidity can also raise water temperature.

The TSS, DO, BOD and COD ranged from 3.0 to 172, 4.10 to 5.80, 14.0 to 28 and 5.10 to 12.40 mg L^{-1} respectively (Table 4.1) with Ilesa, Eko-Ende, Ikire and Ede recording the highest mean values respectively. DO is a measure of the degree of pollution by organic matter and the destruction of organic substances, as well as the self-purification capacity of the water body. The maximum tolerance limit for fish is 5 mg L^{-1}, and below 2 mg L^{-1} leads to death. The Dissolved oxygen (DO) depends upon the water temperature, salinity and pressure and its level indicate the degree of pollution in the water bodies. In all dams, the BOD and COD readings were relatively high (Table 4.1). These high values might be due to the presence of leftover food trash from bottles and cans, antifreeze, and emulsified oils in the studied dams. The presence of marine organism remnants could be contributing to the high levels of BOD and COD in the dams.

Similarly, the mean concentration of NO_3^-, SO_4^{2-} and PO_4^{3-} ranged from 2.3 to 5.7, 5.0 to 8.0 and 0.04 to 0.86 mg L^{-1} respectively. Although low concentrations of NO_3^-, SO_4^{2-} and PO_4^{3-} in surface water samples were observed throughout the sampling locations, higher concentrations of PO_4^{3-} of 0.86 and 0.75 mg L^{-1} were observed at Iba and Ede dam respectively. The high concentration of phosphate at these two dams could be due to fertilizer runoff and industrial effluents. Phosphates become harmful when they nurture aquatic vegetation excessively, causing eutrophication.

Generally, the result in Table 4.1 showed that the physicochemical results for Temp, EC, TDS, Alk., TH, TSS, pH, DO, NO_3^-, SO_4^{2-} and PO_4^{3-} for the surface water collected from the six (6) selected dams were below the WHO permissible limit except BOD, COD and Turb which were above the WHO limit of 10, 4 and 5 mg L^{-1} respectively[4]. The BOD, COD and Turb measured values ranged from 14.0 to 28.0, 12.40 to 5.10 and 30.55 to 1.00 respectively (Table 4.1). The TDS, TSS, and NO_3^- values of the surface water samples taken from the six (6) dams all fell under the WHO permissible levels in all of the measured sites, yet had significant variability ($p < 0.05$), implying the various factors at each site had an effect. Likewise, there were no noteworthy contrasts in the pH, DO, Temp, EC, and Th values over all the six (6) dams, further illustrating how similar activities had an impact on these locations (Table 4.1).

Although the PO_4^{3-} values ranged from 0.86 to 0.04 mg L^{-1} and 66.7% of the sites were within the WHO permissible limits of 0.5 mg L^{-1}, values at Iba and Ikire were higher and significantly different for others.

Table 4.1: Physico-Chemical Parameters of Surface Water from Six Selected Dams

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE	WHO[4]
Temp	20.4 ± 0.06^{a}	19.50 ± 0.23^{a}	19.07 ± 0.57^{a}	20.63 ± 1.90^{a}	23.30 ± 0.22^{b}	21.33 ± 0.12^{ab}	20-30
EC	195 ± 0.02^{a}	225 ± 0.04^{b}	232 ± 0.03^{b}	208 ± 0.01^{a}	210 ± 0.06^{ab}	225 ± 0.00^{b}	1000
TDS	92.5 ± 2.20^{a}	112.5 ± 3.60^{b}	166.00 ± 4.33^{d}	86.20 ± 2.27^{a}	114.00 ± 3.38^{b}	125.00 ± 0.02^{c}	500
Alk	26.5 ± 0.2^{a}	29.20 ± 0.1^{b}	26.50 ± 0.2^{a}	29.20 ± 0.1^{b}	26.50 ± 0.2^{a}	29.20 ± 0.1^{b}	500
TH	32.2 ± 0.1^{a}	30.01 ± 0.3^{a}	32.20 ± 0.1^{a}	30.01 ± 0.3^{a}	32.20 ± 0.1^{a}	30.01 ± 0.3^{a}	150
Turb	6.00 ± 0.01^{b}	10.0 ± 0.02^{c}	30.55 ± 0.00^{e}	21.0 ± 0.01^{d}	6.00 ± 0.02^{b}	1.00 ± 0.00^{a}	5
TSS	16 ± 0.04^{b}	$17 \pm .04^{b}$	172 ± 0.04^{d}	125 ± 0.01^{c}	15 ± 0.01^{b}	3.0 ± 0.06^{a}	<1500
pH	6.45 ± 0.24^{a}	6.64 ± 0.25^{a}	6.60 ± 0.25^{a}	6.66 ± 0.22^{a}	6.67 ± 0.26^{a}	6.84 ± 0.07^{a}	6.5-8.5
DO	5.80 ± 0.0^{b}	4.60 ± 0.01^{a}	4.10 ± 0.02^{a}	4.20 ± 0.00^{a}	4.92 ± 0.02^{ab}	4.80 ± 0.01^{ab}	>4.0
BOD	14.00 ± 6.00^{a}	18.00 ± 10^{b}	24 ± 12.00^{c}	20 ± 2.00^{b}	22 ± 2.01^{bc}	28 ± 1.20^{d}	10
COD	10.30 ± 4.02^{c}	7.10 ± 1.00^{b}	7.60 ± 5.01^{b}	7.30 ± 3.00^{b}	12.40 ± 4.03^{c}	5.10 ± 1.02^{a}	4
NO_3^-	2.3 ± 0.04^{a}	5.7 ± 0.03^{d}	3.8 ± 0.02^{b}	3.0 ± 0.04^{b}	4.7 ± 0.01^{c}	4.81 ± 0.03^{c}	50
SO_4^{2-}	5.0 ± 0.1^{a}	6.0 ± 0.2^{ab}	7.0 ± 2.0^{c}	8.0 ± 0.9^{c}	5.0 ± 0.9^{a}	6.0 ± 2.03^{ab}	250
PO_4^{3-}	0.06 ± 0.01^{a}	0.86 ± 0.02^{c}	0.09 ± 0.01^{a}	0.11 ± 0.00^{ab}	0.75 ± 0.02^{c}	0.04 ± 0.01^{a}	0.5

Values are in mg L^{-1} (mean ± SD), EC: Electrical Conductivity (µs cm^{-1}), Alk: Alkalinity, TH: Total hardness, Turb: Turbidity (NTU), DO: Dissolves Oxygen, BOD: Biological Oxygen Demand, COD: Chemical Oxygen Demand. In each row, different letters indicate significant difference ($p < 0.05$) for each element.

Source: Author Analysis, 2023.

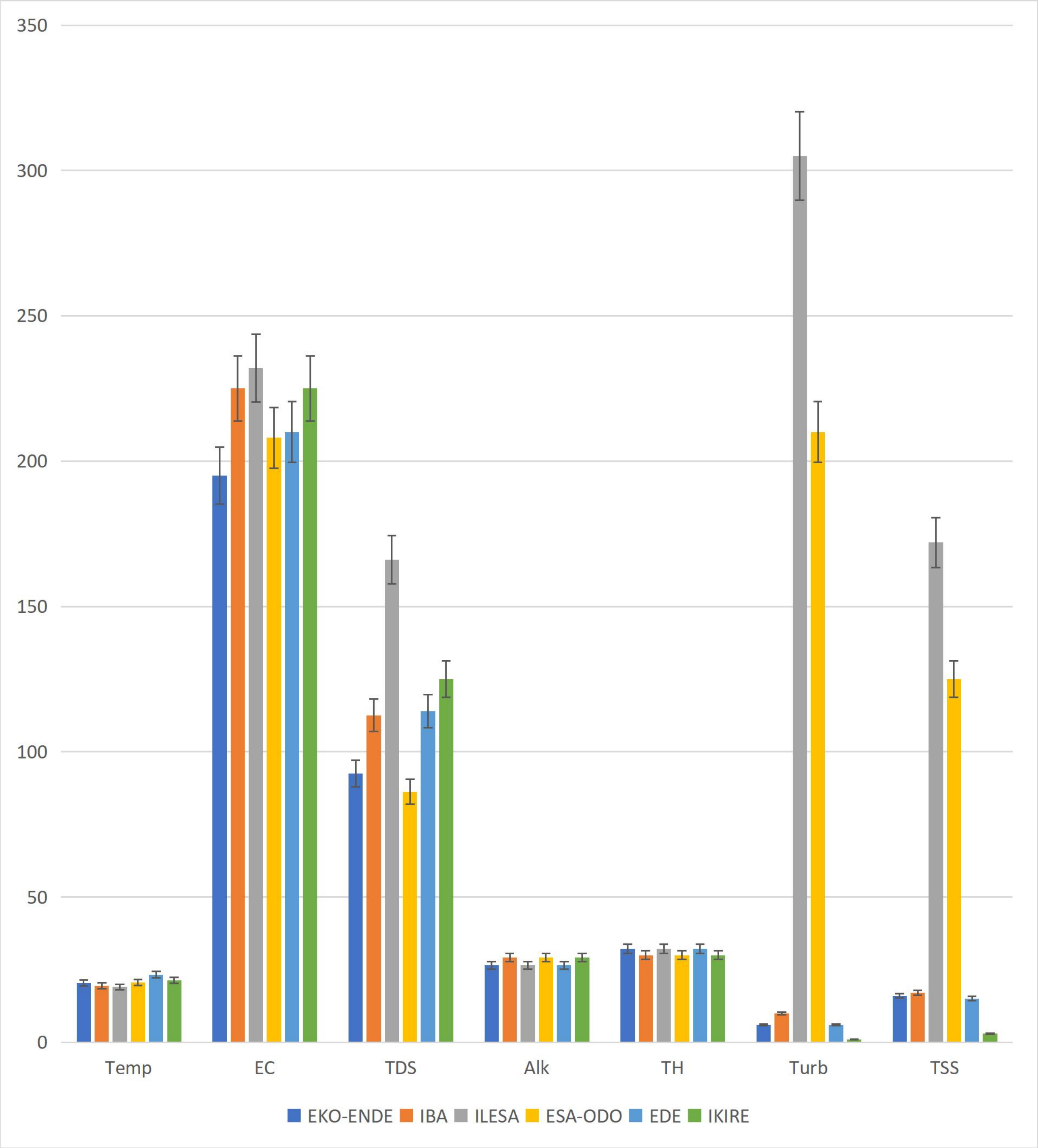

Figure 4.1: Distribution of Temp, EC, TDS, Alk, TH, Turb and TSS in Six Selected Dams.

Source: Author Analysis, 2023.

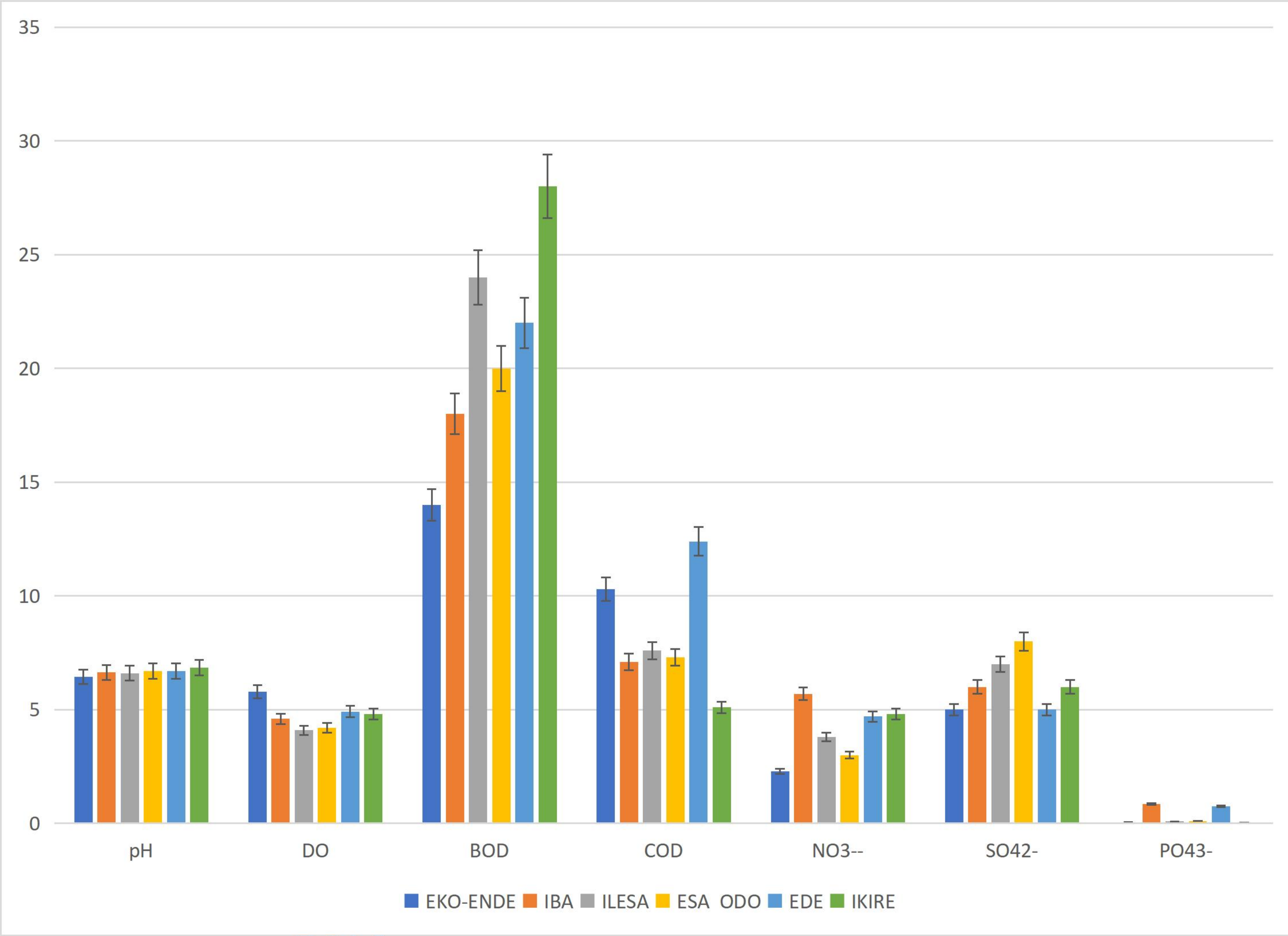

Figure 4.2: Distribution of pH, DO, BOD, COD, NO_3^-, SO_4^{2-} and PO_4^{2-} in Six Selected Dams.

Source: Author Analysis, 2023.

4.2 Elemental Method Validation

The results from the recovery experiments verified the reliability of the analytical method, and the recoveries yielded were between 99.5 and 100%. Likewise, elemental calibration standards were made using dilutions from 1000 mg L^{-1} spectroscopic grade stock standard solutions.

4.3 Heavy Metal Concentrations

4.3.1 Concentration of Essential Microelements in Surface Water

Table 4.2 summarized the concentrations of micro-elements in the surface water samples collected from the selected six (6) dams in Osun State. Generally, the average concentration of the studied micro-element was in the decreasing order of Cu > Fe > Zn >Mn. The concentrations of Fe, Cu, Zn and Mn were below the WHO-permitted limits of 1.0, 2.0, 5.0 and 0.5 mg L^{-1} respectively[4]. The concentrations of Fe in surface water ranged from 0.12 to 0.66, Cu from 0.16 to1.16, Zn from 0.32 to 1.46 and Mn from 0.04 to 0.16 mg L^{-1} (Table 4.2). Moreover, the average concentrations of Fe and Mn were not as significantly different ($p < 0.05$) across the dams when compared to that Cu and Zn (Table 4.2 and Figure 4.3). This indicates a common source for Fe and Mn, but the influence of different factors for Cu and Zn.

Overall, Cu concentration had the highest value of 1.16 mg L^{-1} across all the dams investigated, whereas Mn had the lowest concentration of 0.04 mg L^{-1}. This result is consistent with another report on surface water[6]. Copper (Cu) is an essential mineral for life and a vital component of a balanced diet. It aids the formation of red blood cells in the body, as well as the health of blood vessels, neurons, the immune system, and bones. Copper (Cu) enhances iron absorption as well. Likewise, every cell in the human body contains Zn and it is necessary for the body's defensive (immune) system to function normally. Cell division, cell development, wound healing, and glucose digestion are all aided by this protein. The senses of smell and taste require Zn as well. Iron is necessary for psychomotor development, physical activity maintenance, labour capability, and infection resistance. Manganese (Mn) is necessary for the formation of connective tissue, bones, blood clotting factors, and sex hormones in the body. It's important for fat and carbohydrate metabolism, calcium absorption, and blood sugar control. Manganese (Mn) is also required for the regular function of the brain and nerves[7].

Table 4.2: Concentrations of Essential Micro-Elements in Surface Water from Six Selected Dams in Osun State

	EKO-ENDE	IBA	ILESA	ESA ODO	EDE	IKIRE	WHO[4]
Fe	0.47 ± 0.02^{b}	0.66 ± 0.01^{c}	0.35 ± 0.02^{ab}	0.12 ± 0.03^{a}	0.24 ± 0.02^{a}	0.22 ± 0.00^{a}	1.0
Cu	0.92 ± 0.01^{b}	1.16 ± 0.02^{c}	1.11 ± 0.01^{c}	0.16 ± 0.03^{a}	0.82 ± 0.02^{b}	0.94 ± 0.04^{b}	2.0
Zn	1.34 ± 0.01^{c}	1.46 ± 0.00^{c}	0.42 ± 0.00^{a}	0.32 ± 0.01^{a}	0.71 ± 0.01^{b}	0.60 ± 0.00^{b}	5.0
Mn	0.06 ± 0.01^{ab}	0.08 ± 0.02^{b}	0.08 ± 0.02^{b}	0.04 ± 0.01^{a}	0.13 ± 0.11^{b}	0.16 ± 0.01^{c}	0.5

Values are in mg L^{-1} (Mean ± SD). In each row, different letters indicate significant difference ($p < 0.05$) for each element.

Source: Author Analysis, 2023.

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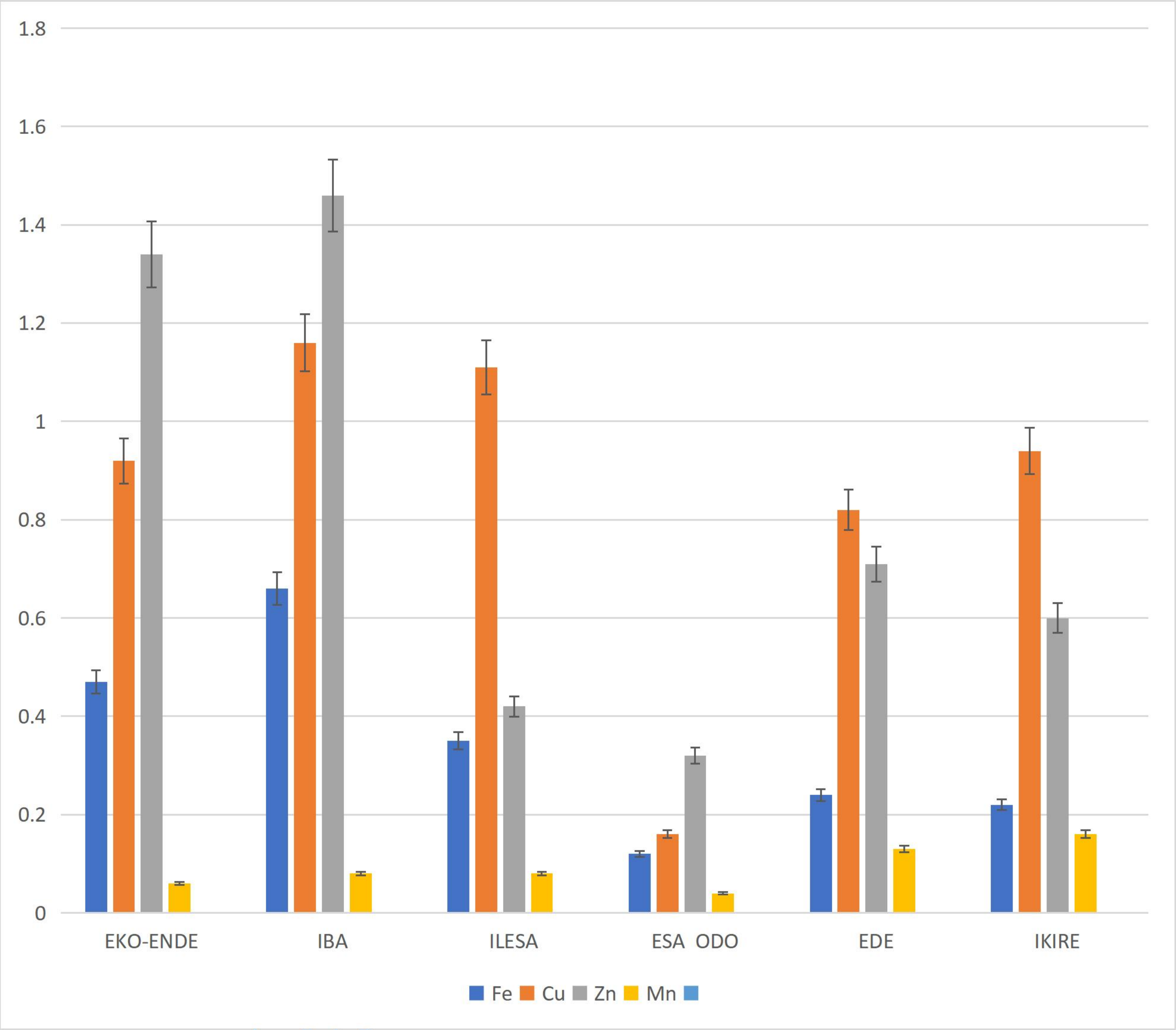


Figure 4.3: Distribution of Micro-Elements in Surface Water from SElected Six Dams.

Source: Author Analysis, 2023.

4.3.2 Concentration of Potentially Toxic Elements (Ptes) in Surface Water.

The results of the concentrations of PTEs (Ni, Cr, Cd, and Pb) in surface water samples from the six selected dams in Osun State is summarized in Table 4.4 and illustrated in Figure 4.4. Generally, the average concentration of the PTEs in surface water samples was in the decreasing order of Cr > Ni > Cd > Pb, with concentration of Ni, Cr and Cd ranging from 0.02 to 0.04, 0.02 to 0.04 and 0.001 to 0.006 mg L^{-1} respectively. However, Pb was below the limit of detection across all the sampling locations from the six selected dams (Table 4.4). The concentrations of all the PTEs were below the WHO permissible limit for drinking water except for Ni at Ilesa (0.03 mg L^{-1}), Esa Odo (0.03 mg L^{-1}), Ede (0.03 mg L^{-1}) and Ikire (0.04 mg L^{-1}) dams and Cd at Iba (0.006 mg L^{-1}) dam. The Ni result is consistent with previous study[8]. Nickel (Ni) is thought to play a role in physiological processes such as iron absorption from the intestine as a co-factor. Furthermore, statistical analysis showed that the average concentrations of the studied PTEs did not differ significantly ($p < 0.05$) across the sampling sites, indicating similar PTEs profile and origin.

Table 4.3: Concentrations of Potentially Toxic Elements (PTE) in Surface Water from Six Selected Dams in Osun State

	EKO-ENDE	IBA	ILESA	ESA ODO	EDE	IKIRE	WHO[4]
Ni	0.02 ± 0.01^{a}	0.02 ± 0.02^{a}	**0.03 ± 0.03^{a}**	**0.03 ± 0.01^{a}**	**0.03 ± 0.00^{a}**	**0.04 ± 0.02^{a}**	0.02
Cr	0.03 ± 0.01^{a}	0.04 ± 0.02^{a}	0.04 ± 0.01^{a}	0.03 ± 0.01^{a}	0.02 ± 0.01^{a}	0.03 ± 0.01^{a}	0.05
Cd	0.001 ± 0.01^{a}	**0.006 ± 0.02^{b}**	0.001 ± 0.00^{a}	0.002 ± 0.01^{a}	0.003 ± 0.01^{a}	0.002 ± 0.01^{a}	0.003
Pb	BDL	BDL	BDL	BDL	BDL	BDL	0.001

Values are in mg L^{-1} (Mean ± SD). In each row, different letters indicate significant difference ($p < 0.05$) for each element.

Source: Author Analysis, 2023.

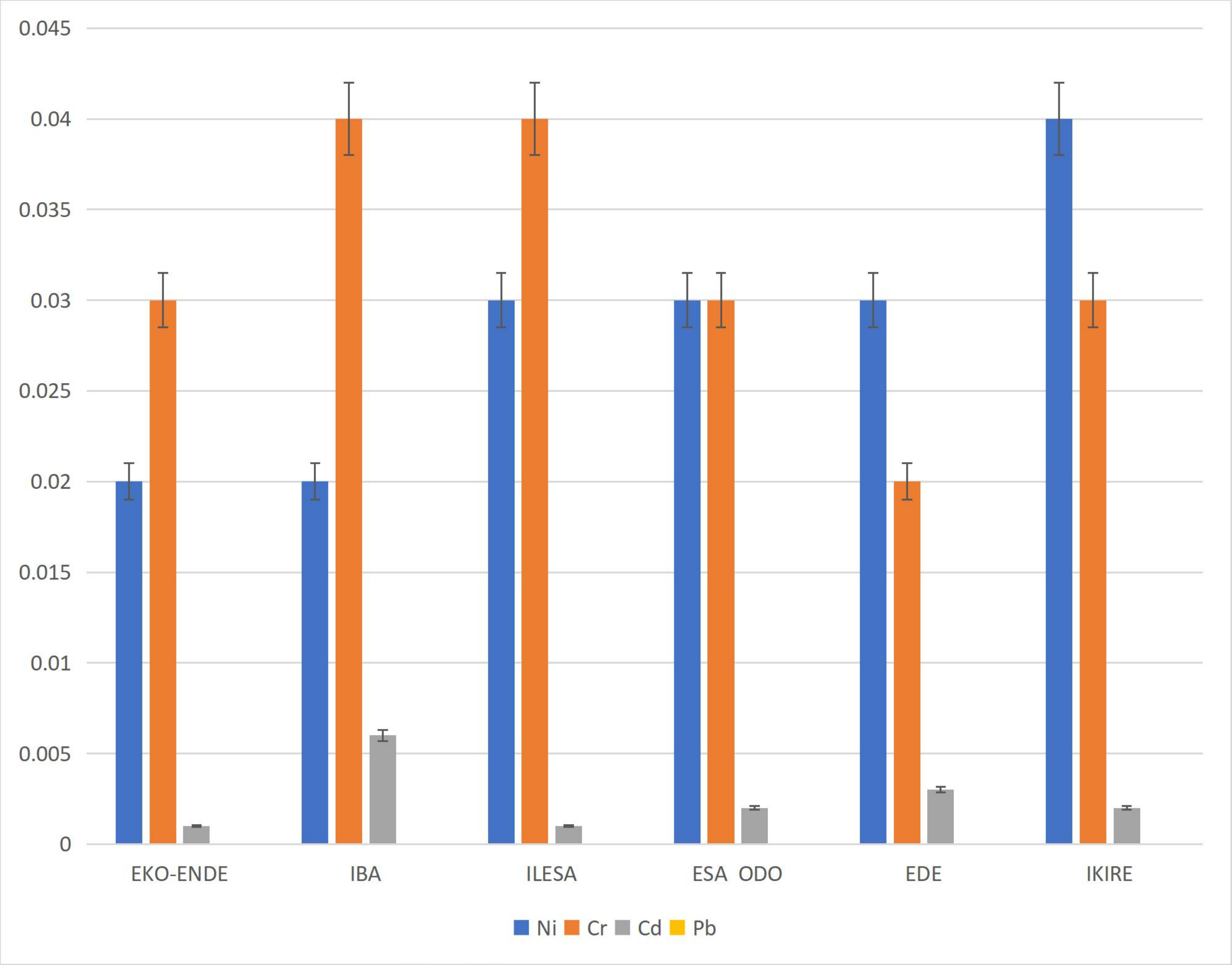


Figure 4.4: Distribution of PTEs in Surface Water from Six Selected Dams in Osun State.

Source: Author Analysis, 2023.

4.3.3 Concentration of Essential Micro Elements in Sediment Samples

The results of the concentrations of essential micro elements in sediment samples from the six selected dams in Osun State is summarized in Table 4.5 and illustrated in Figure 4.5. The concentration of essential micro elements in sediment samples was in the decreasing order of Zn > Mn > Fe > Cu. The average concentrations of Fe, Cu, Zn and Mn in sediment samples from the six selected dams ranged from 41.3 to 88.8, 38.3 to 69.1, 119 to 212 and 75.3 to 147 mg L^{-1} respectively. All the concentrations of the essential micro elements in sediment samples were significantly above the WHO permissible limit of 5.0, 50, 50 mg L^{-1} for Fe, Zn and Mn respectively except for Cu. This elevated concentration is consistent with several studies that have shown that sediment can behave as a sink for heavy metals[9]. Benefits to humans from trace amounts of micro elements have been documented; however, a toxic accumulation of metals in the body may result from the consumption of tainted aquatic species. This can be seen in the condition known as haemosiderosis, where hemoglobin that usually prevents anemia is not produced due to an overabundance of iron (Fe). Across the various dams, no significant difference ($p < 0.05$) was found in the average concentrations of Fe, suggesting that the source of the Fe is similar.

Table 4.4: Concentrations of Essential Micro-Elements in Sediment from Six Selected Dams in Osun State

	EKO-ENDE	IBA	ILESA	ESA ODO	EDE	IKIRE	WHO
Fe	**42.6 ± 11.5**^{a}	88.8 ± **10.6**^{b}	**81.0 ± 12.4**^{b}	**50.4 ± 50.9**^{a}	**41.3 ± 16.8**^{a}	**71.9 ± 44.6**^{b}	**5.0**
Cu	38.3 ± 10.7^{a}	64.5 ± 13.1^{b}	52.0 ± 33.6^{b}	63.3 ± 7.8^{b}	41.7 ± 9.7^{a}	69.1 ±12.4^{bc}	**100.0**
Zn	**138 ± 0.65**^{ab}	**138 ± 0.65**^{ab}	**173 ± 0.23**^{c}	**119 ± 0.23**^{a}	**128 ± 0.45**^{a}	**212 ± 0.23**^{d}	**50.0**
Mn	**78.2 ± 0.21**^{a}	**78.2 ± 0.21**^{a}	**123 ± 1.02**^{b}	**147 ± 0.60**^{c}	**75.3 ± 0.41**^{a}	**137 ± 0.43**^{c}	**50**

Values are in mg L^{-1} (Mean ± SD). In each row, different letters indicate significant difference ($p < 0.05$) for each element. WHO (World Health Organization, 2011)[4]. Source**:** Author Analysis, 2023.

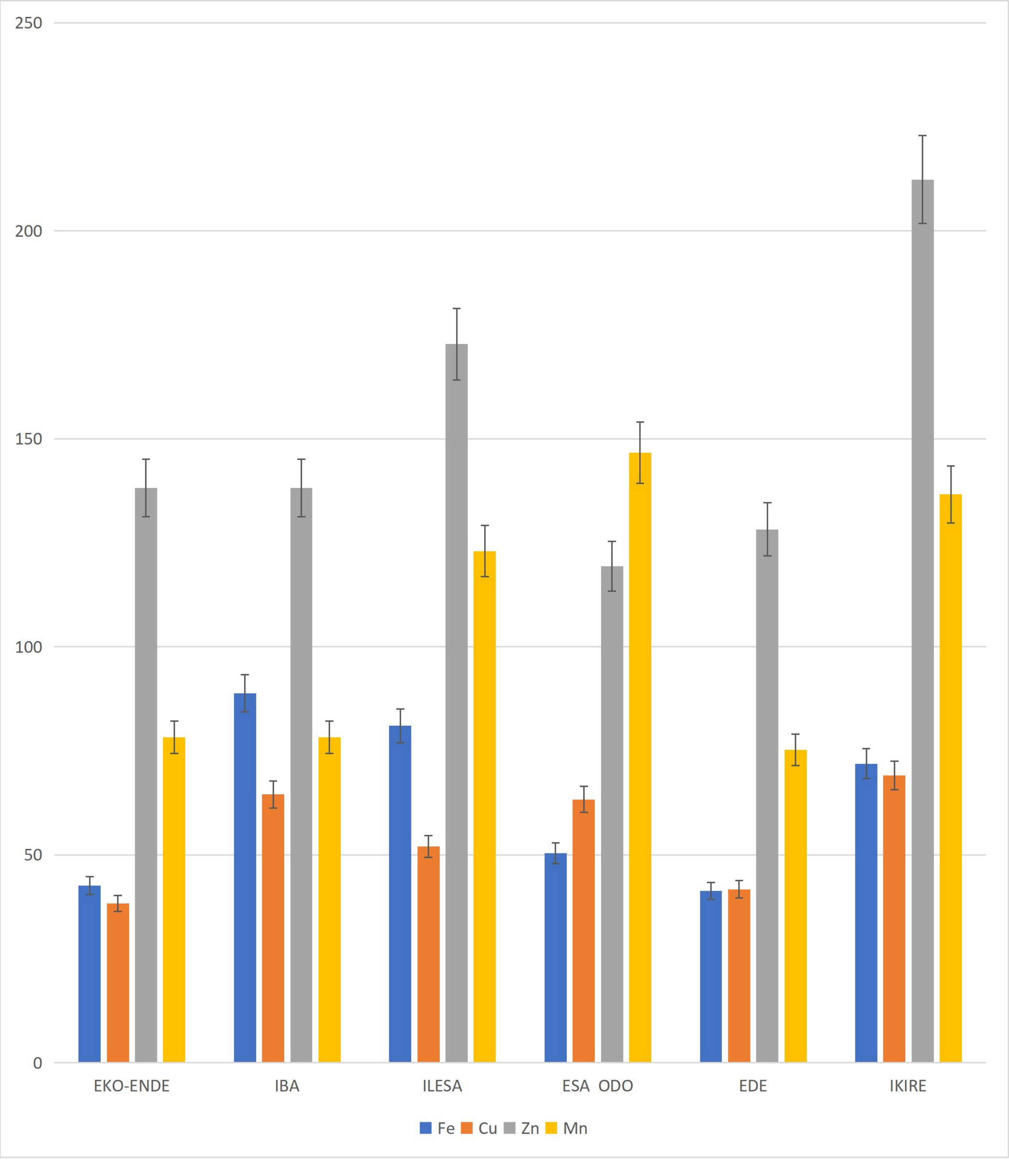


Figure 4.5: Distribution of Essential Micro-Elements in Sediment from Six Selected Dams.

Source: Author Analysis, 2023.

4.3.4 Concentration of Potentially Toxic Elements (PTEs) in Sediment

The concentrations and distribution of potentially toxic elements in sediments samples from six selected dams in Osun State are shown and illustrated in Table 4.6 and Figure 4.6 respectively. For all of the dams studied, the concentrations of the studied PTEs in sediment were in the decreasing order Pb > Cr > Ni > Cd (Table 4.6) can cause stomach irritation, vomiting, and diarrhea, as well as kidney disease, weak bones, and lung damage[10].

Table 4.5: Concentrations of Potentially Toxic Elements (PTE) in Sediment from Six Selected Dams

	EKO-ENDE	**IBA**	**ILESA**	**ESA ODO**	**EDE**	**IKIRE**	**WHO[4]**
Ni	31.6 ± 6.4^{a}	**70.7 ± 14.2^{b}**	**67.9 ± 19.8^{b}**	**67.8 ± 11.1^{b}**	32.4 ± 3.1^{a}	**77.6 ± 14.6^{b}**	**35.0**
Cr	36.3 ± 7.1^{a}	79.3 ± 7.6^{b}	77.1 ± 4.6^{b}	79.4 ± 6.6^{b}	32.7 ± 7.3^{a}	84.4 ± 9.3^{b}	100.0
Cd	**14.0 ± 5.2^{a}**	**39.0 ±10.3 ^{b}**	**38.7 ± 15.5^{b}**	**41.0 ± 15.1^{b}**	**13.9 ± 2.2^{a}**	**45.0 ± 10.9^{bc}**	**0.8**
Pb	61.9 ± 7.2^{a}	**92.3 ± 9.9^{b}**	**90.9 ± 4.7^{b}**	**112 ± 46.6^{c}**	59.1 ± 10.1^{a}	**97.1 ± 11.7^{b}**	**85.0**

Values are in mg L^{-1} (Mean ± SD). In each row, different letters indicate significant difference ($p < 0.05$) for each element.
Source: Author Analysis, 2023.

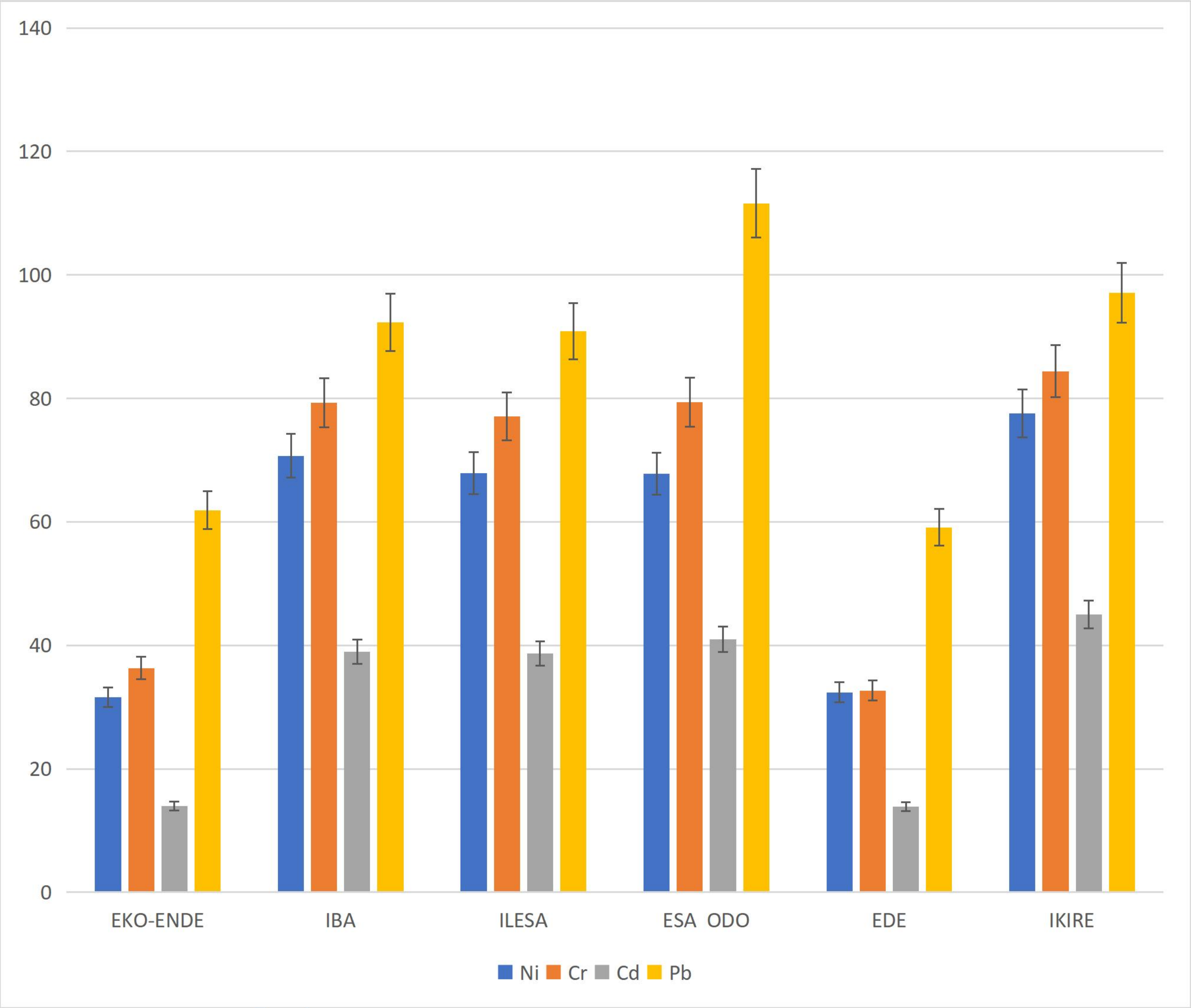


Figure 4.6: Distribution of PTEs in Sediment from Six Selected Dams.

Source: Author Analysis, 2023.

4.3.5 Concentrations of Essential Micro-Elements in Fish Samples

The concentrations of critical micro elements (iron (Fe), copper (Cu), zinc (Zn), and manganese Mn) detected in fish across the six selected dams in Osun State are shown in Table 4.7. Fe > Zn > Cu > Mn was the general order of decreasing concentrations (micro elements). Similarly, Fe had the highest content across all dams studied, ranging from 94.3 mg L^{-1} to 16.6 mg L^{-1}. Zinc (Zn), copper (Cu), and manganese (Mn) concentrations in six dams varied from 17.0 to 5.50 mg L^{-1}, 26.4 to 4.40 mg L^{-1}, and 4.90 to 1.30 mg L^{-1}, respectively. The distribution of micro elements in the six dams used for this study is depicted in Figure 4.7. All of the micro elements tested had higher concentrations above the two permitted limits of 0.3, 5.0, 2.3, and 0.5 mg L^{-1}. Copper (Cu) is essential for the biochemistry of all living things. Copper (Cu) accumulation in the body of an animal in excess is poisonous, and in humans, it can cause hepatic cirrhosis and hemolytic anemia[11]. Copper (Cu) is highly hazardous to fish, affecting their growth, reproduction, and enzyme activity, among other things. Additionally, high copper concentrations can cause anemia, neutropenia, and osteoporosis, as well as impaired cupro-enzyme activity, skeletal and vascular systems, and anemia, neutropenia, and osteoporosis. Excessive Fe accumulation in the brain has also been linked to neurological illnesses including Alzheimer's disease[12]. Zinc (Zn) is also known to be a cofactor for over 300 enzymes involved in RNA and DNA metabolism, particularly at higher concentrations. At high doses, manganese (Mn) becomes harmful and poisonous, and it can cause neurologic and psychologic disorders. Iron (Fe) is an important trace metal, but excessive amounts can cause weakness, sensitivity, and difficulty to concentrate. The concentrations of iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn) in the six dams were not statistically different ($p < 0.05$).

Table 4.6: Concentrations of Essential Micro-Elements in Fish Fauna from Six Selected Dams in Osun State

	EKO-ENDE	IBA	ILESA	ESA ODO	EDE	IKIRE	WHO[4]
Fe	**16.6 ± 6.99^{a}**	**20.3 ± 10.69^{a}**	**39.6 ± 12.82^{b}**	**71.3 ± 30.90^{c}**	**81.1 ± 34.2^{c}**	**94.3 ± 54.5^{d}**	0.3
Zn	**9.4 ± 5.20^{b}**	**17.0 ± 4.40^{d}**	**12.5 ± 2.50^{c}**	**7.50 ± 3.60^{a}**	**5.50 ± 2.00^{a}**	**8.20 ± 2.30^{b}**	5.0
Cu	**14.0 ± 0.03^{c}**	**4.40 ± 0.30^{a}**	**26.4 ± 1.84^{e}**	**5.10 ± 0.20^{a}**	**8.20 ± 0.10^{b}**	**17.4± 2.70^{d}**	2.3
Mn	**1.70 ± 0.20^{ab}**	**4.90 ± 1.20^{c}**	**1.90 ± 0.00^{b}**	**1.40 ± 0.80^{a}**	**1.30 ± 0.10^{a}**	**4.30 ± 0.20^{c}**	0.5

Values are in mg L^{-1} (dry weight) (Mean ± SD). In each row, different letters indicate significant difference ($p < 0.05$) for each element. WHO (World Health Organization, 2011)[4].

Source: Author Analysis, 2023.

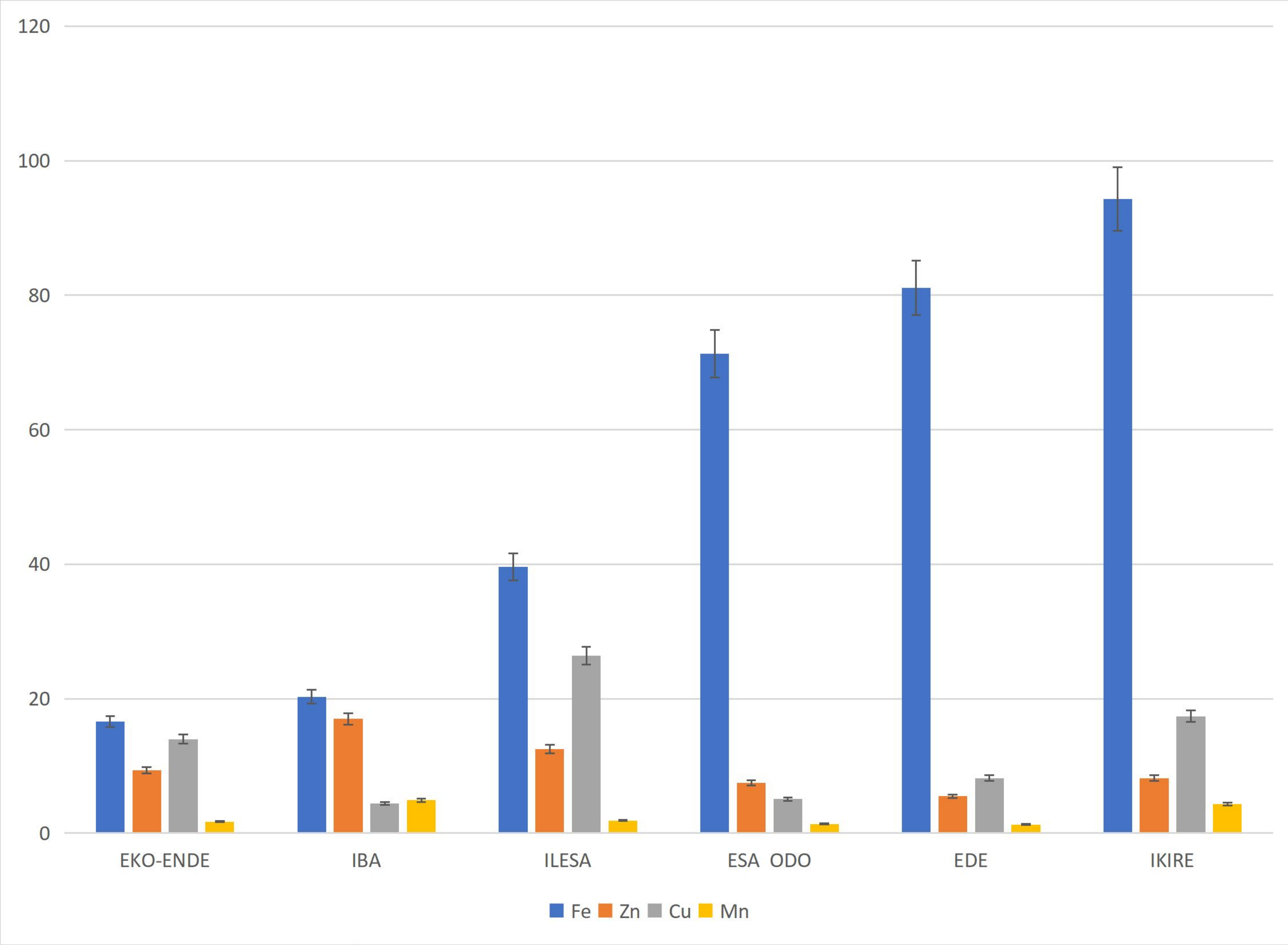


Figure 4.7: Distribution of Essential Micro-Elements in Fish Fauna from Six Selected Dams.

Source: Author Analysis, 2023.

4.3.6 Concentrations of Potentially Toxic Elements (PTEs) in Fish Samples

Likewise, the average concentrations and distribution of potentially toxic elements in tilapia fish (*Oreochromis niloticus*) samples from six selected dams in Osun State are shown and illustrated in Table 4.8 and Figure 4.8 respectively. In all, the selected PTEs; Cd, Cr, Ni and Pb had 100% frequency of detection in the muscle tissues of *Oreochromis niloticus*. In general, the concentration of PTE in fish was in the decreasing order of Ni > Cd > Pb > Cr. The mean concentration of Cr, Ni, Pb, and Cd ranged from 1.18 to 2.31, 3.15 to 3.92, 2.36 to 3.73 and 0.41 to 14.2 mg kg^{-1} respectively. Although the mean concentrations of Cr, Ni, Cd, and Pb were all above the WHO tolerable values (0.7, 0.6, 0.3 and 0.3 mg kg^{-1} respectively) in fish at all the dams, about 75% of fish samples from Ede dam had the highest concentrations of the studied PTEs. This significant concentration of PTEs in fish samples from Ede dam suggests a form of contamination, consequently, sustained consumption may result in gradual build-up of the studied PTEs in humans.

The highest Ni concentration of 3.92 ± 3.01 mg kg^{-1} in fish samples was detected at the Ilesha dam. Continuous exposure to a high level of Ni in humans may lead to an increased risk of lung and nasal cancer[13]. Nickel (Ni) is also a carcinogen that causes fibrosis, tumors, lung inflammation, and emphysema in human with high concentrations. When fish are exposed to high levels of Ni in their environment, it accumulates in several tissues. Similar to the presence of silt, mud, algae, plant pieces, sawdust, wood ashes, or chemicals in the water, excessive concentrations of all heavy metals measured in fish could be due to the presence of silt, mud, algae, plant pieces, sawdust, wood ashes, or chemicals in the water.

Similarly, there were significant elevations of Cd in fish samples from Ede (14.2 ± 3.29 mg kg^{-1}) and Esa Odo (3.10 ± 1.99 mg kg^{-1}). The main source of Cd exposure in the human body is food. Cadmium is a known endocrine disruptor, and it has been well-shown that it can induce breast cancer, prostate cancer, renal damage, hypertension, tumors, poor reproductive performance, and hepatic dysfunction in humans. Previously, we reported on the elevated concentrations of Ni and Cd in water sources in two States in Nigeria.

Likewise, fish samples from Ede had the highest average concentration of 3.73 ± 2.40 and 2.31 ± 1.32 mg kg^{-1} for Pb and Cr respectively (Figure 4.8). Generally, the average Cd and Pb concentrations found in this study were higher than those reported for farmed Oreochromis niloticus but lower than those reported for Nile Tilapia except for Cd at Ede. Similarly, the report described significantly elevated concentrations of Ni in the muscle tissues of Nile Tilapia compared to this study[14]. Increased Pb concentrations in water bodies may result from the erosion of corroded lead-containing objects. Lead (Pb) compounds may also come from fertilizers, herbicides, and pesticides used on agriculture fields in the dam vicinity. Lead (Pb) is a naturally occurring and man-made element that is extremely harmful to humans, particularly children. Because of their less effective renal elimination and increased gastrointestinal absorption, children are the most sensitive to Pb. When compared to the mature brain, the fetal brain is more sensitive to the harmful effects of lead. Lead can also be hazardous to the kidneys and the nervous system. This is consistent with the findings of, which show that the gills are the primary site of Pb bioaccumulation[14]. Chromium's main hazard is chronic accumulation in the kidneys, which causes itai-itai illness and bone thinning. It also decreases body fat at high concentrations.

Analyses of Lead (Pb), Nickel (Ni), Chromium (Cr), and cadmium (Cd) in sampled fish indicated that there had been both point and non-point sources of pollution that had affected the dam and its surrounding waters. This is in line with the research, which found that growing industrialization, combined with agricultural technical advancements, has introduced a variety of contaminants (both synthetic and organic) into aquatic environments[14].

This general elevation of PTEs might be due to anthropogenic activities, such as uncontrolled application of fertilizers, herbicides, and pesticides for farming activities around the dams. Other contributing factors might be due to leaching from abandoned parts of major pumping machines and equipment littering most of the dams' environs at the time of this study. These machines' batteries contain Pb compounds that could end up in water bodies through erosion, especially following heavy rains.

The results of post hoc evaluation saw negligible divergences in the presence of Ni found in fish specimens taken from the same sites ($p > 0.05$). This suggests that human activities, like petrochemical pollution, were likely influential in the reservoirs that were investigated (Table 4.8 and Figure 4.8). Additionally, Ni is a reliable barometer of oil contamination[14]. The main source of Ni contamination in this study area is the activities of fishing boats such as fuelling, maintenance and repairs. But Cr, Pb, and Cd mean concentration vary slightly ($p < 0.05$), also suggesting an influence of multiple sources. also reported Ni as the most abundant of the PTEs in rainbow trout.

Table 4.7: Concentrations of Potentially Toxic Elements (PTEs) in Fish Samples from Six Selected Dams in Osun State

	EKO-ENDE	IBA	ILESA	ESA ODO	EDE	IKIRE	WHO^{4}
Cd	**0.41 ± 0.30^{a}**	**0.45 ± 0.33^{a}**	**0.78 ± 0.68^{b}**	**3.10 ± 1.99^{c}**	**14.2 ± 3.29^{d}**	**0.91 ± 0.82^{b}**	0.3
Cr	**1.18 ± 0.50^{a}**	**1.32 ± 0.28^{a}**	**1.64 ± 1.06^{b}**	**1.20 ± 0.50^{a}**	**2.31 ± 1.32^{c}**	**1.83 ± 1.30^{b}**	0.7
Ni	**3.34 ± 2.16^{ab}**	**3.16 ± 2.53^{a}**	**3.92 ± 3.01^{b}**	**3.40 ± 2.09^{ab}**	**3.45 ± 2.45^{ab}**	**3.15 ± 2.24^{a}**	0.6
Pb	**2.48 ± 1.06^{a}**	**2.36 ± 0.94^{a}**	**2.75 ± 1.67^{b}**	**2.99 ± 0.99^{bc}**	**3.73 ± 2.40^{c}**	**2.74 ± 1.98^{b}**	0.3

Values are in mg L^{-1} (dry weight) (Mean ± SD). In each row, different letters indicate significant difference ($p < 0.05$) for each element. WHO (World Health Organization, 2011)^{4}.

Source: Author Analysis, 2023.

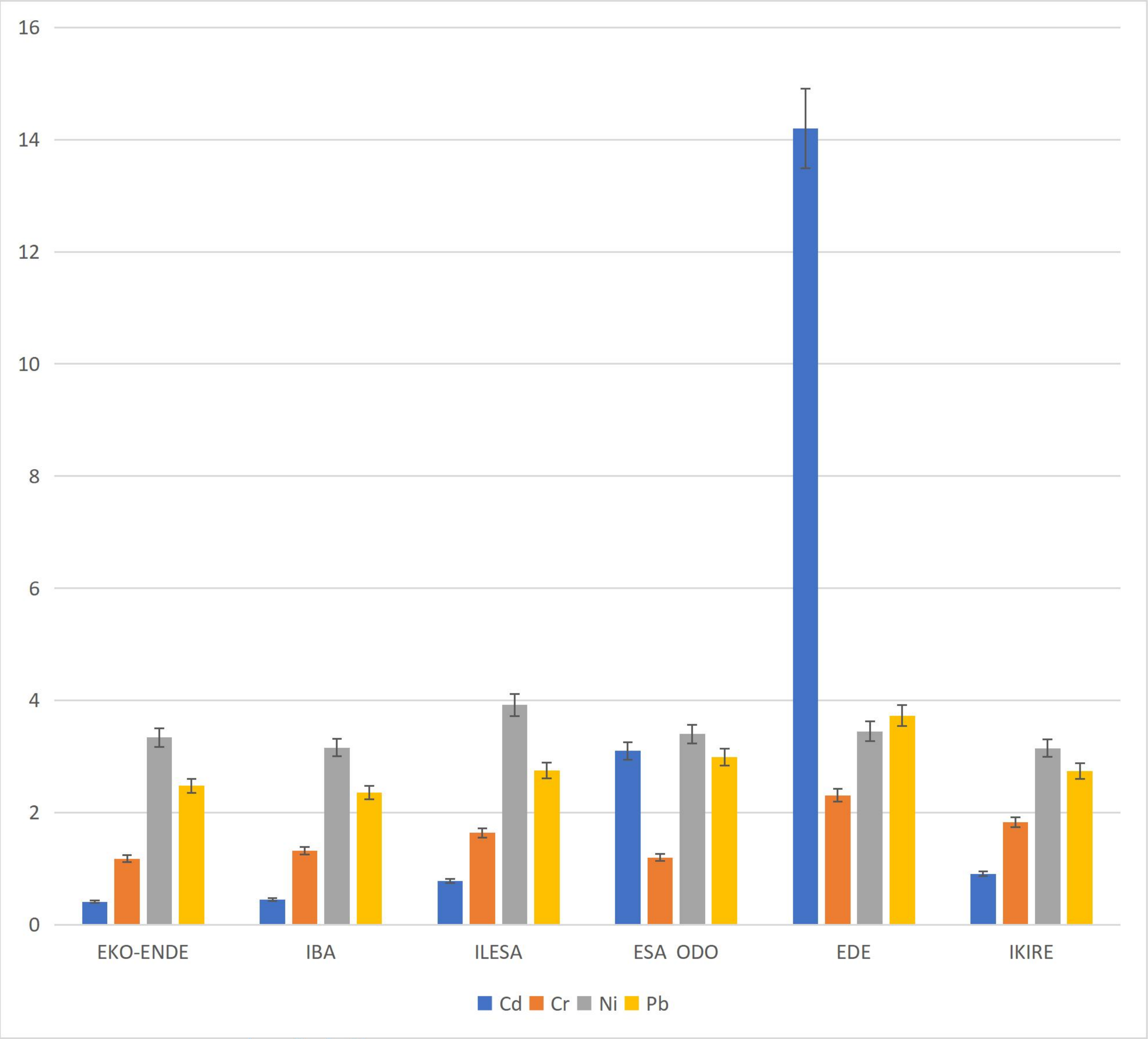


Figure 4.8: Distribution of PTEs in Fish Samples from Six Selected Dams.

Source: Author Analysis, 2023.

4.3.7 Concentrations of Essential Micro-Elements in Okra

Table 4.9 summarized the concentrations of the analyzed essential micro-elements (Cu, Zn, Fe and Mn) in the okra (*Abelmoschus esculentus*) samples collected from six (6) selected dams in Osun State. The Essential mirco-elements concentration was in the decreasing order of Cu > Zn > Fe and > Mn ranged from 1.66 to 1.93, 0.02 to 0.07, 0.07 to 0.09 and 0.001 to 0.01 mg kg^{-1} for Cu, Fe, Zn and Mn respectively. The concentrations of copper, zinc, iron and manganese in okra samples taken from multiple sites around the six surveyed reservoirs were all below the threshold set by the World Health Organization, and there were no statistically ($p < 0.05$) significant differences in the concentrations among any of the tested locations[15]. The results of the post-hoc test showed similarity in the factor responsible for the availability of these studied macro-elements (Cu, Zn, Fe and Mn) in okra samples across the six dams.

Table 4.8: Concentration of Essential Micro Elements in Okra Samples (*Abelmoschus esculentus*) from Six Selected Dams

	EKO-ENDE	IBA	ILESA	ESA ODO	EDE	IKIRE	WHO[4]
Cu	1.78 ± 0.02^{a}	1.75 ± 0.12^{a}	1.94 ± 0.01^{a}	1.87 ± 0.42^{a}	1.66 ± 0.31^{a}	1.93 ± 0.22^{a}	10.0
Fe	0.05 ± 0.01^{ab}	0.07 ± 0.001^{b}	0.03 ± 0.01^{a}	0.05 ± 0.01^{ab}	0.06 ± 0.05^{ab}	0.02 ± 0.01^{a}	0.30
Zn	0.08 ± 0.21^{a}	0.08 ± 0.12^{a}	0.09 ± 0.01^{a}	0.09 ± 0.42^{a}	0.07 ± 0.31^{a}	0.09 ± 0.22^{a}	0.60
Mn	0.004 ± 0.11^{a}	0.001 ± 0.10^{a}	0.002 ± 0.000^{a}	0.01 ± 0.02^{ab}	0.003 ± 0.002^{a}	0.01 ± 0.001^{ab}	0.05

Values are in mg kg^{-1} (Mean ± SD). In each row, different letters indicate significant difference ($p < 0.05$) for each element. WHO (World Health Organization, 2011)[4].

Source: Author Analysis, 2023.

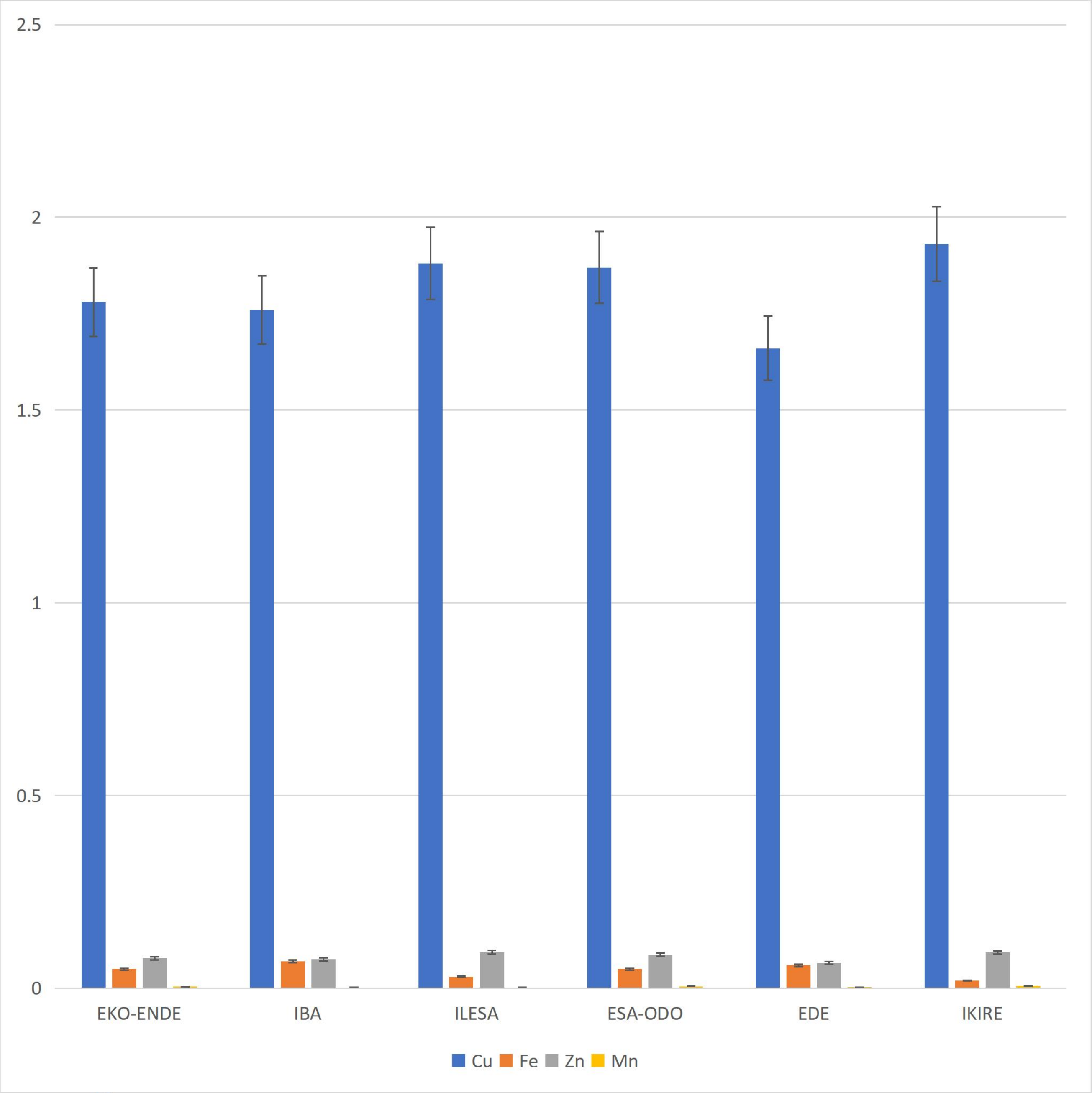


Figure 4.9: Distribution of Essential Micro-Elements in Okra from Six Selected Dams

Source: Author Analysis, 2023.

4.3.8: Levels of Potentially Toxic Elements (PTEs) in Okra

Table 4.10 summarized the average concentrations of PTEs in Okra (*Abelmoschus esculentus*) planted and consumed by the immediate communities of the selected Dams. The mean concentrations measured across all the sampling locations for Cr, Ni, Pb and Cd were all lower than the WHO's maximum allowable levels of 1.3, 10, 2 and 0.022 mg kg^{-1}, respectively (as depicted in Figure 4.10).

The PTEs concentrations in okra were in the decreasing order of Ni > Pb > Cr > Cd and ranged from 0.121 to 0.218, 0.030 to 0.220, 0.041 to 0.081, and 0.002 to 0.004 mg kg^{-1} for Ni, Pb, Cr, and Cd respectively (Table 4.10). This finding is in line with another report[6]. The concentrations of Cd, Cr, and Ni were not significantly different ($p < 0.05$) between the six selected dams in Osun State, but the concentration of Pb varied slightly at Iba and Esa-Odo dams. This indicates similarity in the source of PTEs in Okra (*Abelmoschus esculentus*) planted and consumed around the six selected dams in Osun State.

Table 4.9: Concentrations of Potentially Toxic Elements (PTE) in Okra (*Abelmoschus esculentus*) from Six Selected Dams

	EKO-ENDE	IBA	ILESA	ESA ODO	EDE	IKIRE	WHO[4]
Cr	0.064 ± 0.021^{ab}	0.061 ± 0.010^{ab}	0.041 ± 0.101^{a}	0.041 ± 0.101^{a}	0.081 ± 0.020^{b}	0.050 ± 0.102^{a}	1.30
Ni	0.127 ± 0.021^{a}	0.121 ± 0.014^{a}	0.131 ± 0.514^{a}	0.131 ± 0.514^{a}	0.138 ± 0.014^{a}	0.218 ± 0.072^{ab}	10.00
Pb	0.220 ± 0.014^{a}	0.060 ± 0.051^{b}	0.060 ± 0.051^{b}	0.060 ± 0.014^{b}	0.030 ± 0.051^{a}	0.060 ± 0.050^{b}	2.0
Cd	0.010 ± 0.001^{a}	0.002 ± 0.001^{a}	0.003 ± 0.000^{a}	0.004 ± 0.001^{a}	0.003 ± 0.000^{a}	0.002 ± 0.001^{a}	0.022

Values are in mg L^{-1} (Mean ± SD). In each row, different letters indicate significant difference ($p < 0.05$) for each element. WHO (World Health Organization, 2011)[4].

Source: Author Analysis, 2023.

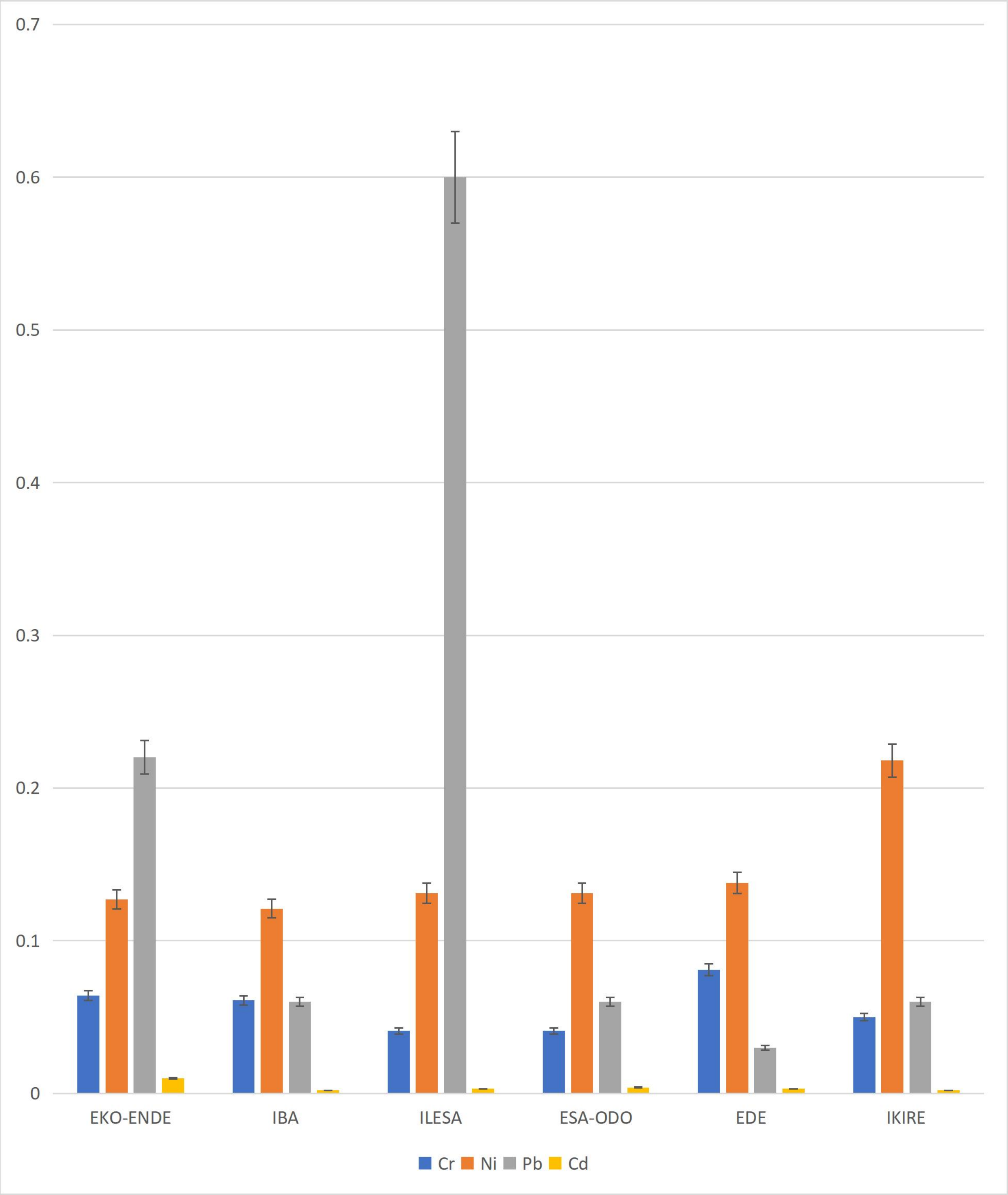


Figure 4.10**: Distribution of Potentially Toxic Elements (PTE) in okra from Six Selected Dams.**

Source: Author Analysis, 2023.

4.3.9 Concentrations of Essential Micro-Elements in Bitter Leaf

The average concentration of the essential-micro elements (Fe, Zn, Cu, and Mn) in Bitter Leaf (*Vernonia amygdalina*) planted and consumed by the immediate communities of the six selected dams in Osun State is summarized in Table 4.11. Generally, the average concentrations of the studied essential-micro elements were in the decreasing order Cu > Zn > Fe > Mn and ranged from 1.11 to 1.48, 0.01 to 0.217, 0.074 to 0.142 and 0.001 to 0.005 mg kg^{-1} for Cu, Fe, Zn and Mn respectively across the six dams in Osun State. The Cu levels were consistent with those reported by Emmanuel and it associates[17].

According to the study, the concentrations of the essential-micro elements Cu, Fe, and Mn in Bitter Leaf were lower than the established World Health Organization permissible limits for these metals in plants (10 mg kg^{-1}, 0.30 mg kg^{-1}, and 0.05 mg kg^{-1}, respectively) except for Zn, which was 0.06 mg kg^{-1}. The concentrations of Cu, Zn, Fe and Mn at the sampling sites were not significantly ($p < 0.05$) different, indicating a common source or origin.

Table 4.10: Concentration of Essential Micro Elements in Bitter Leaf (*Vernonia amygdalina*) from Six Selected Dams

	EKO-ENDE	IBA	ILESA	ESA ODO	EDE	IKIRE	WHO[4]
Cu	1.110 ± 0.000^{a}	1.360 ± 1.000^{a}	1.480 ± 0.101^{a}	1.350 ± 0.111^{a}	1.120 ± 0.120^{a}	1.180 ± 0.122^{a}	10.0
Fe	0.217 ± 0.021^{c}	0.055 ± 0.030^{ab}	0.051 ± 0.111^{ab}	0.060 ± 0.001^{ab}	0.010 ± 0.000^{a}	0.022 ± 0.012^{a}	0.30
Zn	**0.101 ± 0.001^{ab}**	**0.112 ± 0.020^{ab}**	**0.098 ± 0.001^{a}**	**0.074 ± 0.011^{a}**	**0.131 ± 0.003^{ab}**	**0.142 ± 0.000^{ab}**	0.06
Mn	0.004 ± 0.012^{a}	0.004 ± 0.100^{a}	0.003±0.110^{a}	0.001 ± 0.000^{a}	0.00 5± 0.000^{ab}	0.002 ± 0.000^{a}	0.05

Values are in mg kg^{-1} (Mean ± SD). In each row, different letters indicate significant difference ($p < 0.05$) for each element. WHO (World Health Organization, 2011)[4]. **Source:** Author Analysis, 2023.

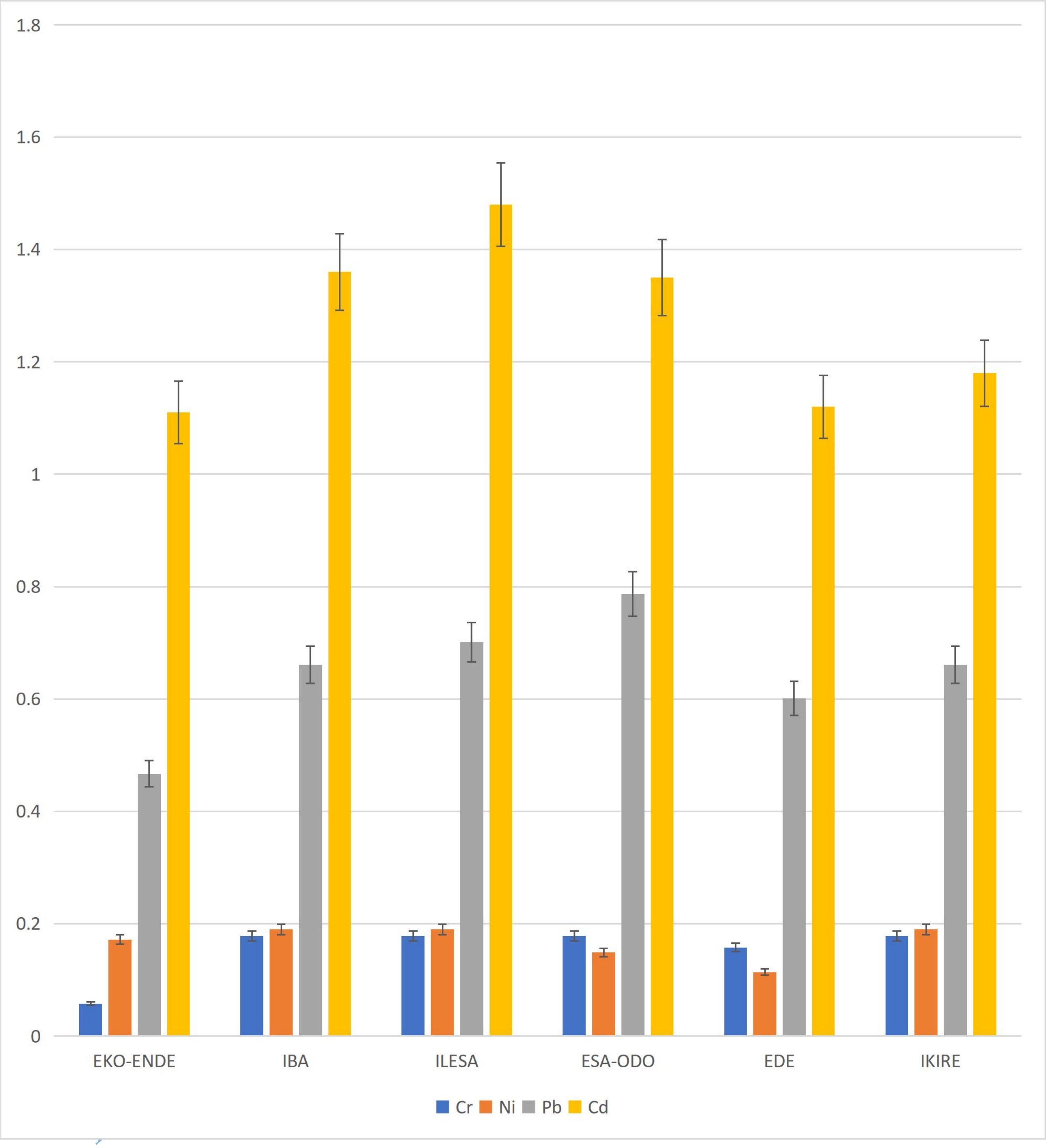


Figure 4.11: Distribution of Essential Micro-Elements in Bitter Leaf from Six Selected Dams.

Source: Author Analysis, 2023.

4.3.10: Levels of Potentially Toxic Elements (PTEs) in Bitter Leaf

Equally, the average concentrations and distribution of potentially toxic elements in bitter Leaf (*Vernonia amygdalina*) planted and consumed by the immediate communities of the six selected dams in Osun State are shown and illustrated in Table 4.12 and Figure 4.12 respectively. Generally, the mean concentrations of the selected PTEs across all the sampling locations were all below the WHO permissible limits of 1.3, 10, 2 and 0.022 mg kg^{-1} for Cr, Ni, Pb and Cd respectively (Figure 4.12).

The concentrations of the studied potentially toxic elements (PTEs) (Pb, Ni, Cr, and Pb) in bitter leaf was in the decreasing order of Pb> Ni > Cr > Cd across the six dams in Osun State. Similarly, the concentration ranged from 0.058 to 0.178, 0.114 to 0.190, 0.467 to 0.787 and 0.002 to 0.020 mg kg^{-1} for Cr, Ni, Pb and Cd respectively. This is consistent with the results reported by other researchers[18,19,20]. The concentrations of Pb, Ni, Cr and Cd at the sampling sites were not significantly different ($p < 0.05$), implying a common source and origin of the PETs in bitter Leaf (*Vernonia amygdalina*) planted and consumed across the sampling locations.

Table 4.11: Concentrations of Potentially Toxic Elements (PTE) in Bitter Leaf (*Vernonia amygdalina*) from Six Selected Dams

	EKO-ENDE	IBA	ILESA	ESA ODO	EDE	IKIRE	WHO[4]
Cr	0.058 ± 0.021^{a}	0.178 ± 0.031^{ab}	0.178 ± 0.031^{ab}	0.178 ± 0.031^{ab}	0.158 ± 0.011^{ab}	0.178 ± 0.031^{ab}	1.30
Ni	0.172 ± 0.091^{a}	0.190 ± 0.021^{a}	0.190 ± 0.021^{a}	0.149 ± 0.721^{a}	0.114 ± 0.005^{a}	0.190 ± 0.031^{a}	10
Pb	0.467 ± 0.03^{a}	0.661 ± 0.020^{ab}	0.701± 0.020^{ab}	0.787 ± 0.021^{ab}	0.601 ± 0.021^{ab}	0.661 ± 0.020^{ab}	2.0
Cd	0.012 ± 0.002^{ab}	0.020 ± 0.002^{b}	0.020 ± 0.007^{b}	0.005 ± 0.005^{a}	0.002 ± 0.000^{a}	0.020 ± 0.000^{b}	0.022

Values are in mg kg^{-1} (Mean ± SD). In each row, different letters indicate significant difference ($p < 0.05$) for each element. WHO (World Health Organization, 2011)[4].
Source: Author Analysis, 2023.

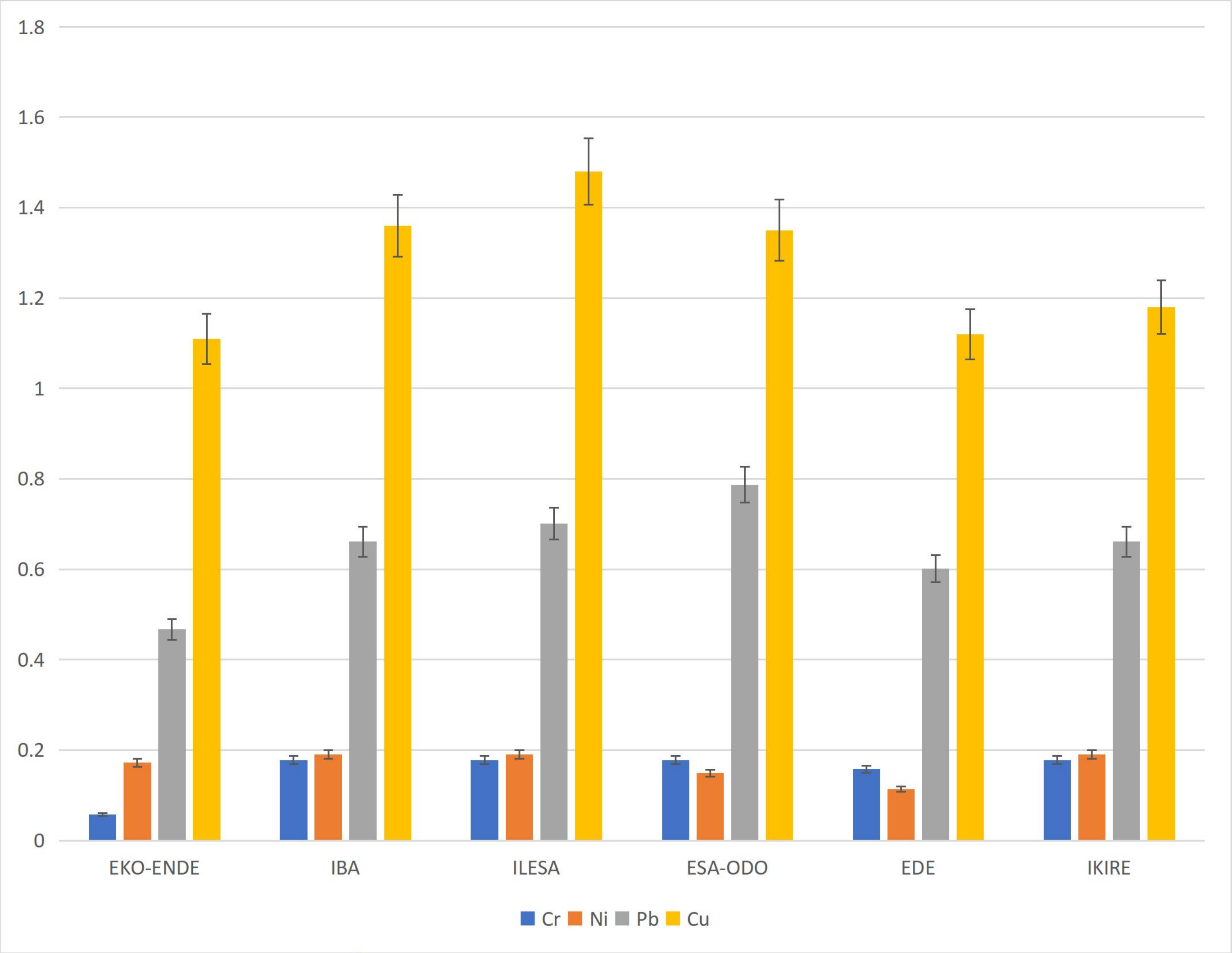


Figure 4.12: Distribution of PTEs in Bitter Leaf from Six Selected Dams.

Source: Author Analysis, 2023.

4.4 Human Health Risk Assessments

The Estimated Daily Intake (EDI) of each element was calculated using the formula EDI = [C x DI] / [BW], to determine daily human exposure.

The estimated daily intake (EDI), where EDI stands for human exposure risk through the fish pathway (mg kg^{-1}/day), C stands for heavy metal concentration in fish (mg kg^{-1}), DI is for daily intake (0.2 kg/ day/ person), and BW stands for body weight (adult = 68 kg and children = 15 kg), respectively as input through Eq. 1

$$\text{EDI} = \frac{(\text{C} \times \text{DI})}{(\text{BW})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

4.4.1 Hazard Quotient (HQ)

The health risk associate with the consumption of fish was evaluated as the non-carcinogenic hazard through the hazard quotient (HQ) using Eq. 2.

$$\text{THQ} = \frac{\text{EDI}}{(\text{EDI})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where the oral toxicity reference dose (RfD) values in (mg/kg/day) are given as: 0.005, 0.003, 0.02, 0.04, 0.8, 0.14, 0.0035 and 0.3 mg/kg/day for Cd, Cr, Ni, Cu, Fe, Mn, Pb and Zn respectively[22]. When the value of the toxic hazard quotient (THQ) is less than 1, the exposed population is assumed to be safe. However, if THQ is greater than 1, there is an unacceptable risk of adverse non-carcinogenic effects on human health. Risks are classified as follows: low risk ($1 < \text{THQ} \leq 5$), medium risk ($5 < \text{THQ} \leq 10$) and high risk ($\text{THQ} > 10$)[21].

The oral carcinogenic slope factor (SF) from USEPA for Cd, Cr, Ni and Pb were 0.38, 0.5, 1.7 and 0.009 mg/kg/day^{-1} respectively[22]. When used to convert the EDI to the incremental risk of an individual developing cancer, TCR values higher than the USEPA recommended safe limit of (1×10^{-4}) for cancer risk is an indication of possible carcinogenic risk[22].

4.4.2 Target Carcinogenic Risk (TCR)

The potential cancerous health risk associated with eating fish was calculated using the Slope Factor (SF) toxicity index to calculate an individual's risk of developing cancer over a lifetime as a result of exposure to suspected carcinogens using Eq. 3.

$$\text{TCR} = \text{SF} \times \text{EDI} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3)$$

The oral carcinogenic slope factor (SF) from USEPA for Cd, Cr, Ni and Pb were 0.38, 0.5, 1.7 and 0.009 $(\text{mg/kg/day})^{-1}$ respectively, when used to convert the EDI to the incremental risk of an individual developing cancer, TCR values higher than the USEPA recommended safe limit of (1×10^{-4}) for cancer risk is an indication of possible carcinogenic risk[22]. Table 4.12 and 4.13 shows the non-Carcinogenic Risk of the Elements in adult and Toxicity responses to heavy metals as Reference dose (RfD) and Cancer Slope Factor (CSF) respectively.

Table 4.12: Toxicity Responses to Heavy Metals as Reference Dose (RfD) and Cancer Slope Factor (CSF)

Metals	Oral RfD (mg kg^{-1}/day) (Non-carcinogenic)	Oral CSF (mg kg^{-1}/day) (Carcinogenic)
Cd	5.0×10^{-4}	0.38
Cr	3.0×10^{-3}	5.0×10^{-1}
Pb	3.6×10^{-3}	9.0×10^{-3}
Ni	2.0×10^{-2}	1.7
Fe	0.3	0.3
Cu	0.04	2.250

Source: USEPA IRIS (2015)[22]

Table 4.13: Non-Carcinogenic Risk of the Elements in Adult

	EKO-ENDE	IBA	ILESA	ESA ODO	EDE	IKIRE
Cd	0.003	0.003	0.006	0.024	0.110	0.007
Cr	0.007	0.008	0.010	0.007	0.014	0.011
Ni	0.006	0.005	0.070	0.006	0.060	0.005
Fe	0.264	0.483	0.207	0.219	0.181	0.226
Cu	0.582	0.598	1.103	0.657	0.579	0.597
Pb	0.810	0.771	0.899	0.977	1.219	0.895

Source: Author Analysis, 2023.

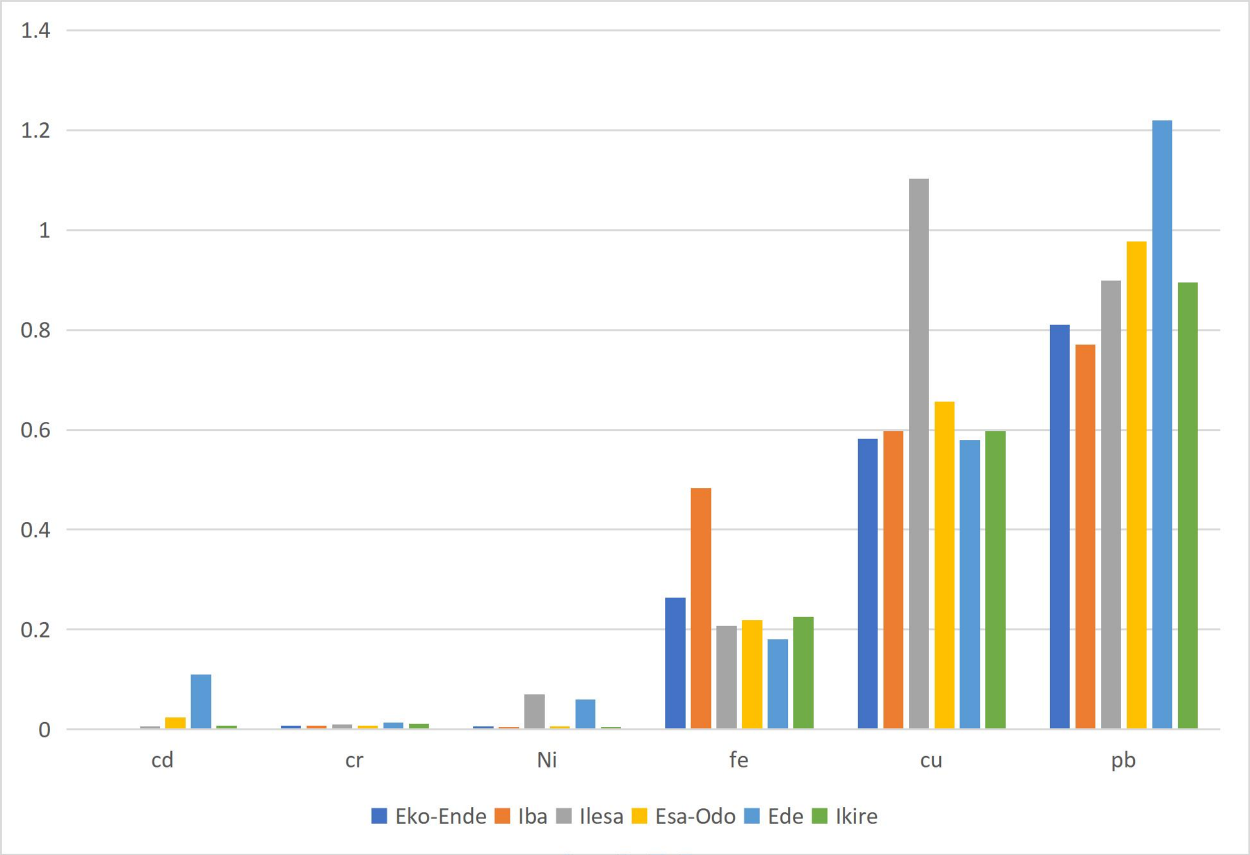


Figure 4.13: Distribution of Non-Carcinogenic Risk of the Elements in Adult

Source: Author Analysis, 2023.

Table 4.14: Non-Carcinogenic Risk of the Elements in Children

	EKO-ENDE	IBA	ILESA	ESA ODO	EDE	IKIRE
Cd	0.014	0.016	0.027	0.109	0.498	0.032
Cr	0.031	0.035	0.044	0.032	0.062	0.049
Ni	0.026	0.025	0.025	0.027	0.030	0.025
Pb	3.674	3.496	4.074	4.430	5.526	4.060
Fe	1.198	2.189	0.939	0.992	0.819	1.027
Cu	2.638	2.709	4.998	2.977	2.627	2.706

Source: Author Analysis, 2023.

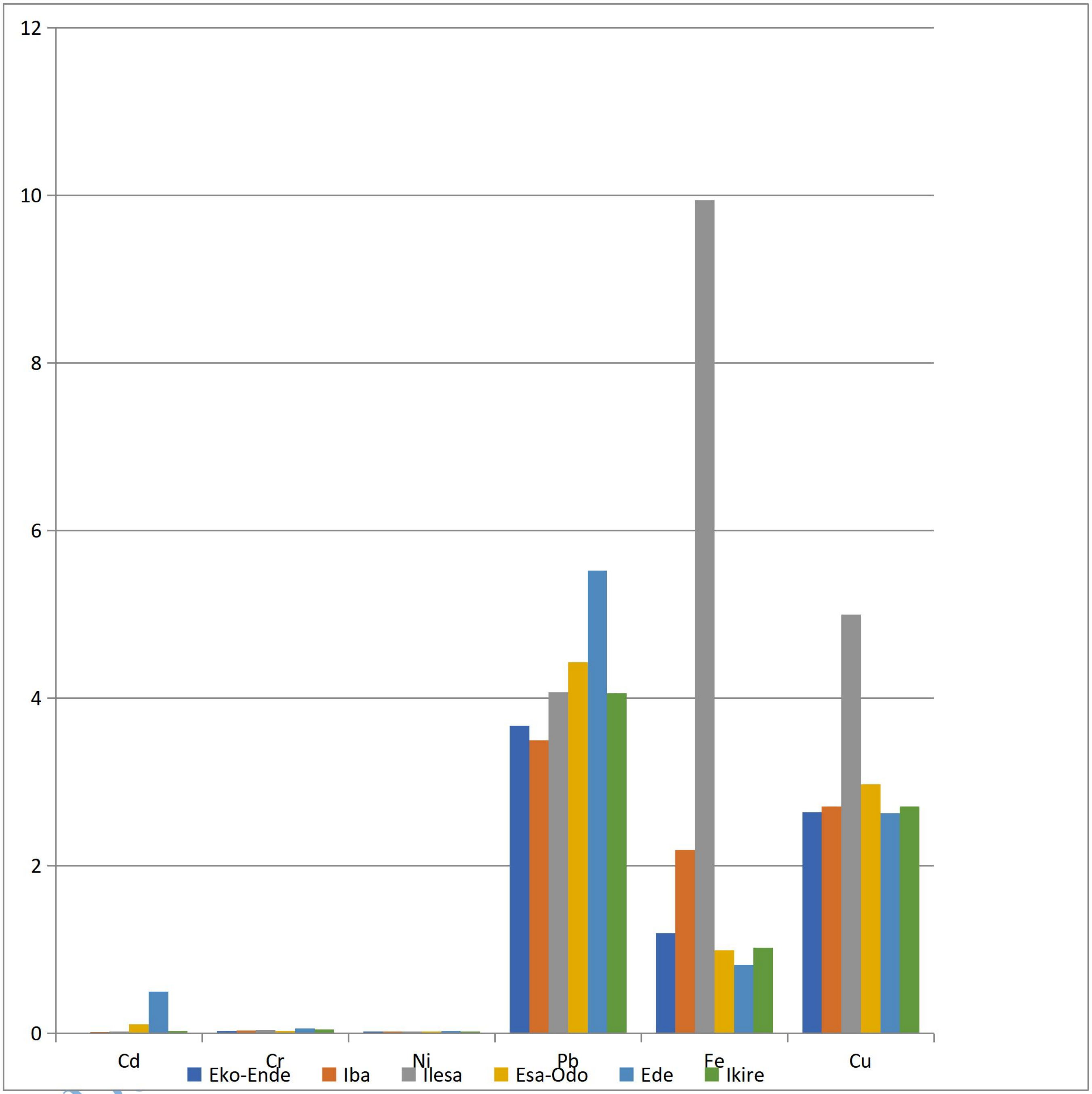


Figure 4.14: Distribution of Non-Carcinogenic Risk of the Elements in Children

Source: Author Analysis, 2023.

4.4.3 Target Carcinogenic Risk (TCR)

The lifetime targets carcinogenic risk (TCR) was calculated using the excess lifetime cancer risk equation: TCR = CSF × EDI to assess an individual's lifetime exposure to the incremental risk of acquiring cancer.

The incremental risk of an individual acquiring cancer is exactly proportional to the estimated daily intake (EDI) of PTE in the body throughout a lifetime of exposure. If the TCR is greater than $1x10^{-4}$, it is regarded unsatisfactory and unbearable[23,24].

Table 4.15: Carcinogenic Risk of the Elements in Adult

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE
Cd	**0.001**	**0.001**	**0.001**	**0.003**	**0.016**	**0.001**
Cr	0.002	0.001	0.002	0.002	0.003	0.003
Ni	0.017	0.016	0.019	0.006	0.001	0.016
Fe	0.014	0.019	0.035	0.063	0.071	0.083
Pb	0.001	0.001	0.001	0.017	0.017	0.001
Cu	0.092	0.029	0.174	0.033	0.054	0.115

Source: Author Analysis, 2023.

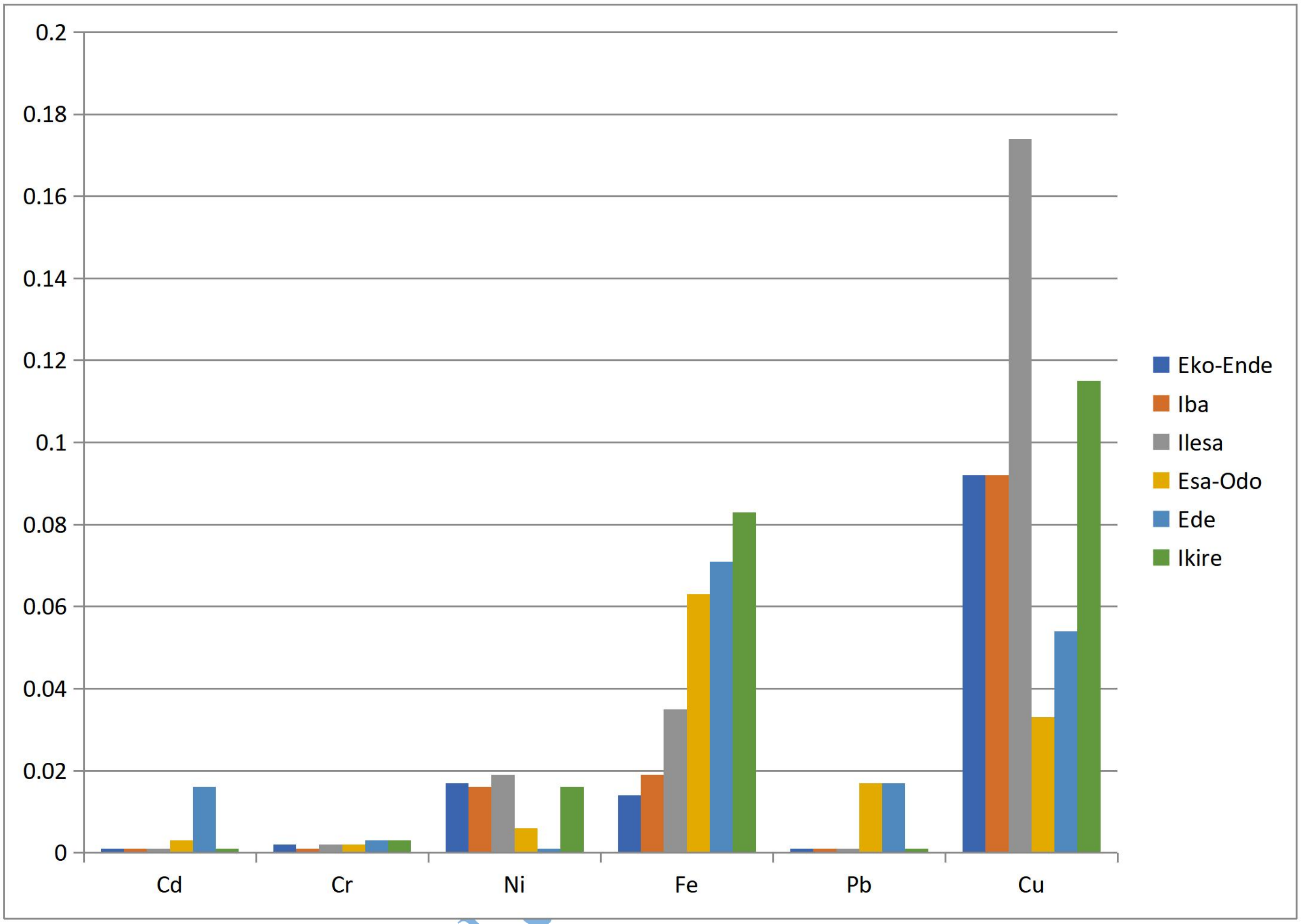


Figure 4.15: Carcinogenic Risk of The Elements in Adult

Source: Author Analysis, 2023.

Table 4.16 Carcinogenic Risk of the Elements in Children

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE
Cd	**0.002**	**0.002**	**0.004**	**0.157**	**0.071**	**0.005**
Cr	0.008	0.009	0.011	0.008	0.015	0.012
Ni	0.076	0.072	0.089	0.077	0.001	0.001
Pb	0.001	0.002	0.003	0.001	0.078	0.071
Fe	0.066	0.081	0.158	0.285	0.324	0.377
Cu	0.042	0.132	0.792	0.153	0.246	0.522

Source: Author Analysis, 2023.

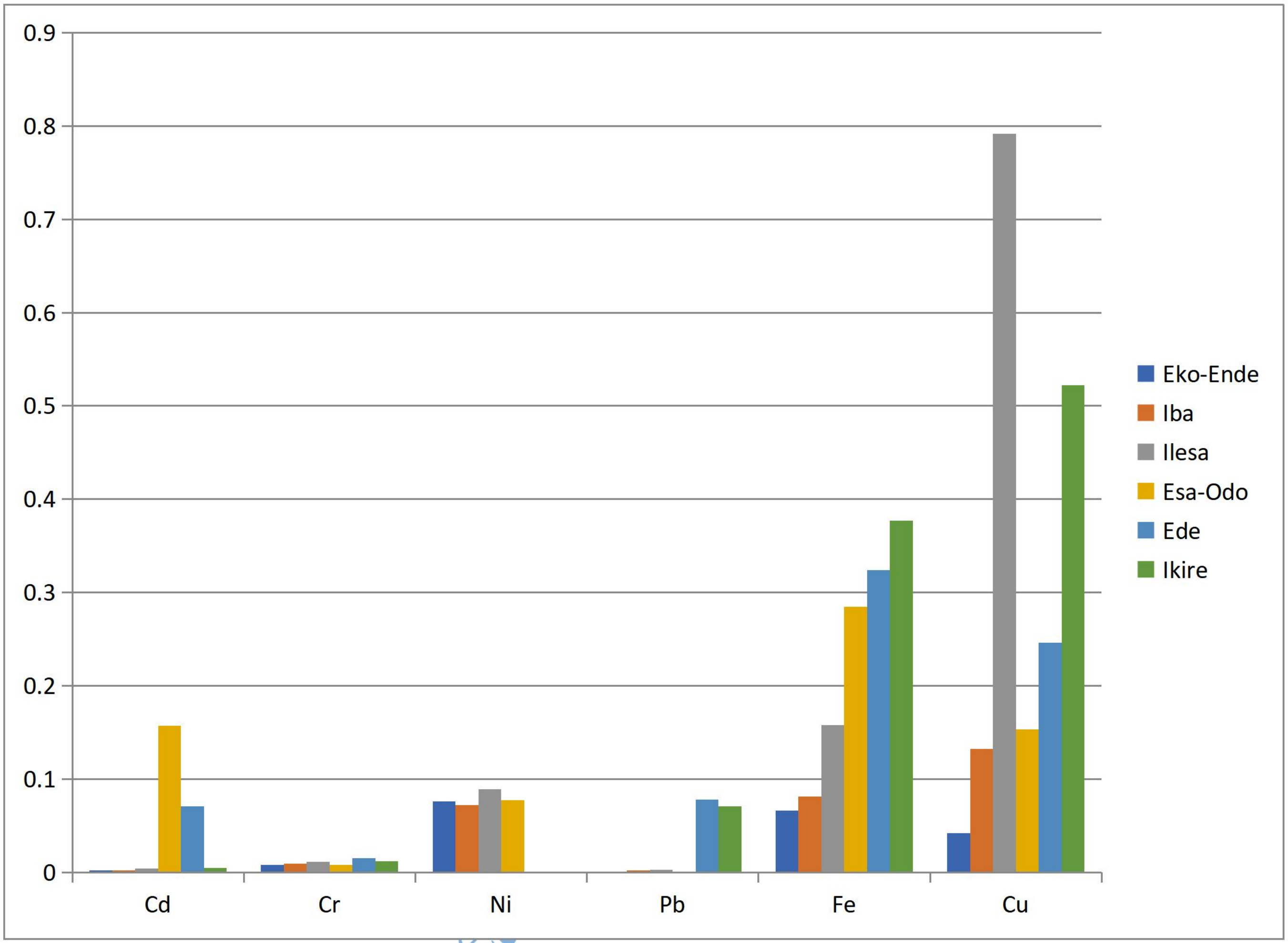


Figure 4.16: Carcinogenic Risk of the Elements in Children

Source: Author Analysis, 2023.

4.5 Bivariate Statistical Analysis

Furthermore, the results of the correlation study on the studied parameters from samples from the six selected dams in Osun State are summarized in Tables 4.15 to 4.20 with some significant ($p < 0.05$) associations.

4.5.1 Correlation matrix for physico-chemical parameters in the surface water samples

For surface water samples, the physico-chemical parameters' correlation matrix had positive significant correlations ranging from 0.6 to 0.9 while negative significant correlations ranged from -0.6 to -1.0. Positive significant correlations between BOD and TDS (r = 0.6), TH and COD (r = 0.8), TSS and SO_4^{2-} (r = 0.8), PO_4^{3-} and NO_3^- (r = 0.7) were observed.

A positive three-way synergy between NO_3^-, pH, and EC and SO_4^{2-}, Turb, and TSS with significant correlations of r = 0.6 and 0.7 and 0.8 respectively were observed (Table 4.15). Equally, a four-way synergy between BOD, pH, EC and TDS corresponding to r = 0.9, 0.7 and 0.6 respectively was also observed. Likewise, a positive five-way synergy between pH, EC, Alk, BOD and NO_3^- was also observed for surface water samples. These positive significant correlations indicate similarity in the sources of studied parameters.

Likewise, negative significant correlations between pH and TH (r = -0.6), Turb and DO (r = -0.7), TSS and DO (r = -0.7), DO and SO_4^{2-} (r = -0.8) and COD and SO_4^{2-} (r = -0.6) were observed. There were also negative two-way and three-way synergies between studied physicochemical parameters. Conversely, these negative significant correlations indicate different sources of studied parameters.

Table 4.17: Correlation Matrix for Physico-Chemical Parameters in the Surface Water Samples

	Temp	pH	EC	TDS	Alk	TH	Turb	TSS	DO	BOD	COD	NO_3^-	SO_4^{2-}	PO_4^{3-}
Temp	1													
pH	0.3	1												
EC	-0.4	**0.6***	1											
TDS	-0.3	0.2	**0.8***	1										
Alk	-0.2	**0.6***	0.3	-0.3	1									
TH	0.2	**-0.6***	-0.3	0.3	**-1.0***	1								
Turb	-0.5	-0.1	0.4	0.5	-0.1	0.1	1							
TSS	-0.5	-0.2	0.3	0.4	-0.2	0.2	**1.0***	1						
DO	0.3	-0.5	**-0.7***	-0.5	-0.4	0.4	**-0.7***	**-0.7***	1					
BOD	0.2	**0.9***	**0.7***	**0.6***	0.2	-0.2	0.2	0.2	-0.5	1				
COD	0.5	-0.5	**-0.6***	-0.2	**-0.8***	**0.8***	-0.2	-0.2	0.5	-0.5	1			
NO_3^-	0.1	**0.6***	**0.7***	0.3	0.4	-0.4	-0.3	-0.4	-0.3	0.4	-0.2	1		
SO_4^{2-}	-0.5	0.2	0.3	0.1	0.5	-0.5	**0.8***	**0.8***	**-0.8***	0.3	**-0.6***	-0.2	1	
PO_4^{3-}	0.3	0.1	0.1	-0.1	0.1	-0.1	-0.4	-0.4	-0.0	-0.2	0.4	**0.7***	-0.4	1

*Correlations significant at $P \leq 0.05$

Source: Author Analysis, 2023.

4.5.2 Correlation Matrix for Heavy Metals in the Surface Water Samples

Table 4.16 summarized the results of the correlation matrix for the studied heavy metals in surface water samples from the six selected dams in Osun State.

The correlation statistical analysis results showed both positive and negative correlation matrices ranging from -0.1 to -0.8 and 0.2 to 1.0 for negative and positive correlation matrices respectively, with some significant ($p < 0.05$) associations: Mg and Ni (r = 0.7) and Zn and Ni (r = -0.8). A negative significant ($p < 0.05$) correlation (r = -0.8) was also observed between Fe and Ni (Table 4.16) indicating different source.

Likewise, there was a positive five-way synergy between Fe, Cu, Zn, Cr and Cd with the correlation matrix ranging from 0.6 to 0.9. The surface water Fe strongly correlated with Zn (0.9) and Ni (-0.8) and moderately with Cu (0.7), Cr (0.06) and Cd (0.6). This positive five-way synergy indicates similarity in the sources of the studied heavy metals and suggests a common source of contamination for the surface water samples and hence, the selected six dams in Osun State.

However, surface water Fe correlated weakly with Mn (-0.2) while Cd weakly correlate with Cu (0.3), Zn (0.5), Mn (0.1), Ni (-0.4) and Cr (0.2).

Table 4.18: Correlation Matrix for Elemental Concentration in the Surface Water Samples

	Fe	Cu	Zn	Mn	Ni	Cr	Cd
Fe	**1**						
Cu	**0.7***	**1**					
Zn	**0.9***	**0.5**	**1**				
Mn	**-0.20**	**0.4**	**-0.1**	**1**			
Ni	**-0.8***	**-0.2**	**-0.8***	**0.7***	**1**		
Cr	**0.6***	**0.4**	**0.2**	**-0.4**	**-0.3**	**1**	
Cd	**0.6***	**0.3**	**0.5**	**0.1**	**-0.4**	**0.2**	**1**

*Correlations significant at $P \leq 0.05$

Source: Author Analysis, 2023.

4.5.3 Correlation Matrix for Heavy Metals in the Sediment Samples

Similarly, Table 4.17 summarized the outcomes of the correlation matrix for the studied heavy metals in sediment samples from the six selected dams in Osun State. Table 4.17 shows a more significant correlation relative to Table 4.16 suggesting that the concentrations of the studied heavy metals was more enhanced in the sediment samples corroborating those sediments are sinks for heavy metals[25]. Previously, we also reported similar enhancement of heavy metals in sediment samples relative to surface water[26]. The sediment Fe strongly correlated with Ni (0.8) and Cr (0.8), moderately with Cd (0.7), Cu (0.6), Zn (0.5) and Pb (0.5) and weakly with Mn (0.2). A four-way synergy between Ni and Cr (0.9), Cd (1.0) and Pb (0.9), three-way synergy between Cr and Cd (1.0), and Pb (0.9), as well as a two-way synergy between Cd and Pb (0.9), were observed, indicating very strong associations. These high correlation coefficients signify strong association among the related heavy metals, and hence common origin of contributions. The typical source of heavy metal contamination includes runoffs from anthropogenic activities such as the uncontrolled application of fertilizers, herbicides, and pesticides for farming activities around the dams. Other contributing factors might be due to leaching from abandoned parts of major pumping machines and equipment littering most of the dams' environs at the time of this study. Apart from V, Ni is an indicator of oil pollution, the main source of Ni contamination in this study area is the activities of fishing boats such as fueling, maintenance and repairs. However, Zn did not correlate significantly ($p < 0.05$) with the other studied heavy metals (Table 4.17).

Table 4.19: Correlation Matrix for Elemental Concentration in the Sediment Samples

	Fe	Cu	Zn	Mn	Ni	Cr	Cd	Pb
Fe	1							
Cu	**0.6***	1						
Zn	0.5	0.4	1					
Mn	0.2	**0.6***	0.4	1				
Ni	**0.8***	**0.9***	0.5	**0.7***	1			
Cr	**0.8***	**0.9***	0.5	**0.7***	**0.9***	1		
Cd	**0.7***	**0.9***	0.5	**0.7***	**1.0***	**1.0***	1	
Pb	0.5	**0.9***	0.2	**0.8***	**0.9***	**0.9***	**0.9***	1

*Correlations significant at $P \leq 0.05$

Source: Author Analysis, 2023.

4.5.4 Correlation Matrix for Elemental Concentration in the Fish Samples

Furthermore, Table 4.18 summarized the correlation matrix of the heavy metals' concentration in fish samples from the six selected dams across Osun State, Nigeria. The correlation matrix for the selected heavy metal concentrations in fish samples showed some significant ($p < 0.05$) associations (Table 4.18). A three-way synergy between Cr, Pb and Fe with significant correlations ranging from r = 0.6 to 0.8 was observed, suggesting a common origin. The fish Cd correlated positively significantly to Cd (r = 0.7) and Pb (1.0), suggesting similar sources, but negatively significantly to Zn (-0.6) indicating an influence of a different source (Table 4.18).

Table 4.20: Correlation Matrix for Elemental Concentration in the Fish Samples

	Cd	Cr	Ni	Pb	Fe	Zn	Cu	Mn
Cd	1							
Cr	**0.7***	1						
Ni	0.1	0.2	1					
Pb	**1.0***	**0.8***	0.2	1				
Fe	0.5	**0.6***	-0.1	**0.7***	1			
Zn	**-0.6***	-0.5	-0.0	**-0.8***	**-0.7***	1		
Cu	-0.3	0.2	**0.6***	-0.2	-0.0	0.0	1	
Mn	-0.5	-0.1	**-0.6***	**-0.6***	-0.1	**0.6***	-0.1	1

*Correlations significant at $P \leq 0.05$.

Source: Author Analysis, 2023.

4.5.5 Correlation Matrix for Elemental Concentration in Okra and Bitter Leaf Samples

Tables 4.19 and 4.20 reveal a substantial association between Ni-Cd, Pb-Cr, Cu-Pb, and Cu-Cr, with correlation coefficients of 0.95, 0.87, 0.72, and 0.60, respectively, in the correlation matrix of heavy metals in bitter leaf and Okra.

The findings also indicated that there is little or no significant relationship between other heavy metals analyzed in the bitter leaf, whereas there is no strong relationship between the heavy metals analyzed in Okra, with the exception of Zn-Cu, which has a correlation co-efficient of 1.00, indicating a strong relationship in the samples.

Table 4.21: Correlation Matrix for Elemental Concentration in Okra Samples

	Cd	Cr	Ni	Pb	Fe	Cu	Zn	Mn
Cd	1							
Cr	0.2	1						
Ni	-0.3	-0.2	1					
Pb	0.1	-05	-0.2	1				
Fe	0.1	**0.6***	**-0.7***	-0.4	1			
Cu	-0.2	**-0.9***	0.5	0.5	**-0.8***	1		
Zn	-0.2	**-0.9***	0.5	0.5	**-0.8***	1	1	
Mn	0.2	-0.3	**0.7***	-0.4	**-0.6***	0.4	0.4	1

*Correlations significant at $P \leq 0.05$.

Source: Author Analysis, 2023.

Table 4.22: Correlation Matrix for Elemental Concentration in Bitter Leaf Samples

	Cd	Cr	Ni	Pb	Fe	Zn	Cu	Mn
Cd	1							
Cr	0.2	1						
Ni	**1.0***	0.1	1					
Pb	0.0	**0.9***	0.1	1				
Fe	0.0	**-0.9***	0.2	**-0.7***	1			
Zn	0.2	0.1	0.0	-0.4	-0.4	1		
Cu	0.4	**0.6***	0.5	**0.7***	-0.3	-0.5	1	
Mn	-0.1	-04	-0.3	**-0.7***	0.2	0.42	-0.4	1

*Correlations significant at P ≤ 0.05

Source: Author Analysis, 2023.

4.6. Multivariate Statistics

Although Cd, Cr, Cu, Fe, Ni, Pb Mn and Zn were detected in all samples comprising surface water, sediments, tilapia (*Oreochromis niloticus*), Okra (*Abelmoschus esculentus*) and bitter leaf (*Vernonia amygdalina*) samples. The concentrations of potentially toxic elements such as Cd, Cr, Ni and Pb were significantly ($p < 0.05$) above the WHO permissible limits in all fish samples across all the sampling locations (Tables 4.1 to 4.12). Hence, the results of multivariate statistics analysis of the studied potentially toxic elements (Cd, Cr, Ni and Pb) in surface water, sediment and selected vegetables are excluded, but multivariate statistics analysis results for fish samples across selected dams from Osun State, Nigeria are presented in Table 4.21 and Figure 4.15.

4.6.1 Principal Component Analysis (PCA)

The principal component analysis (PCA) result for potentially toxic elements (PTEs) in fish samples is presented and shown in Table 4.21 and Figure 4.15 respectively. However, the principal component analysis (PCA) results for plant samples (selected vegetables) are excluded since concentrations of potentially toxic elements (PTEs) in Okra (*Abelmoschus esculentus*) and Bitter leaf (*Vernonia amygdalina*) samples were significantly ($p < 0.05$) below the WHO permissible limits (Table 4.10 and Table 4.12). The preliminary results of the KMO test (0.5), further validated the results of the principal component analysis (PCA).

Two principal components dominated the principal component analysis (PC 1 and PC 2), accounting for 65.2% of the total variance (Table 4.21 and Figure 4.15), with PC 1 (37.7%) representing the dominant variance. The Cd loading (0.68) is not as high as that of Ni in PC 1 (Table 4.21), suggesting a quasi-independent behaviour and the influence of a different factor. This was further validated by a large distance in the 3-D PCA loading plot (Figure 4.16), which may suggest a poor correlation and the influence of different sources.

Table 4.23: Rotated Component Matrix for Variables in Fish Samples

	Component	
Element	1	2
Cd	0.68	-0.16
Cr	-0.22	0.82
Ni	0.82	0.20
Pb	0.44	0.70
Eigenvalues	1.51	1.10
% Total variance	37.74	27.44
Cumulative %	37.74	65.18

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization (Bold figures indicate values ≥ 0.5). Source: Author Analysis, 2023.

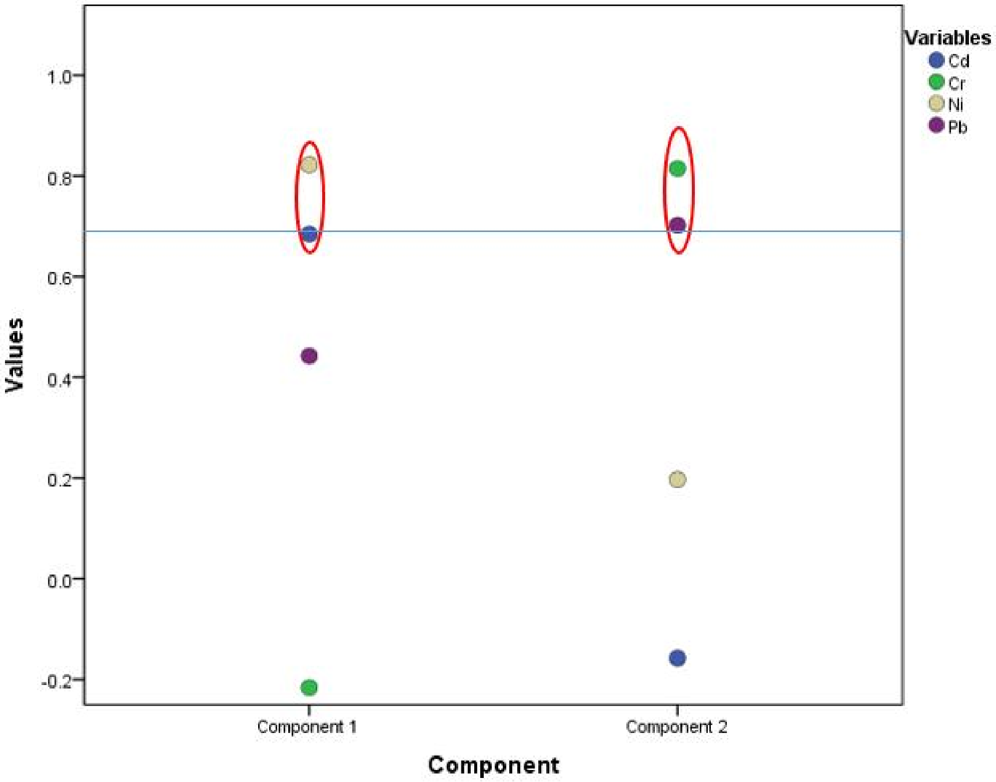


Figure 4.17: Rotated Component Matrix Dot Plot for PTE Concentration in Fish Samples

Source: Author Analysis, 2023.

Similarly, Cr was found to be strongly associated with Pb in PC 2, contributing 27.4% to the total variance with high loadings of 0.82 and 0.70 respectively. These high loadings suggest common anthropogenic sources. These associations strongly suggest that the elements have a similar source.

4.6.2. Hierarchical Cluster Analysis (HCA)

The interpoint distances and similarities between samples were analyzed via hierarchical cluster analysis (HCA) with Ward's linkage method, using Euclidean distances. The resulting dendrogram from the data matrix, comprising concentrations of potentially toxic elements (PTEs), is illustrated in Figure 4.17. This dendrogram indicates the association between the PTEs through the distance between clusters; the closer the distance, the stronger the association[26,27].

Figure 4.17 shows that the studied potentially toxic elements (PTEs) in fish samples were grouped into two main clusters, the first cluster containing (Cr, Pb and Ni) and the second one, a stand-alone cluster containing (Cd) joined together at a relatively high level, hence implying perhaps a common source but different factors. The proximity in the dendrogram between the two clusters also suggests a form of similarity in the distribution of the potentially toxic elements (PTEs).

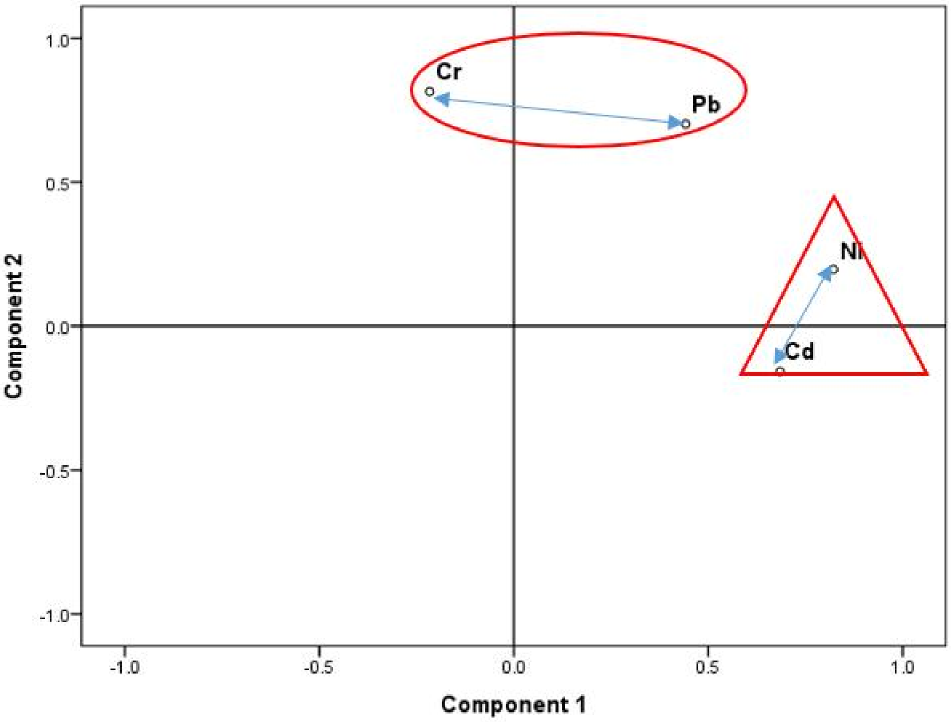


Figure 4.18: 3-D Plot of Principal Component Analysis (PCA) Loading (PC 1 vs PC 2) for PTE in Fish Samples.

Source: Author Analysis, 2023.

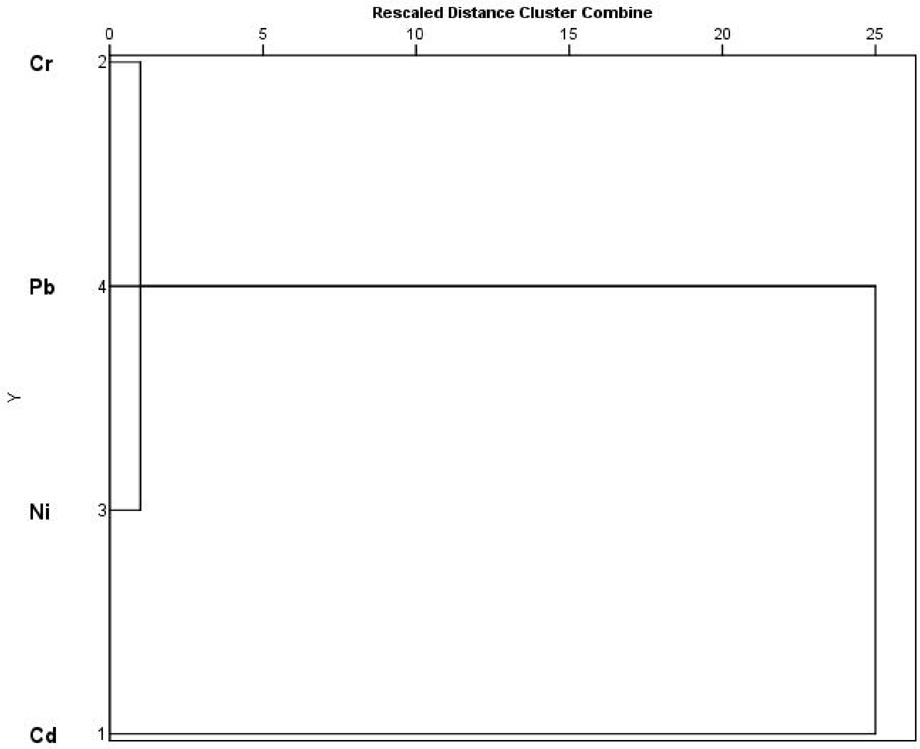


Figure 4.19: Hierarchical Cluster Analysis Dendrogram Showing the Relationship Between Four PTEs in Fish Samples by Ward's Methods (Distances Reflect the Degree of Correlation Between Different PTEs).

Source: Author Analysis, 2023.

Endnotes

[1] I. M. Chiromawa, S. B. Adamu, & I. G. Shitu, "*Determination of Physico-Chemical Parameters of Drinking Water in Kafin-Hausa: an Index Analysis Approach*", **African Journal of Earth and Environmental Sciences**, 1(2), 2019, 150-159.

[2] G. Wyasu, "*Determination of Physicochemical Pollutants in Wastewater and Some Food Crops Grown along Kakuri Brewery Wastewater Channels, Kaduna State, Nigeria*", **Science World Journal,** 15(3), 2020, 111-115.

[3] C. Ogbodo, R. Wuana, A. U. Itodo & I. S. Eneji, "*Physicochemical Parameters and Water Quality Index of Water in the Lower Usuma Dam, FCT, Nigeria.*" **IIARD International Journal of Geography and Environmental Management,** 6(2), 2020,30-30

[4] World Health Organization (WHO), Guidelines for drinking water quality. 4th edn. World Health Organization, Geneva, 2011.

[5] A. Rahman, I. Jahanara & Y. N. Jolly, "*Assessment of Physicochemical Properties of Water and their Seasonal Variation in an Urban River in Bangladesh", ***Water Science and Engineering***,* 14(2), 2021, 139-148.

[6] S. T. Palisoc, R. I. Vitto, M. G. Noel, K. T. Palisoc, & M. T. Natividad, "*Highly Sensitive Determination of Heavy Metals in Water Prior to and after Remediation Using Citrofortunella Microcarpa*". **Scientific Reports**. 11(1), 2021,1-4.

[7] S. Erdoğan, G. B. Kankılıç, M. Seyfe, U. N. Tavşanoğlu, & S. Akın, "*Assessment of Heavy Metal Pollution with Different Indices in Süreyyabey Dam Lake in Turkey*". **Chemistry and Ecology**. 2022, 1-20.

[8] B. Utete & B. T. Fregene, "*Assessing the Spatial and Temporal Variability and Related Environmental Risks of Toxic Metals in Lake Asejire, South-Western Nigeria*", **Scientific African**, 7, 2020, e00259.

[9] H. Flefel, D. Nokhrin & I. Donnik, "*Determine Heavy Metals in Water, Aquatic Plants, and Sediment in Water Systems"*, **E3S Web of Conferences**, 222 (10), 2020,02028.

[10] M. Nasir, I. Iqbar, M. Munira, Z. A. Muchlisin, S. Saiful, S. Suhendrayatna & E. Erdiwansyah, "*Investigation of Heavy Metals in River Water, Sediment and Fish in Krueng Geumpang, Pidie Regency, Aceh Province*", **Journal of Advanced Research in Fluid Mechanics and Thermal Sciences,** 75(1), 2020, 81-93.

[11] I. O. Ayanda, U. I. Ekhator & O. A. Bello, "*Determination of Selected Heavy Metal and Analysis of Proximate Composition in Some Fish Species from Ogun River, Southwestern Nigeria"*, **Heliyon**, 5, 2019,1-6.

[12] N. K. Kortei, M. E. Heymann, E. K. Essuman, F. M. Kpodo, P.T. Akonor, S. Y. Lokpo, N. O. Boadi, M. Ayim-Akonor & C. Tettey, "*Health Risk Assessment and Levels of Toxic Metals in Fishes (Oreochromis Noliticus and Clarias Anguillaris) from Ankobrah and Pra Basins: Impact of Illegal Mining Activities on Food Safety*", **Toxicology Reports**, 7, 2020, 360-369.

[13] E. K. Magna, S. S. Koranteng, A. Donkor & C. Gordon, *"Health Risk Assessment and Levels of Heavy Metals in Farmed Nile Tilapia (Oreochromis Niloticus) from the Volta Basin of Ghana"*, **Journal of Chemistry**, 2021.

[14]. N. Majed, M. K. Alam, M. I. Real & M. S. Khan, "*Accumulation of Copper and Zinc Metals from Water in Anabus Tesudineus Fish Species in Bangladesh"*, **Aquaculture Studies**, 19(2), 2019,91-102.

[15] P. H. Bukar & M. A. Onoja, "*Assessment of Heavy Metals in Okra (Abelmoschus Esculentus) Cultivated Through Irrigation, in Maiduguri, Nigeria*", **Open Journals of Environmental Research,** 1(1), 2020,59-70.

[16] C. K. Yap, W. H. Cheng, A. Yaacob, Z. Hassan, R. Nulit, F. B. Edward, K. W. Wong, M. H. Ibrahim, S. H. Peng, C. W. Yap, & W. S. Tan, "*Human Health Risks of Heavy Metals in Okra (Abelmochus Esculentus) and Lettuce (Lactuta Sativa) Collected from Selected Farms in Peninsular Malaysia",* **Food Science and Nutrition Technology,** 2021, 91-97.

[17] I. U. Emmanuel, C. U. Namnso & A. E. Uduak, "*Distribution of Some Trace Metals in Bitter Leaf (Vernonia Amygdalina) Obtained in Oil Exploration Area of Ibeno, Nigeria"*, **American Journal of Quantum Chemistry and Molecular Spectroscopy**, 4(1), 2020, 7-16.

[18] A. K. Amah, E. C. Ogbodo, E. L. Mbanaso, C. C. Akunneh-Wariso, D. C. Ejiofor, C. M. Njoku, O. Okhiai, C. B. Iheukwumere, C. O. Timothy & I. P. Amaechi, "*Determination of the Heavy Metal Contents of Vernonia Amygdalina (Bitter Leaf) Collected from Eke Okigwe Market in Imo State, South-Eastern Nigeria",* **International Journal of Medical Science and Health Research,** 2(5), 2018,1-6.

[19] O. O. Ogunlaja, R. Moodley, H. Baijnath, S. B. Jonnalagadda, "*Nutritional Evaluation, Bioaccumulation and Toxicological Assessment of Heavy Metals in Edible Fruits of Ficus Sur Forssk (Moraceae)",* **Journal of Environmental Science and Health, Part B**, 52(2), 2017, 84-91.

[20] O. O. Ogunlaja, R. Moodley, H. Baijnath, S. B. Jonnalagadda, "*Elemental Distribution and Health Risk Assessment of the Edible Fruits of Two Ficus Species, Ficus Sycomorus L. and Ficus Burtt-Davyi Hutch*", **Biological Trace Element Research**, 198 (1), 2020,303-314.

[21]. A. Ogunlaja, O. O. Ogunlaja, D. M. Okewole, O. A. Morenikeji, "*Risk Assessment and Source Identification of Heavy Metal Contamination by Multivariate and Hazard Index Analyses of a Pipeline Vandalised Area in Lagos State, Nigeria*", **Science of the Total Environment,** 651, 2019, 2943-2952.

[22] USEPA (United States Environmental Protection Agency), Reference dose (RfD): Description and use in health risk assessments, Background Document 1A, Integrated risk information system (IRIS): **United States Environmental Protection Agency**: Washington, DC, 2015.
[23]USEPA (United States Environmental Protection Agency), Risk-based concentration table. United State Environmental Protection Agency, Washington, USA, 2011

[24]USEPA, (United States Environmental Protection Agency), Regional Screening Level (RSL) Summary Table, November, 2015

[25] S. S. Durodola, O. Ayinuola, O. T. Ore & O. W. Makinde, *"Assessment of Human Health Risk of Potential Toxic Metals in Herbal Concoction Teas Commonly Consumed in Nigeria"*, **World Journal of Applied Chemistry,** 4(3), 2019,41-47.

[26] O. O. Adesanya, O. O. Ogunlaja, F. O. Agunbiade, A. Ogunlaja, E. I. Unuabonah & L. O. Adebajo, *"Source Identification and Human Health Risk Assessment of Heavy Metals in Water Sources around Bitumen Field in Ondo State, Nigeria",* **Environmental Forensics**, 2020, 1-12.

[27] A. K. Gupta & S. Sinha, *"Assessment of Single Extraction Methods for the Prediction of Bioavailability of Metals to Brassica Juncea L. Czern. (Var. Vaibhav) Grown on Tannery Waste-Contaminated Soil",* **Journal of hazardous materials,** 149(1), 2007, 144-150.

Chapter Five

Conclusion

5.1 Summary of Findings

Summarily, physico-chemical parameters measured for surface water from the six chosen dams in Osun State, Nigeria, were all lower than the WHO prescribed levels except for BOD, COD, and Turb, which were higher. The elemental concentrations in the surface were lower than the WHO standards, though Cd (0.006 mg L^{-1}) was recorded at a single site and Ni (0.03 - 0.04 mg L^{-1}) in almost 67% of the sites. Nevertheless, in terms of sediments, the PTEs concentrations were larger than the World Health Organization's permissible values besides Cu and Cr. Even though the PTEs concentration in surface water and plant samples were lower than the WHO limits, the same was not true for the fish samples because the concentration of Cr (1.18 - 2.31 mg kg^{-1}), Ni (3.15 - 3.92 mg/kg), Pb (2.36 - 3.73 mg kg^{-1}) and Cd (0.41 - 14.2 mg kg^{-1}) surpassed the WHO threshold levels of 0.7, 0.6, 0.3, and 0.3 mg kg^{-1} respectively. In general, the concentrations of the potentially toxic elements in fish decreased based on the order Ni > Cd > Pb > Cr.

5.2 Conclusion

Generally, the analysis of the four samples (water, sediments, fish and vegetables) from the selected dams in the study area, indicates several observable trends in terms of elemental variation.

This study revealed significant variations in the concentrations of heavy metals among the different samples. Each sample exhibited a unique combination and level of heavy metal contamination, indicating spatial heterogeneity within the dam ecosystem. The observed elemental variations suggest that the contamination of heavy metals in the dams may be influenced by diverse pollution sources. Anthropogenic activities such as industrial discharges, agricultural runoff, and urbanization likely contribute to the presence of heavy metals in the water, sediment, fish, and flora.

In conclusion, data from this study indicated that the concentrations of Cd, Cr, Ni and Pb in fish from six dams in Osun State, Nigeria were higher than expected ($p < 0.05$), implying that they contain potentially hazardous elements.

Generally, the average concentrations of the PTEs in surface water samples were below the WHO permissible limit for drinking water except for Ni at Ilesa (0.03 mg L^{-1}), Esa Odo (0.03 mg L^{-1}), Ede (0.03 mg L^{-1}) and Ikire (0.04 mg L^{-1}) dams and Cd at Iba (0.006 mg L^{-1}) dam. Additionally, statistical analysis showed that the average concentrations of the studied PTEs did not differ significantly ($p < 0.05$) across the selected dams, indicating similar PTEs profiles. Similarly, the average concentrations of the studied PTEs in sediment were in the decreasing order Pb > Cr > Ni > Cd and were all greater than the WHO permissible limit except for Cr.

Moreover, this study showed that sediment tends to accumulate higher concentrations of heavy metals compared to water samples. Sediment can act as a sink, receiving and storing heavy metal pollutants over time. This finding emphasizes the importance of considering sediment quality in assessing overall ecosystem contamination.

Also, the fish samples revealed higher concentrations of certain heavy metals compared to water and sediment. This observation suggests the phenomenon of biomagnification, where heavy metals are absorbed and accumulate in higher concentrations as they move up the food chain. The consumption of contaminated fish from these dams could pose a potential risk to human health. The risk assessment results demonstrated that eating Okra, Bitter leaf, and Tilapia from these dams can be harmful to human health. Therefore, consuming these foods, specifically

Tilapia, over an extended period of time from these analyzed dams may result in a gradual increase of trace substances such as the studied potentially toxic elements in consumers.

5.3 Recommendations

Based on the findings from this study, the following recommendations can be made:

1. Strengthen Pollution Control Measures: Implementation of stringent regulations and enforcement mechanisms to control and monitor industrial discharges, agricultural runoff, and other potential sources of heavy metal contamination in the dams. Regular inspections and strict penalties for non-compliance should be imposed to ensure adherence to pollution control measures.
2. Improve Waste Management Practices: Enhancement of waste management systems in the surrounding areas of the dams to minimize the release of heavy metals into the environment. Encouragement of proper disposal and recycling of hazardous materials, as well as the treatment of industrial and domestic wastewater before discharge.
3. Conduct Regular Monitoring Programs: Establishment of long-term monitoring programs to assess the levels of heavy metals in the dams, including water, sediment, fish, and flora. Regular sampling and analysis should be carried out to track any temporal variations and identify emerging pollution hotspots. This data will provide a baseline for comparison and help in identifying trends and potential risks.
4. Promote Sustainable Land Use Practices: Encouragement of sustainable land use practices, such as agroforestry, organic farming, and afforestation, in the catchment areas of the dams. These practices can help reduce soil erosion, improve water quality, and minimize the input of contaminants into the dams.

5. Public Awareness and Education: Conduct awareness campaigns to educate local communities, fishermen, and farmers about the risks associated with heavy metal contamination and the importance of sustainable practices. Promote responsible fish consumption and provide guidelines on proper cooking methods to reduce potential health risks.
6. Collaboration and Stakeholder Engagement: Foster collaboration between government agencies, research institutions, local communities, and relevant stakeholders to address the issue of heavy metal contamination collectively. Encourage information sharing, knowledge exchange, and collaborative research to develop effective management strategies and mitigation measures.
7. Further Research: Support further research on the sources, transport pathways, and fate of heavy metals in the dam ecosystems. Investigate the long-term impacts of heavy metal contamination on aquatic organisms, human health, and ecosystem dynamics. This research can provide valuable insights for future management and conservation efforts.

By implementing these recommendations, it is possible to mitigate the risks associated with heavy metal contamination in the dams of Osun State, South-Western Nigeria, ensuring the protection of both the environment and human well-being.

5.3.1 Contribution to Knowledge

This study on the evaluation of heavy metals in water, sediment, fish, and flora from six selected dams in Osun State, South-Western Nigeria makes several significant contributions to the existing knowledge:

1. This study evaluates the presence of heavy metals in a wide range of environmental samples, including water, sediment, fish, and plants. By considering all of these factors, it

provides a comprehensive picture of the presence and distribution of heavy metals in the chosen dams.

2. By detecting and assessing the spatial variation of heavy metal pollution across the six dams in Osun State, this work contributes to our understanding of this phenomenon. It draws attention to regional differences in heavy metal concentrations, which might shed light on the nature and extent of pollution in the area.

3. This study contributes to our knowledge of the threats that heavy metal contamination poses to the aquatic ecosystem and to human health by an assessment of these metals in water, sediment, fish, and vegetation. It aids in assessing the level of contamination and potential dangers associated with the dams evaluated by estimating the quantities of heavy metals and comparing them to regulatory standards.

5.3.2 Suggested Areas for Further Studies

While the evaluation of heavy metals in water, sediment, fish, and flora from six selected dams in Osun State, South-Western Nigeria provides valuable insights, there are several areas that warrant further investigation. These suggested areas for future studies include:

1. Long-Term Monitoring Entails Studying temporal fluctuations in heavy metal contamination, locating its origins, and gauging the efficacy of its control by repeated measurements.

2. Heavy metal contamination in dams can be mitigated through focused interventions and pollution prevention techniques, but first it is necessary to identify the precise sources of this pollution, such as industrial effluents, agricultural runoff, or atmospheric deposition.

3. Bioaccumulation and Biomagnification: Assessing the Risks to Human Health from Consuming Contaminated Fish by Studying the Transfer of Heavy Metals by the Food Chain in Fish Species from the Dams.
4. Ecological Effects: Evaluating the Threat to Biodiversity, Community Structure, and Ecosystem Functioning Caused by Heavy Metal Contamination in Aquatic Ecosystems.

Bibliography

Journals

Abdul Baki, M. Hossain, M, M, Akter, J. Quraishi, S. B. Shojib, M. F. H. Atique Ullah, A. K. M. & Khan, M. F. " *Concentration of Heavy Metals in Seafood (Fishes, Shrimp, Lobster and Crabs) and Human Health Assessment in Saint Martin Island, Bangladesh.* **Ecotoxicology and Environmental Safety,** 159, 2018,153–163.

Adamo, N. Al-Ansari, N. Sissakian, V. Laue, J. & Knutsson, S. *"Dam safety: General considerations,"* **Journal of Earth Sciences and Geotechnical Engineering**, 10(6), 2020, 1-21.

Adesanya, O. O. Ogunlaja, O. O. Agunbiade, F. O. Ogunlaja, A. Unuabonah E. I. & Adebajo, L. O. *"Source Identification and Human Health Risk Assessment of Heavy Metals in Water Sources around Bitumen Field in Ondo State, Nigeria",* **Environmental Forensics**, 2020, 1-12.

Agrelli, D. Caporale A. G. & Adamo, P. *"Assessment of the Bioavailability and Speciation of Heavy Metal(loid)s and Hydrocarbons for Risk-Based Soil Remediation",* **Journal of Agronomy,** 10(9), 2020, 1440.

Agu, Z. "When will Osun Osogbo Festival be this Year?". Legit.ng-Nigeria News. 2019, 8-19.

Ahsan, M. A. Siddique, M. A. Munni, M. A. Akbor, M. A. Bithi, U. H. Mia, M. Y. & Siddique, M. *"Analysis of Major Heavy Metals in the Available Fish Species of the Dhaleshwari River, Tangail, Bangladesh"*, **International Journal of Fisheries and Aquatic Studies,** 6(4), 2018,349-354.

Akintan, O. B. Olusola, J. A. & Azeez, A. M. *"Heavy Metals Loads in Soil, Farmlands and Plant Crop at Open Dumpsite",* **Global Journal of Environmental Science and Management**, 5(4), 2019, 449-460.

Al Naggar, Y. Khalil, M. S. & Ghorab, M. A. "*Environmental Pollution by Heavy Metals in the Aquatic Ecosystems of Egypt.*" **Open Access Journal of Toxicology,** 3(1), 2018,555603.

Ali, H. & Khan, E. "*What are Heavy Metals? Long-Standing Controversy over the Scientific Use of the Term 'Heavy Metals'*—Proposal of a comprehensive definition", **Toxicological and Environmental Chemistry,** 100(1), 2018, 6-19.

Almashhadany, D. A. Khalid, H. S. & Ali, H. S. "*Determination of Heavy Metals and Selenium Contents in Fish Meat Sold at Erbil City, Kurdistan Region*," **Journal of Food Safety**, 9 (3), 2020, 8753.

Alrabie, N. A. Mohamat-Yusuff , F. Hashim, R. Zulkeflee, Z. Arshad A. & Amal, M. N. "*Heavy Metals Concentrations in Stormwater and Tilapia Fish (Oreochromis Niloticus) in Kuala Lumpur Holding and Storage SMART Ponds, Pertanika,* " **Journal of Tropical Agricultural Science**, 42(1), 2019,225- 236.

Amah, A. K. Ogbodo, E. C. Mbanaso, E. L. Akunneh-Wariso, C. C. Ejiofor, D. C. Njoku, C. M. Okhiai, O. Iheukwumere, C. B. Timothy C. O. & Amaechi, I. P. "*Determination of the Heavy Metal Contents of Vernonia Amygdalina (Bitter Leaf) Collected from Eke Okigwe Market in Imo State, South-Eastern Nigeria",* **International Journal of Medical Science and Health Research,** 2(5), 2018,1-6.

Ashaolu, E. D. Olorunfemi, J. F. & Ifabiyi, I. P. "*Effect of Land-Use /Land Cover Change On Groundwater Recharge in Osun Drainage Basin, Nigeria.*"**Journal of Geology, Geography & Geoecology,** 28 (3), 2019, 381-394.

Ayanda, I. O. Ekhator, U. I. & Bello, O. A. "*Determination of Selected Heavy Metal and Analysis of Proximate Composition in Some Fish Species from Ogun River, Southwestern Nigeria"*, **Heliyon**, 5, 2019,1-6.

Azhar, U. Ahmad, H. Shafqat, H. Babar, M. Munir, H. M. Sagir, M. Arif, M. Hassan, A. Rachmadona, N. Rajendran, S. & Mubashir M. "*Remediation Techniques for Elimination of Heavy Metal Pollutants from Soil: A Review*". **Environmental research**, 2022,113918.

Balali-Mood, M. Naseri, K. Tahergorabi, Z. Khazdair M. R., & Sadeghi, M. *"Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium, and Arsenic"*, **Frontiers in Pharmacology**, 2021, 227.

Barman, H. Das, S. K. & Roy, A. *"Zinc in Soil Environment for Plant Health and Management Strategy"*, **Universal Journal of Agricultural Research,** 6(5), 2018,149-154.

Bashir, I. Lone, F. A. Bhat, R. A. Mir, S. A. Dar, Z. A. & Dar, S. A. *"Concerns and Threats of Contamination on Aquatic Ecosystems"*, **Journal of Bioremediation and Biotechnology,** 2020, 1-26.

Bielecka, J. Markiewicz-Zukowska, R. Nowakowski, P. Grabia, M. Puscion-Jakubik, A. Mielcarek, K. Gromkowska-Kepka, K. J. Soroczynska, J. & Socha, K. *"Content of Toxic Elements in 12 Groups of Rice Products Available on Polish Market"*, **Human Health Risk Assessment**, **Foods**, 9(12), 2020,1906.

Briffa, J. Sinagra, E. & Blundell, R. "*Heavy Metal Pollution in the Environment and their Toxicological Effects on Humans* ". **Heliyon**, 6(9), 2020,6.

Bukar P. H & Onoja, M. A. "*Assessment of Heavy Metals in Okra (Abelmoschus Esculentus) Cultivated Through Irrigation, in Maiduguri, Nigeria*", **Open Journals of Environmental Research,** 1(1), 2020,59-70.

Buxton, S. Garman, E. Heim, K. E. Lyons-Darden, T. Schlekat, C. E. Taylor, M. D. & Oller, A.R. *"Concise Review of Nickel Human Health Toxicology and Ecotoxicology",* **Journal of Inorganic Chemistry,** 7(7), 2019, 89.

Chinemelu E. S. & Nwankwor, G. I. *"Seasonal Variations of Heavy Metals in Groundwater of Warri And Environs, Southwestern Nigeria"*, **International Journal of Advanced Academic Research | Sciences, Technology and Engineering**, 5(6), 2019,2-5.

Chiromawa, I. M. Adamu, S. B. & Shitu, I. G. "*Determination of Physico-Chemical Parameters of Drinking Water in Kafin-Hausa: an Index Analysis Approach*", **African Journal of Earth and Environmental Sciences**, 1(2), 2019,150-159.

David, E. & Cosio, C. *"New Insights into Impacts of Toxic Metals in Aquatic Environments"*, **Environmental Journal,** 2020, 8(1), 1.

Dayo-Olagbende, G. O. Adejoro, S. A. Ewulo B. S. & Awodun, M. A. *"Effects of Oxidation-Reduction Potentials on Soil Microbes"*, **Agricultural,** 16(1-2), 2019,35-42.

Delahaut, V. Rašković, B. Salvado, M. S. Bervoets, L. Blust, R. & De Boeck, G. "*Toxicity and Bioaccumulation of Cadmium, Copper and Zinc in a Direct Comparison at Equitoxic Concentrations in Common Carp (Cyprinus Carpio) Juveniles*". **PLoS One**. 15(4), 2020, e0220485.

Dinu, M. I. & Shkinev,V. M. *"Complexation of Metal Ions with Organic Substances of Humus Nature: Methods of Study and Structural Features of Ligands, and Distribution of Elements between Species",* **Geochemistry International**, 58, 2020,200-211.

Doamekpor, I. K. Abusa, Y. H. Ketemepi, K. Klake, R. K. Doamekpor, M. E. Anom, P. A. & Obeng, J. "*Assessment of Heavy Metals in Water and Sediments of Sakumo II, Chemu and Kpeshie Lagoons – Ghana*," **West African Journal of Applied Ecology**, 26(2), 2018, 56–71.

Durodola, S. S. Ayinuola, O. Ore O. T. & Makinde, O. W. *"Assessment of Human Health Risk of Potential Toxic Metals in Herbal Concoction Teas Commonly Consumed in Nigeria",* **World Journal of Applied Chemistry,** 4(3), 2019, 41-47.

Emmanuel, I. U. Namnso C. U. & Uduak, A. E. "*Distribution of Some Trace Metals in Bitter Leaf (Vernonia Amygdalina) Obtained in Oil Exploration Area of Ibeno, Nigeria"*, **American Journal of Quantum Chemistry and Molecular Spectroscopy**, 4(1), 2020, 7-16.

Emurotu, J. E. *"Chemical Speciation and Potential Mobility of some Metals of Selected Farmland in Kogi State, North Central Nigeria",* **Nigerian Journal of Basic and Applied Science,** 28(1), 2020,48-55.

Engwa, G. A. Ferdinand, P.U. Nwalo, F. N. & Unachukwu, M. N. *"Mechanism and Health Effects of Heavy Metal Toxicity in Humans",* **Archives of Biological Sciences**, 10, 2019,70-90

Erdoğan, Ş. Kankılıç, G. B. Seyfe, M. Tavşanoğlu, Ü. N. & Akın, Ş. "*Assessment of Heavy Metal Pollution with Different Indices in Süreyyabey Dam Lake in Turkey*". **Chemistry and Ecology**. 2022 1-20.

Fan, P. Cho, M. S. Lin, Z. Ouyang, Z. Qi, J. Chen J, J. & Moran, E. F. "*Recently Constructed Hydropower Dams were Associated with Reduced Economic Production, Population,* *and Greenness in nearby Areas*", **Science of The Total Environment**, 119(8), 2022, e2108038119

Fan, X. Dufresne, A. Subramanian, S. S. Strom, A. Hermanns, R. Stefanelli, C. T. Hewitt, K Yunus, A. Dunning, S. Capra, L. & Geertsema, M. "*The Formation and Impact of Landslide Dams: State of the Art*," **Earth-Science Reviews**, 203, 2020,103116.

Feng, J. Lin, Y. Li, M. Ouyang, T. & Yu, M. "*Characterization and Risk Assessment of Heavy Metals in Surface Sediments From Jian and Moyang Rivers in Western Guangdong*". **Frontiers in Environmental Science**. 2022,1040.

Flefel, H. Nokhrin D.& Donnik, I. "*Determine Heavy Metals in Water, Aquatic Plants, and Sediment in Water Systems"*, **E3S Web of Conferences**, 222 (10), 2020,02028.

Fonge, B. A. Larissa M. T., Egbe, A. M. Afanga, Y. A. Fru N. G. & Ngole-Jeme, V. M. *"An Assessment of Heavy Metal Exposure Risk Associated with Consumption of Cabbage and Carrot Grown in a Tropical Savannah Region. Sustainable Environment",* **An International Journal of Environmental Health and Sustainability**, 7(1), 2021,1909860.

Fu, Z. & Xi, S. "*The Effects of Heavy Metals on Human Metabolism*". **Journal of Toxicology mechanisms and methods**. 30(3), 2020,167-176.

Garai, P. Banerjee, P. Mondal, P. & Saha, N. C. "*Effect of Heavy Metals on Fishes: Toxicity and Bioaccumulation*". **Journal of Clinical Toxicology**. 2021,18.

Ghaderpoori, M. Jafari, A. Ghaderpoury, A. & Karami, M. "*Heavy Metals Analysis and Quality Assessment in Drinking Water – Khorramabad City, Iran.*" **Data in Brief**, 16, 2018, 685-692.

Giménez, E. Salinas M. & Manzano-Agugliaro, F" *Worldwide Research on Plant Defense against Biotic Stresses as Improvement for Sustainable Agriculture*, "**Sustainability**, 10(2), 2018, 391.

Gupta A. K. & Sinha, S. *"Assessment of Single Extraction Methods for the Prediction of Bioavailability of Metals to Brassica Juncea L. Czern. (Var. Vaibhav) Grown on Tannery Waste-Contaminated Soil",* **Journal of hazardous materials,** 149(1), 2007,144-150.

He, K. Wang, J. Chen, Q. Wu, F. Yang, X. & Chen, J. "*Effects of Cascade Dams on the Occurrence and Distribution of Microplastics in Surface Sediments of Wujiang River Basin, Southwestern China*". **Ecotoxicology and Environmental Safety**. 240, 2022,113715.

Huang, Z. Liu, C. Zhao, X. Dong, J. & Zheng, B. "*Risk Assessment of Heavy Metals in the Surface Sediment at the Drinking Water Source of the Xiangjiang River in South China*". **Environmental Sciences Europe**. 32, 2020, 1-9.

Islam, S. M. Rohani, M. F. Zabed, S. A. Islam, M. T. Jannat, R. Akter, Y. & Shahjahan, M. "*Acute Effects of Chromium on Hemato-Biochemical Parameters and Morphology of Erythrocytes in Striped Catfish Pangasianodon Hypophthalmus*". **Toxicology Reports**. 7, 2020, 664-670.

Jalali M. & Najafi, S. *"Effect of pH on Potentially Toxic Trace Elements (Cd, Cu, Ni, and Zn) Solubility in Two Native and Spiked Calcareous Soils",* **Experimental and Modeling. Communications in Soil Science and Plant Analysis,** 49(7), 2018,814-827.

Javed, T. Ahmad, N. & Mashiatullah, A. "*Heavy Metals Contamination and Ecological Risk Assessment in Surface Sediments of Namal Lake, Pakistan,* "Polish **Journal of Environmental Studies**, 27(2), 2018,675–688.

Joda, B. A. Alheloo, H. S. Al-Mankosh, H. J. & Maitham, S. A. "*Determination of Heavy Metals Arsenic, Cadmium and Lead in Water, Sediments and Fish from Al Delmaj Marshes-Iraq*," InAIP Conference Proceedings, 2144(1), 2019,020012. AIP Publishing LLC.

Khan, K. Shah, G. M. Shah, A. Saqib, Z. Hussain, M. & Rahman, I. U. "*Elemental Composition and Heavy Metals Determination of Some Wetland Plants of Family Polygonaceae*." **International Journal of Biosciences**, 15(3), 2019,483–488.

Kortei, N. K. Heymann, M. E. Essuman, E. K. Kpodo, F. M. Akonor, P.T. Lokpo, S. Y. Boadi, N. O. Ayim-Akonor M. & Tettey, C."*Health Risk Assessment and Levels of Toxic Metals in Fishes (Oreochromis Noliticus and Clarias Anguillaris) from Ankobrah and Pra Basins: Impact of Illegal Mining Activities on Food Safety"*, **Toxicology Reports**, 7, 2020,360-369.

Krivokapić, M. "*Study on the Evaluation of (Heavy) Metals in Water and Sediment of Skadar Lake (Montenegro), with BCF Assessment and Translocation Ability (TA) by Trapa Natans and a Review of SDGs*". **Water**. 3(6), 2021,876.

Kulkarni S. & Goswami, A. *"Effect of Excess Fertilizers and Nutrients: A Review on Impact on Plants and Human Population"*, **International Conference on Sustainable Computing in Science, Technology and Management (SUSCOM),** 2019, 1-4.

Li, S. Wang, M. Zhao, Z. Ma, C. & Chen, S. *" Adsorption and Desorption of Cd by Soil Amendment - Mechanisms and Environmental Implications in Field-Soil Remediation",* **Sustainability**, 10(7), 2018,2337.

Liu, G. Yu, Z. Liu, X. Xue, W. Dong, L. & Liu,Y. *"Aging Process of Cadmium, Copper, and Lead under Different Temperatures and Water Contents in Two Typical Soils of China",* **Journal of Chemistry,** 2020, 1-10.

Liu, Q. Sheng, Y. Jiang, M. Zhao, G. & Li, C. "*Attempt of Basin-Scale Sediment Quality Standard Establishment for Heavy Metals in Coastal Rivers* ". **Chemosphere**, 245, 2020,125596.

Ma, Q. Han, L. Zhang, J. Zhang, Y. Lang, Q. Li, F. Han, A. Bao, Y. Li, K. & Alu, S. *"Environmental Risk Assessment of Metals in the Volcanic Soil of Changba Mountain",* **International Journal of Environmental Research and Public Health**, 16(11), 2019,2047.

Magna, E. K. Koranteng, S. S. Donkor, A. & Gordon, C. *"Health Risk Assessment and Levels of Heavy Metals in Farmed Nile Tilapia (Oreochromis Niloticus) from the Volta Basin of Ghana"*, **Journal of Chemistry**, 2021.

Majed, N.. Alam, M. K Real M. I. & Khan, M. S. "*Accumulation of Copper and Zinc Metals from Water in Anabus Tesudineus Fish Species in Bangladesh"*, **Aquaculture Studies**, 19(2), 2019, 91-102.

Manisalidis, I. Stavropoulou, E. Stavropoulos A. & Bezirtzoglou, E. "*Environmental and Health Impacts of Air Pollution*: A Review*"*, **Frontiers in Public Health**, 2020, 14.

Mensoor, M. & Said, A. "*Determination of Heavy Metals in Freshwater Fishes of the Tigris River in Baghdad."* **Fishes**, 3(2), 2018, 23.

Miao, X. Hao, Y. Liu, H. Xie, Z. Miao, D. & He, X. "*Effects of Heavy Metals Speciations in Sediments on their Bioaccumulation in Wild Fish in Rivers in Liuzhou—A Typical Karst*

Catchment in Southwest China". **Ecotoxicology and Environmental Safety**. 214, 2021,112099.

Milacic, R. Zuliani, T. Vidmar, J. Bergant, M. Kalogianni, E. Smeti, E. Skoulikidis, N. & Scancar, J. "*Potentially Toxic Elements in Water, Sediments and Fish of the Evrotas River under Variable Water Discharges*, " **Science of the Total Environment,** 648, 2019,1087–1096.

Mitra, S. Chakroborty, A. J. Tareq, A. M. Emran, T. B. Nainu, F. Khusro, A. Idris, A. M. Khandaker, M. U. Osman, H. Alhumaydhi F. A. & Simal-Gandara, J. *"Impact of Heavy Metals on the Environment and Human Health: Novel Therapeutic Insight to Counter the Toxicity",* **Journal of King Saud University Science**, 2022, 101865.

Mokarram, M. Saber, A. & Sheykhi, V. "*Effects of Heavy Metal Contamination on River Water Quality Due to Release of Industrial Effluents*". **Journal of Cleaner Production**. 277, 2020, 123380.

Nasir, M. Iqbar, I. Munira, M. Muchlisin, Z. A. Saiful, S. Suhendrayatna, S.& Erdiwansyah, E. "*Investigation of Heavy Metals in River Water, Sediment and Fish in Krueng Geumpang, Pidie Regency, Aceh Province*", **Journal of Advanced Research in Fluid Mechanics and Thermal Sciences,** 75(1), 2020, 81-93.

Neina, D. *"The Role of Soil pH in Plant Nutrition and Soil Remediation",* **Journal of Applied and Environmental Soil Science,** 2019, 1-9.

Nkinda, M. S. Rwiza, M. J. Ijumba, J. N. & Njau, K. N. "*Heavy Metals Risk Assessment of Water and Sediments Collected from Selected River Tributaries of the Mara River in Tanzania,*" **Discover Water**, 1(1), 2021, 3.

Obayemi, O. Komolafe, O. O. & Onana, E. E. "*Limnological Variables as a Determinant of Fish Parasites Abundance in the Esa-Odo Reservoir, Esa-Odo Southwestern Nigeria*". **Journal of Water and Health.** 2023.

Ogbodo, C. Wuana, R. Itodo, A. U. & Eneji, I. S. "*Physicochemical Parameters and Water Quality Index of Water in the Lower Usuma Dam, FCT, Nigeria.*" **IIARD International Journal of Geography and Environmental Management,** 6(2), 2020, 30-30.

Ogundele, K. T. Oluyemi, E. A. Oyekunle, J. A. Makinde, O.W. & Gbenu, S. T. "*An Evaluation of Health Hazards Indices of Natural Radioactivity of the Sediments from Eko-Ende Dam, Osun State, Nigeria*", **Open Journal of Ecology**, 8, (11), 2018, 607-621.

Ogunlaja, A. Ogunlaja, O. O. Okewole, D. M. Morenikeji , O. A. "*Risk Assessment and Source Identification of Heavy Metal Contamination by Multivariate and Hazard Index Analyses of a Pipeline Vandalised Area in Lagos State, Nigeria*", **Science of the Total Environment,** 651, 2019,2943-2952.

Ogunlaja, O. O. Moodley, R. Baijnath, H. Jonnalagadda, S. B. "*Nutritional Evaluation, Bioaccumulation and Toxicological Assessment of Heavy Metals in Edible Fruits of Ficus Sur Forssk (Moraceae)",* **Journal of Environmental Science and Health, Part B**, 52(2), 2017, 84-91.

Ogunlaja, O. O. Moodley, R Baijnath, H. Jonnalagadda, S. B. "*Elemental Distribution and Health Risk Assessment of the Edible Fruits of Two Ficus Species, Ficus Sycomorus L. and Ficus Burtt-Davyi Hutch*", **Biological Trace Element Research**, 198 (1), 2020,303-314.

Olalekan, A. S. Adewoye, S.O. Sawyerr, O. H, & Raimi M. O. "*Comparative Assessment of Seasonal Variations in the Quality of Surface Water and its Associated Health Hazards in Gold Mining Areas of Osun State, South-West Nigeria*". **Advance Environmental Engineering Research**. 4(1), 2023,11.

Olubanjo, O. O. & Adeleke, E. B. ″Assessment of Physico-Chemical Properties and Water Quality of River Osse, Kogi State″, **Applied Research Journal of Environmental Engineering**, 3(1), 2020,21–30.

Onyeakagbu, A. N. G. "Pulse"., **Journal of Experimental and Applied Mathematics,** 15(3), 2020, 233-237.

Owolabi, B. Adewumi, A. A. Odewumi, O. S. Okosodo, E. F. & Orimaye, J. O. "*Survey of Avifauna Species of a Degraded Environment, Case Study of Osun State University, College of Agriculture, Ejigbo, Nigeria*", **Merit Research Journal of Environmental Science and Toxicology**, 6 (2), 2018,1-7.

Palisoc, S. T. Vitto, R. I. Noel, M. G. Palisoc, K. T. & Natividad, M. T. "*Highly Sensitive Determination of Heavy Metals in Water Prior to and after Remediation Using Citrofortunella Microcarpa*". **Scientific Reports**. 11(1), 2021 ,1-4.

Pan, Z. Nong, X. Xie, Y. Li, Y. Zeng, H. Liang Y.& Zhang, M. *"Field Determination of Phosphate in Environmental Water by Using a Hand-Powered Paper Centrifuge for Preconcentration and Digital Image Colorimetric Sensing"*, **Journal of Analytical Methods in Chemistry**, 2022, 1–7.

Prakash S. & Verma, A. K. *"Arsenic: It's Toxicity and Impact on Human Health",* **International Journal of Biological Innovations,** 3(1), 2021, 38-47.

Rahman, A. Jahanara I. & Jolly, Y. N. “*Assessment of Physicochemical Properties of Water and their Seasonsal Varsiation in an Urban River in Bangladesh”,* **Water Science and Engineering**, 14(2), 2021,139-148.

Rajeshkumar, S. & Li, X. "*Bioaccumulation of Heavy Metals in Fish Species from the Meiliang Bay, Taihu Lake, China*, ". **Toxicology Reports**, 5, 2018,288–295.

Rajeshkumar, S. Liu, Y. Zhang, X. Ravikumar, B. Bai G. & Li, X. "*Studies on Seasonal Pollution of Heavy Metals in Water, Sediment, Fish and Oyster from the Meiliang Bay of Taihu Lake in China*", **Chemosphere**, 191, 2018, 626-638.

Razzak, S. A. Farooque, M. O. Alsheikhd, Z. Alsheikhmohamadc, L. Alkuroudd, D. Alfayez, A. Hossain, S. Z. & Hossain, M. M. *"A Comprehensive Review on Conventional and Biological-Driven Heavy Metals Removal from Industrial Wastewater"*, **Environmental Advances**, 2022, 100168

Salam, M. A. Paul, S. C. Shaari, F.I. Rak, A. E. Ahmad, R. B. & Kadir, W. R. "*Geostatistical Distribution and Contamination Status of Heavy Metals in the Sediment of Perak River, Malaysia* ". **Hydrology**, 6(2), 2019, 30.

Sawidis, T. Chettri, M. K. Zachariadis, G. A. & Stratis, J. A. “*Heavy Metals in Aquatic Plants and Sediments from Water Systems in Macedonia, Greece*”. **Ecotoxicology and environmental safety**. 32(1), 1995,73-80.

Shaari, N. E. Tajudin, M. T. Khandaker, M. M. Majrashi, A. Alenazi, M. M. Abdullahi U. A. & Mohd, K. S. *"Cadmium Toxicity Symptoms and Uptake Mechanism in Plants*: A Review*"*, **Brazilian Journal of Biology,** 2022, 84.

Silva, C. S. Moutinho, C. Ferreira da Vinha, A. & Matos, C. *"Trace Minerals in Human Health: Iron, Zinc, Copper, Manganese and Fluorine",* **International Journal of Science and Research Methodology**, 13(3), 2019, 57-80.

Singh A. M. & Rashid, M. *"Impact of Animal Waste on Environment, its Managemental Strategies and Treatment Protocols to Reduce Environmental Contamination",* **Veterinary Science Research Journal,** 8 (1&2), 2017, 1-12.

Sobhanardakani, S. Tayebi, L. & Hosseini, S. V. "*Health Risk Assessment of Arsenic and Heavy Metals (Cd, Cu, Co, Pb, and Sn) through Consumption of Caviar of Acipenser Persicus from Southern Caspian Sea*, " **Environmental Science and Pollution Research,** 25(3), 2018,2664–2671.

Sobhanardakani, S. "*Ecological and Human Health Risk Assessment of Heavy Metal Content of Atmospheric Dry Deposition*, a Case Study: Kermanshah, Iran." **Biological Trace Element Research**, 187(2), 2019,602–610.

Steffan, J. J. Brevik, E. C. Burgess, L. C. & Cerdà, A. *"The Effect of Soil on Human Health: an Overview.* **European Journal of Soil Science***"*. 69(1), 2018,159-171.

Speckhann, G. A. Kreibich, H. & Merz, B. "*Inventory of Dams in Germany*," **Earth System Science Data**, 13(2), 2021,731–740.

Stofejova, L. Fazekas J. & Fazekasova, D. *"Analysis of Heavy Metal Content in Soil and Plants in the Dumping Ground of Magnesite Mining Factory",* **Journal of Sustainability,** 13(8), 2021, 4508.

Sylwan, I. & Thorin, E. *"Removal of Heavy Metals during Primary Treatment of Municipal Wastewater and Possibilities of Enhanced Removal: A Review"*, **Journal of water**, 13(08), 2021, 1121.

Thangiah, A. S. *"Spectrophotometric Determination of Sulphate and Nitrate in Drinking Water at Asia-Pacific International University campus",* **Rasayan Journal of Chemistry,** 12(03), 2019, 1503–1508.

Tibu, C. Annang, T. Y. Solomon, N. & Yirenya- Tawiah, D. *"Effect of the Composting Process on Physic-Chemical Properties and Concentration of Heavy Metals in Market Waste with Additive Materials in the Ga West Municipaliity, Ghana",* **International Journal of Recycling of Organic Waste in Agriculture**, 8, 2019,393-403.

Ugwu, I. M. & Igbokwe, O. A. *"Sorption of Heavy Metals on Clay Minerals and Oxides*: A Review, **Advanced Sorption Process Applications,** 2019, 1-23.

Utete,B. & Fregene,B. T. "*Assessing the Spatial and Temporal Variability and Related Environmental Risks of Toxic Metals in Lake Asejire, South-Western Nigeria,*" **Scientific African Journal**, 7, 2020, e00259.

Vaikosen, E. N. & Alade, G.O. *"Determination of Heavy Metals in Medicinal Plants from the Wild and Cultivated Garden in Wilberforce Island, Niger Delta Region, Nigeria",* **Journal of Pharmacy and Pharmacognosy Research**, 5(2), 2017,129–143.

Wang, Y. Tian Y. & Cao, Y. *"Review: Dam Siting: A Review,*" **WATER**, 13, 2021, 2080.

Witkowska, D. Słowik, J. & Chilicka, K. "*Heavy Metals and Human Health*: Possible exposure pathways and the competition for protein binding sites.*"* **Molecules**, 26(19), 2021, 6060.

Wyasu, G. "*Determination of Physicochemical Pollutants in Wastewater and Some Food Crops Grown along Kakuri Brewery Wastewater Channels, Kaduna State, Nigeria*", **Science World Journal,** 15(3), 2020, 111-115.

Yap, C. K. Cheng, W. H. Yaacob, A. Hassan, Z. Nulit, R. Edward, F. B. Wong, K. W. Ibrahim, M. H. Peng, S. H. Yap, C. W. & Tan, W. S. "*Human Health Risks of Heavy Metals in Okra (Abelmochus Esculentus) and Lettuce (Lactuta Sativa) Collected from Selected Farms in Peninsular Malaysia",* **Food Science and Nutrition Technology,** 2021, 91-97.

Youdeowei, P. O. Nwankwoala, H. O. & Desai, D. D. *"Review Article: Dam Structures and Types in Nigeria: Sustainability and Effectiveness,"* **Water Conservation and Management**, 3(1), 2019, 20-26.

Zhao, Q. Tang, J. Li, Z. Yang, W. & Duan, Y. *"The Influence of Soil Physico-Chemical Properties and Enzyme Activities on Soil Quality of Saline-Alkali Agroecosystems in Western Jilin Province, China",* **Sustainability,** 10(5), 2018, 1529.

Articles

Akinnifesi, O. Adesina, F. Ogunwole, G. & Abiya, S. "*Occurrence and Impact of Heavy Metals on Some Water, Land, Flora and Fauna Resources across Southwestern Nigeria*". In Heavy Metals-Their Environmental Impacts and Mitigation 2021, 3.

Khassaf, S. I. *Dams and Reservoir, University of Bashra College of Engineering, Civil Engineering Department, Iraq*, 2020.

Lavers, T. & Dye, B. "*Theorising the Political Economy of Dams, Towards a Research Agenda,"* Working Paper 001. Manchester: The University of Manchester, Future **DAMS**, 2019, Available at SSRN 3538193.

Mengistu, G. Sahilu, G. Alakangas, L. Mulat, W. & Kloos, H. "*Assessment of Heavy Metal Pollution Associated with Tailing Dam in Gold Mining Area, Southern Ethiopia*". Geosystem Engineering. 26, 2022, 1-1.

Nyiramigisha, P. “*Harmful impacts of heavy metal contamination in the soil and crops grown around dumpsites*”. Reviews in Agricultural Science. 9, 2021,271-282.

Oyewale,T. A. & Adesakin, T. "*Mycotoxigenic Fungi Distribution and Water Quality of Raw and Treated Water from Ede-Erinle and Opa Waterworks Systems, Osun State Nigeria,"* Preprint In Review Research-Article, Science Open Preprints, 2020.

United States Environmental Protection Agency, *"Factors Affecting the Environment", Retrieved from*. https://www.epa.gov/environmental-factors-affecting-health, 2019.

USEPA (United States Environmental Protection Agency), Reference dose (RfD): Description and use in health risk assessments, Background Document 1A, Integrated risk information system (IRIS): United States Environmental Protection Agency: Washington, DC, 2015.

USEPA (United States Environmental Protection Agency), Risk-Based Concentration Table. United State Environmental Protection Agency, Washington, USA, 2011

USEPA (United States Environmental Protection Agency), Regional Screening Level (RSL) Summary Table, November, 2015

World Health Organization (WHO), Guidelines for drinking water quality. 4thedn. World Health Organization, Geneva, 2011.

National Population Commission, "2006 PHC Priority Tables".population.gov.ng, 2017, 10-10.

Books

Ababio, O. Y. "*New School Chemistry*,", Africana First Publishers PLC, Sixth Edition, 2016, 298-315.

Adebisi, G. A. "*Basic Chemistry Laboratory Techniques*,", Iyiola Printing Press, Third Edition, 2020, 28-30.

Akusoba, E. U. & *Ewelukwa,* G. O. "*Calculation in Chemistry*,", Africana First Publishers PLC, 2018, 49-50.

Dhir, R. De Brito, K. J., Mangabhai, R., Lye,C. Q. "*Sustainable Construction Materials*,", *Copper Slag*, Woodhead Publishing, 2016.

Odesina, I. A. "*Essential Chemistry*,", Tonad Publishers Limited, Ninth Edition, 2020: 230-262.

Ojokuku, G. O. "*Understanding Chemistry for Schools and Colleges*," PRESS-ON CHEMBOOKS, Third Edition, 2019, 119-127.

Appendix I

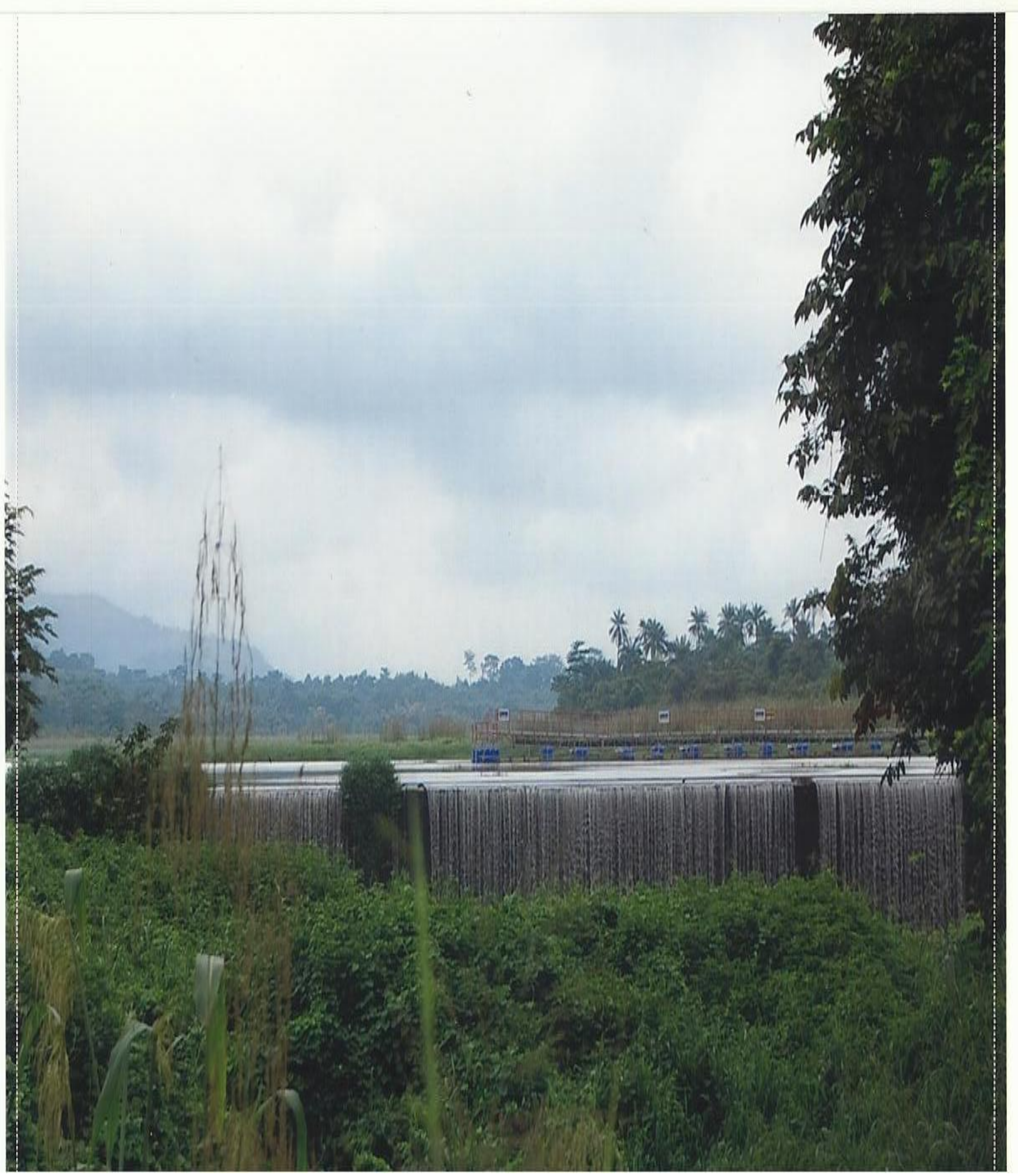
Appendix II

Iba dam

Appendix III

Ilesa Dam

Appendix IV



Esa-Odo Dam

Appendix V

Ede Dam

Appendix VI

Asejire Dam

Appendix VII

Concentration of Physico-Chemical Parameters of Heavy Metals from Six Selected Dams in Osun State

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE
Temp	0.06	0.23	0.57	1.9	0.22	0.12
pH	0.24	0.25	0.25	0.22	0.26	0.07
EC	0.02	0.04	0.03	0.01	0.06	0
TDS	2.2	3.6	4.33	2.27	3.38	0.02
Alk	0.2	0.1	0.2	0.1	0.2	0.1
TH	0.1	0.3	0.1	0.3	0.1	0.3
Turb	0.01	0.02	0	0.01	0.02	0
TSS	0.04	0.04	0.04	0.01	0.01	0.06
DO	0	0.01	0.02	0	0.02	0.01
BOD	6	10	12	2	2.01	1.2
COD	4.02	1	5.01	3	4.03	1.02
NO_3^-	0.04	0.03	0.02	0.04	0.01	0.03
SO_4^{2-}	0.1	0.2	2	0.9	0.9	2.03
PO_4^{3-}	0.01	0.02	0.01	0	0.02	0.01

Appendix VIII

Concentration of heavy metals in surface water from six selected Dams in Osun State

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE	WHO
Fe	0.02	0.01	0.02	0.03	0.02	0	1
Cu	0.01	0.02	0.01	0.03	0.02	0.04	2
Zn	0.01	0	0	0.01	0.01	0	5
Mn	0.01	0.02	0.02	0.01	0.11	0.01	0.5
Ni	0.01	0.02	**0.03**	**0.01**	**0**	**0.02**	0.02
Cr	0.01	0.02	0.01	0.01	0.01	0.01	0.05
Cd	0.01	**0.02**	0	0.01	**0.01**	0.01	0.003
Pb	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	0.001

Appendix IX

Concentration of Heavy Metals in Sediment from six selected Dams in Osun State

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE	WHO
Fe	**11.5**	**10.6**	**12.4**	**50.9**	**16.8**	**44.6**	**5**
Cu	10.7	13.1	33.6	7.8	9.7	12.4	100
Zn	**0.65**	**0.65**	**0.23**	**0.23**	**0.45**	**0.23**	**50**
Mn	**0.21**	**0.21**	**1.02**	**0.6**	**0.41**	**0.43**	**50**
Ni	6.4	**14.2**	**19.8**	**11.1**	3.1	**14.6**	**35**
Cr	7.1	7.6	4.6	6.6	7.3	9.3	100
Cd	**5.2**	**10.3**	**15.5**	**15.1**	**2.2**	**10.9**	**0.8**
Pb	**7.2**	**9.9**	**4.7**	**46.6**	**10.1**	**11.7**	**85**

Appendix X

Concentration of Heavy Metals in Fish from Six Selected Dams in Osun State

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE	WHO
Cd	0.3	0.33	0.68	1.99	32.9	0.82	0.3
Cr	0.5	0.28	1.06	0.5	1.32	1.3	0.7
Ni	2.16	2.53	3.01	2.09	2.45	2.24	0.6
Pb	1.06	0.94	1.67	0.99	2.4	1.98	0.3

Appendix XI

Carcinogenic risk (hazard quotient, HQ) in adult

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE	HI
Cd	0.003	0.003	0.006	0.024	0.11	0.007	0.153
Cr	0.007	0.008	0.01	0.007	0.014	0.011	0.057
Ni	0.006	0.005	0.07	0.006	0.06	0.005	0.152
Pb	0.81	0.771	0.899	0.977	1.219	0.895	5.571
Fe	0.264	0.483	0.207	0.219	0.181	0.226	1.58
Cu	0.582	0.598	1.103	0.657	0.579	0.597	4.116

Appendix XII

Carcinogenic risk (hazard quotient, HQ) in children

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE	HI
Cd	0.014	0.016	0.027	0.109	0.498	0.032	0.696
Cr	0.031	0.035	0.044	0.032	0.062	0.049	0.253
Ni	0.026	0.025	0.025	0.027	0.03	0.025	0.158
Pb	3.674	3.496	4.074	4.43	5.526	4.06	25.26
Fe	1.198	2.189	0.939	0.992	0.819	1.027	7.164
Cu	2.638	2.709	4.998	2.977	2.627	2.706	18.66

Appendix XIII

Heavy Metal Concentrations of Flora (Okra) from six Dams

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE	WHO
Cd	0.001	0.001	0	0.001	0	0.001	0.022
Cr	0.021	0.01	0.101	0.101	0.02	0.102	1.3
Ni	0.021	0.014	0.514	0.514	0.014	0.072	10
Pb	0.014	0.051	0.051	0.014	0.051	0.05	2

Appendix XIV

Heavy metal concentrations of in flora (bitter leaf plant) from six Dams

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE	WHO
Cd	0.002	0.002	0.007	0.005	0	0	0.022
Cr	0.021	0.031	0.031	0.031	0.011	0.031	1.3
Ni	0.091	0.021	0.021	0.721	0.005	0.031	10
Pb	0.035	0.02	0.02	0.021	0.021	0.02	2

Appendix XV

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE
Temp	0.06	0.23	0.57	1.9	0.22	0.12
pH	0.24	0.25	0.25	0.22	0.26	0.07
EC	0.02	0.04	0.03	0.01	0.06	0
TDS	2.2	3.6	4.33	2.27	3.38	0.02
Alk	0.2	0.1	0.2	0.1	0.2	0.1
TH	0.1	0.3	0.1	0.3	0.1	0.3
Turb	0.01	0.02	0	0.01	0.02	0
TSS	0.04	0.04	0.04	0.01	0.01	0.06
DO	0	0.01	0.02	0	0.02	0.01
BOD	6	10	12	2	2.01	1.2
COD	4.02	1	5.01	3	4.03	1.02
NO_3^-	0.04	0.03	0.02	0.04	0.01	0.03
SO_4^{2-}	0.1	0.2	2	0.9	0.9	2.03
PO_4^{3-}	0.01	0.02	0.01	0	0.02	0.01

Appendix XVI

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE	WHO
Fe	0.02	0.01	0.02	0.03	0.02	0	1
Cu	0.01	0.02	0.01	0.03	0.02	0.04	2
Zn	0.01	0	0	0.01	0.01	0	5
Mn	0.01	0.02	0.02	0.01	0.11	0.01	0.5
Ni	0.01	0.02	**0.03**	**0.01**	**0**	**0.02**	0.02
Cr	0.01	0.02	0.01	0.01	0.01	0.01	0.05
Cd	0.01	**0.02**	0	0.01	**0.01**	0.01	0.003
Pb	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	0.001

Appendix XVII

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE	WHO
Fe	**11.5**	**10.6**	**12.4**	**50.9**	**16.8**	**44.6**	**5**
Cu	10.7	13.1	33.6	7.8	9.7	12.4	100
Zn	**0.65**	**0.65**	**0.23**	**0.23**	**0.45**	**0.23**	**50**
Mn	**0.21**	**0.21**	**1.02**	**0.6**	**0.41**	**0.43**	**50**
Ni	6.4	**14.2**	**19.8**	**11.1**	3.1	**14.6**	**35**
Cr	7.1	7.6	4.6	6.6	7.3	9.3	100
Cd	**5.2**	**10.3**	**15.5**	**15.1**	**2.2**	**10.9**	**0.8**
Pb	**7.2**	**9.9**	**4.7**	**46.6**	**10.1**	**11.7**	**85**

Appendix XVIII

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE	WHO
Cd	0.3	0.33	0.68	1.99	32.9	0.82	0.3
Cr	0.5	0.28	1.06	0.5	1.32	1.3	0.7
Ni	2.16	2.53	3.01	2.09	2.45	2.24	0.6
Pb	1.06	0.94	1.67	0.99	2.4	1.98	0.3
Fe	6.99	10.69	12.82	30.90	34.19	54.5	0.3
Zn	5.20	4.40	2.50	3.60	2.00	2.30	5.0
Cu	0.03	0.30	1.84	0.20	0.10	2.70	2.3
Mn	0.20	1.20	0.00	0.80	0.10	0.20	0.5

Appendix XIX

Carcinogenic risk (hazard quotient, HQ) in adult

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE	HI
Cd	0.003	0.003	0.006	0.024	0.11	0.007	0.153
Cr	0.007	0.008	0.01	0.007	0.014	0.011	0.057
Ni	0.006	0.005	0.07	0.006	0.06	0.005	0.152
Pb	0.81	0.771	0.899	0.977	1.219	0.895	5.571
Fe	0.264	0.483	0.207	0.219	0.181	0.226	1.58
Cu	0.582	0.598	1.103	0.657	0.579	0.597	4.116
Zn	0.004	0.023	0.047	0.23	0.052	0.7	1.056
Mn	0.43	0.027	0.093	0.812	0.067	0.02	1.449

Appendix XX

Carcinogenic risk (hazard quotient, HQ) in children

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE	HI
Cd	0.014	0.016	0.027	0.109	0.498	0.032	0.696
Cr	0.031	0.035	0.044	0.032	0.062	0.049	0.253
Ni	0.026	0.025	0.025	0.027	0.03	0.025	0.158
Pb	3.674	3.496	4.074	4.43	5.526	4.06	25.26
Fe	1.198	2.189	0.939	0.992	0.819	1.027	7.164
Cu	2.638	2.709	4.998	2.977	2.627	2.706	18.66
Zn	0.007	0.031	0.092	0.090	0.014	0.014	0.248
Mn	0.034	0.099	0.070	0.045	0.003	0.023	0.274

Appendix XVIII

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE	WHO
Cd	0.001	0.001	0	0.001	0	0.001	0.022
Cr	0.021	0.01	0.101	0.101	0.02	0.102	1.3
Ni	0.021	0.014	0.514	0.514	0.014	0.072	10
Pb	0.014	0.051	0.051	0.014	0.051	0.05	2
Fe	0.012	0.001	0.014	0.012	0.051	0.012	0.30
Cu	0.021	0.120	0.010	0.420	0.310	0.220	10.0
Zn	0.210	0.120	0.010	0.420	0.310	0.220	0.60
Mn	0.110	0.100	0.000	0.020	0.002	0.001	0.05

Appendix XVIX

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE	WHO
Cd	0.002	0.002	0.007	0.005	0	0	0.022
Cr	0.021	0.031	0.031	0.031	0.011	0.031	1.3
Ni	0.091	0.021	0.021	0.721	0.005	0.031	10
Pb	0.035	0.02	0.02	0.021	0.021	0.02	2
Fe	0.021	0.030	0.111	0.001	0.000	0.012	0.3
Zn	0.001	0.020	0.001	0.011	0.003	0.000	0.60
Cu	0.000	1.000	0.101	0.111	0.120	0.122	10
Zn	0.012	0.100	0.110	0.000	0.000	0.000	0.05

Bio-data

A. Personal Data

Full Name:	Ishola Abdul Dimeji
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Place of Birth:	Ikirun
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Permanent Home Address	72, Station Road, Ikirun
Phone No:	09066307142
Name Next of Kin:	Ishola Azeez
Permanent Home Address	72, Station Road, Ikirun

B. Educational Institutions Attended and Dates and Qualification

i.	N.U.D Primary School, Ikirun (Primary school leaving certificate)	1982 - 1988
ii.	Holy Michael High School, Ikirun (Senior Secondary School Certificate)	1988 - 1993
iii.	Ladoke Akintola University of Technology, Ogbomosho (B. Tech (Hons) Chemical Engineering)	1995 - 2000
iv.	University of Ibadan, (MSc. Environmental Chemistry)	2008 –2010

C. Work Experience with Dates

Science Laboratory Technology Department, Osun State Polytechnic, Iree	2005 - till date

D. Membership of Academic Professional Bodies

Chemical Society of Nigeria (CSN)	2005-till date
Institute of Personality Development and Customer Relationship Management (IPD-CRM)	2017

E. Publications

Thesis and Dissertation

1. Potentially toxic elements concentrations and health risk assessment through Consumption of Fish and vegetables from selected Dams in Osun State, Nigeria.

2. Assessment of selected Heavy metals contamination of water and sediment samples from six Selected Dams by multivariate and hazard index analyses

F. Extra-Curricular Activities:

Sport, Academic Research

G. Names of Referees

1. Prof. Jimoh R.O.

Department of Computer Sciences,

University of Ilorin, Kwara State

2. Prof. Fafioye O.O.

Department of Plant Science,

Olabisi Onabanjo University, Ago-Iwoye

3. Dr. Adekambi A.O.

Department of Biology,

University of Ibadan, Ibadan

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Signature **Date**

The University Compliance Certification

This is to certify that this Thesis was written by Ishola Abdul Dimeji with Matric Number LCU/PG/001032 of the Department of Chemical Sciences (Chemistry Unit), Faculty of Natural and Applied Sciences, Lead City University, Ibadan is in full compliance with the approved University format and style.

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Signature **Date**