POST-REMEDIATION ASSESSMENT OF CADMIUM, CHROMIUM AND LEAD IN SOIL, WATER, PLANTS AND FISH IN BAGEGA LAKE, ZAMFARA STATE, NIGERIA

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FEBRUARY, 2022

DECLARATION

I declare that the work in this dissertation entitled "**Post-Remediation Assessment of Cadmium, Chromium and Lead Metal in Soil, Water, Plants & Fish in Bagega Lake, Zamfara State, Nigeria"** has been performed by me in the Department of Biology. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

Bilqis Olorunjuwon AHMED _____ _____

Signature Date

CERTIFICATION

This dissertation entitled "**POST-REMEDIATION ASSESSMENT OF CADMIUM, CHROMIUM AND LEAD IN SOIL, WATER, PLANTS AND FISH IN BAGEGA LAKE, ZAMFARA STATE, NIGERIA"** by **Bilqis Olorunjuwon AHMED** meets the regulations governing the award of the degree of Masters of Science in Biology of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This dissertation is dedicated to Almighty Allah for enabling me go through this program successfully and to my husband and parents for their love and support in all ramification.

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My appreciation goes to God Almighty for giving me the grace to successfully carry out this research work.

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LIST OF ABBREVIATIONS

ANOVA	- Analysis of variance
BLLs	- Blood Lead Levels
BI	-Blacksmith Institute
Cd	- Cadmium
Cr	- Chromium
EC	- Electrical conductivity
GPS	-Global Positioning System
Hg	-Mercury
MMSD	- Ministry of Mines and Steel Development
MP-AES	- Microwave Plasma Atomic Emission Spectroscopy
MPL	-Maximum Permissible Levels
Pb	-Lead
TDS	- Total Dissolved Solid
TG	- TerraGraphics
XRF	- X-ray fluorescence
ZMoH	- Zamfara State Ministry of Health

LISTS OF NON-GOVERNMENTAL ORGANIZATION (NGOs)

ATSDR - Agency for Toxic Substances and Disease Registry

CDC - Center for Disease Control

JEU -Joint Environment Unit

MSF - Medecins Sans Frontieres

TIFO -TerraGraphics Internation Foundation

USEPA - United States Environmental Protection Agency

UNEP/OCHA - United Nations Environment Programme/Office for the Coordination of Humanitarian Affairs.

WHO - World Health Organization

ZESA - Zamfara Environmental Sanitation Agency

ABSTRACT

Bagega community of Zamfara State, Nigeria had Lead poisoning in 2010, many lives were affected and remediation exercise was done in 2013. This study assess the post-remediation concentrations of Cadmium, Lead and Chromium Water, Soil, Plant and Fish samples collected from Bagega Lake and its environment during the dry season (February 2020), from remediated and unremediated sites around Bagega Lake. Agilent 4210 MP-AES machine was used to analyse the metal concentrations after digestion using the Advanced Microwave Digestion System model (Ethos easy) milestone connect company in Centre for Dryland Agriculture (CDA) Bayero University Kano. The data generated were described statistically using the ggplots2 package of R statistical analysis software. Statistical analysis was performed at 5% significant level using the R statistical analysis program version 3.6.3 for macOS Big Sur. Results show that mean concentrations of Lead (0.78mg/l) and Chromium (0.43mg/l) in the water were above the permissible limits of the World Health Organization (Pb 0.01mg/l and Cr 0.1mg/l respectively) while Cadmium (Cd) that was below detection limits. However, Pb had its highest concentration in sediments (3.18mg/kg) and Cr had higher concentration (4.39mg/kg) in soil from remediated site while Cd was highest (0.07mg/kg) but were all within W.H.O., (Pb 200mg/kg, Cr 11mg/kg and Cd 0.43mg/kg) permissible limits. Lead (Pb) concentration in parts of fish (gills 0.09mg/kg) was higher than in others 0.03mg/kg (flesh and liver). Plant species metals recorded were within the World Health Organization (Cd 0.2mg/kg, Cr 1.3mg/kg and Pb 0.3mg/kg) permissible limits. More so, the BAFs in all fish parts as well as plant species sampled revealed no probability of accumulation. Appropriate measures on Bagega Lake Zamfara-State, Nigeria should be taken to avoid any re-occurrence of the hazardous pollution in future

CHAPTER ONE

1.0 INTRODUCTION

The term heavy metal refers to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentration (Srivastava and Goyal, 2010). Heavy metals are significant environmental pollutants and their toxicity is a problem of increasing significance for ecological, evolutionary, nutritional and environmental reasons (Nagajyoti *et al*., 2010 ; Jaishankar *et al*., 2014). The most commonly found heavy metals in water include arsenic, cadmium, chromium, copper, lead, nickel, and zinc, all of which cause risks for human health and the environment (Lambert *et al*., 2000). Heavy metal contamination in water has been linked to agricultural run-offs from pesticides, herbicides, fertilisers, to industrial effluents (Kaur and Sinha, 2019; Singh *et al*., 2020). The term has particular application to cadmium, mercury, lead and arsenic, (Brathwaite and Rabone, 1985) all of which appear in the World Health Organisation's list of 10 chemicals of major public concern (W.H.O, 2003). Other examples include manganese, chromium, cobalt, nickel, copper, zinc, selenium, silver, antimony and thallium.

Heavy metals are natural components of the earth crust. All soils contain trace levels of these elements. Their presence in soils is therefore, not necessarily indicative of contamination. The concentration of metals in uncontaminated soil is primarily related to the geology of the parent material from which the soil was formed. However, human activities have been responsible for the wider diffusion of the elements (Udiba *et al*., 2012).

Heavy metals occur naturally in the ecosystem, most of them in trace quantities (Uriah *et al*., 2013). Depending on their concentration, some of them like Zn, Fe, Mn and Cu are essential

plant nutrients (Tanimu *et al*., 2013) others like Pb, Hg and Cr do not have any known use to plants.

Deposition of heavy metals in soils from anthropogenic activities have been implicated for an increase in heavy metal concentration above background and recommended levels (Tanimu *et al*., 2013). Heavy metals are important components of agro-allied products such as pesticides, herbicides, fertilizers; manufacturing and other synthetic products such as paints and batteries. Mining activities, industrial, municipal and domestic wastes have been reported to be important sources of heavy metal pollution to the environment (Jaishankar *et al*., 2014).

Research has shown that heavy metals are potentially toxic to crops, animals and humans when contaminated soils and water are used for crop production (Udiba *et al*., 2012). Metals such as Lead and Cadmium have been reported to have no bio-importance in human biochemistry and physiology, and consumption even at low concentration can be toxic. These metals enter the human body through food, water and air, and bioaccumulate over time (Lenntech, 2004). Once in the body, they compete with and displace essential minerals, and interfere with organ system function (Ogabiela *et al*., 2011).

Olayinka-Olagunju *et al*., (2021) explains that fish consumption is increasing across the globe because of its health and nutritional benefits. The increase in the demand for fish may be attributed to human population increase as well as some underlying health issues among human. Besides being nutritional, it serves as an essential source of protein, vitamins, minerals and unsaturated fatty acids (low in cholesterols) (Medeiros *et al*., 2012). Previous studies by the American Heart Association showed that it is important to eat fish at least twice a week to get the quantity of omega-3 fatty acids required for humans per day (El-Moselhy *et al*., 2014). However, due to some health issues that may be associated with heavy metal contamination in fish, many

international monitoring programs have been created to evaluate the nutritional values of fish before consumption (Meche *et al*., 2010; Marriott *et al*., 2020; Tacon *et al*., 2020).

High intakes of heavy metals have damaging effects on human beings and other animals, since there is no good mechanism for their elimination. Metals such as lead, mercury, cadmium and copper are cumulative poisons. These metals cause environmental hazards and are reported to be exceptionally toxic (Wong and Lye, 2008).

Heavy metal ions do not degrade into harmless end products and will be toxic to many life forms due to their toxicity and accumulation in biota (Maiti and Banerjee, 2012).

Remediation, the removal of hazardous contaminants from soil, groundwater, sediment, and surface water, provides an opportunity to reduce pollution and, thereby, reducing pollution-related deaths (Landrigan *et al*., 2018; Santé, 2018).

Environmental remediation efforts (hereafter referred to as remediation projects) in developing countries are often conducted by national governments, sometimes in collaboration with local authorities and NGOs. The most common remedial strategy applied was excavation and safe storage (a source recovery and removal method), where contaminated soil was physically removed and stored in an alternate location, typically off-site (O'Brien *et al*., 2020).

In 2010, illegal mining activities in Zamfara state, Northern Nigeria were reported to have resulted to the death of hundreds of people, mostly children (NNP, 2011). The local methods adopted by the miners in processing gold enhanced the release of substantial amounts of lead dust which was spread across the community. The ingestion, inhalation and dermal contact of lead contaminated soil, water and food crops were responsible for the monumental death of the children (Betts, 2012; Bello *et al*., 2016).

Medecins Sans Frontieres (MSF) in March 2010 discovered an epidemic of Lead poisoning in Zamfara State, Northern Nigeria. US Center for Disease Control (CDC), the World Health Organization (WHO) and the Zamfara State Ministry of Health (ZMoH) investigations confirmed the report with over 10,000 people estimated to have been affected (UNICEF, 2011). The concentration of lead in the soil of Bagega reached 23,000 ppm which resulted in the death of many children (Ajumobi *et al*., 2014) and animals (Tijjani *et al*., 2019).The source was traced to environmental exposure to Lead from the processing of Lead-rich ore mined by artisans in the state for Gold extraction. Grinding of the rocks into fine particles in the mills scattered round the villages resulted in the dispersal of lead dust (Kevin, 2011). These contaminants enter into the human body through inhalation, accidental ingestion of contaminated soil, ingestion of contaminated water and absorption through the skin. There have been more deaths from Lead poisoning in Zamfara, than the whole world combined in the last 40 years, particularly amongst children who are uniquely susceptible to Lead poisoning (Shiloh, 2010).

In addition to the death, there were hundreds of children with high lead contamination well over hospitalization levels, most of which had shown signs of neurological disorder, having displayed occasional bout of mental imbalance and abnormal behavior (Shiloh, 2010; Sola Ogundipe 2010). There was therefore the risk of various levels of brain damage, as the authorities concerned failed to respond with commendable alacrity to the epidemic.

An immediate medical response protocol was developed to provide oral chelation therapy to children zero to five years of age, pregnant women and breast feeding mothers. In order not to compromise the efficacy of the chelation therapy an immediate remediation of the villages were carried out by Zamfara State Ministry of Environment with technical assistance from a USA firm

TerraGraphics Environmental Engineering and an international NGO Blacksmith Institutes (UNICEF, 2011).

Albeit decontamination procedures were instituted in affected areas and where mining activities are still on-going. The possibility of recontamination of the environment or, at least, increased background exposure compared to the non-mining areas could exists (Bartrem *et al*., 2014). This could result in chronic toxicosis due to the gradual accumulation of toxicants over time or subclinical toxicosis in animals that may seem healthy but have derangements that may not be observed by routine physical and clinical examinations (Goyer, 1990; Bischoff *et al*., 2012).

In July 2013, *ex situ* decontamination procedures were carried out on the soil in the residential areas of Bagega using a technique that isolated and buried contaminated soil. This reduced the incidence of acute lead poisoning among humans but there have been cases among food animals (Kazaure, 2018).

A plant with high lead concentration fastens the production of reactive oxygen species (ROS), causing lipid membrane damage that ultimately leads to damage of chlorophyll and photosynthetic processes and suppresses the overall growth of the plant (Najeeb *et al*., 2017). A research revealed that lead is capable of inhibiting the growth of tea plant by reducing biomass and debases the tea quality by changing the quality of its components (Yongsheng *et al*., 2011). Even at low concentrations, lead treatment was found to cause huge instability in ion uptake by plants, which in turn leads to significant metabolic changes in photosynthetic capacity and ultimately in a strong inhibition of plant growth (Najeeb *et al*., 2017).

It has been reported that nearly half of the mean ingestion of lead, cadmium and mercury through food is due to plant origin (fruit, vegetables and cereals). Moreover, some population groups seem to be more exposed, especially vegetarians, since they absorb more frequently ‘tolerable

daily doses'. Food contamination by heavy metals depends both on their mobility in the soil and their bioavailability.

1.2 STATEMENT OF RESEARCH PROBLEM

Bishir (2015) discovered that silicon and lead concentrations were of the highest rate while working on metal contaminated soil of Bagega specifically the ore processing site soil and the mining site soil, of which both miners, ore processers, community dwellers as well as their animals always come in contact with the Lake.

Bagega community has been reported to be polluted by some heavy metals; cleanup was done through soil excavation on the residential area only (Tirima *et al*., 2016), excluding the community lake which has several contacts like runoffs from the ore-processing site, unexcavated site, excavated site and direct activities of the ore miners that of the community dwellers domestically.

The unremediated Bagega Lake is currently not the community source of drinking water because they were provided with boreholes all-round the community after pollution was scenario, but domestic activities like washing of cloths and even body washing of miner is done in the lake as well as fish farming by their fishermen in which the community dwellers feed on as well as plant species around the Lake that animals graze on and even drink directly from the water.

Activities like sluicing (washing of the ore material to separate gold particles from other available metals) that was identified as one of the major causes of the pollution back then was also noticed to be in practice in the Lake.

1.3 JUSTIFICATION

Previous post-remediation assessment in Bagega was exercised in areas like residential environment comparing with either the mining sites or ore-processing areas but little or none on Bagega Lake and its environment which serves array of purposes for the community dwellers predominantly known for their agricultural activities ranging from crop farming to cattle rearing.

Various arrays of activities (irrigation farming around the lake, utilization of water from the Lake for domestic purpose, fish farming and animal rearing) which occurred in the community during the dry season, are usually on this Lake and its environment, dependent therefore metal cumulative state in water, sediment/ soil, plants and fish from Bagega Lake and its environment should be known or investigated.

Post-remediation assessment on Bagega Lake and its environment will bring to limelight situation of the already controlled measure that was adopted during the pollution.

1.4 AIM OF THE STUDY

The aim of the study was to assess cadmium, chromium and lead concentration in soil, plants and water in Bagega Lake as well as the dominant fish after a clean-up exercise was carried out.

1.5 OBJECTIVES

i. To determine the concentration of cadmium, chromium and lead in the water and sediment from Bagega Lake
ii. To determine the concentration of cadmium, chromium and lead in soils of remediated and unremediated lands around Bagega Lake
iii. To assess concentration of cadmium, chromium and lead in plants and fish of Bagega Lake

1.6 HYPOTHESES

i. There is no significant difference in heavy metal concentration in water and sediment from different sections of the Bagega Lake

ii. There is no difference in heavy metal concentration of remediated, unremediated soils and sediment of Bagega Lake

iii. There are no differences in heavy metal concentration in plant species around and fish species in Bagega Lake water with the WHO, (2003) maximum permissible limit.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Heavy Metal Pollution

A heavy metal is any metal or metalloid of environmental concern. The term originated with reference to the harmful effects of cadmium, mercury and lead, all of which are denser than iron. It has since been applied to any other similarly toxic metal, or metalloid such as arsenic, regardless of density. Commonly encountered heavy metals are chromium, cobalt, nickel, copper, zinc, arsenic, selenium, silver, cadmium, antimony, mercury, thallium and lead. More specific definitions of a heavy metal have been proposed; none have obtained widespread acceptance (Rajeswari and Sailaja, 2014).

Heavy metals are primarily found as lithophiles (rock-loving) or chalcophiles (ore-loving). Lithophile heavy metals are mainly f-block elements and the more reactive of the d-block elements. They have a strong affinity for oxygen and mostly exist as relatively low density silicate minerals (Yousif, 2007). Chalcophile heavy metals are mainly the less reactive d-block elements, and period 4–6 p-block metals and metalloids. They are usually found in (insoluble) sulphide minerals. Being denser than the lithophiles, hence sinking lower into the crust at the time of its solidification, the chalcophiles tend to be less abundant than the lithophiles (Yousif, 2007).

The meta-conglomerates form several units with thicknesses reaching 150-200 m, but which die out laterally; they are inter-bedded with feldspathic meta-sandstones. In the western part of the belt, phyllites are more dominant but occur together with some meta-siltstone, meta-sandstone,

acid volcanic as well as serpentinite (meta-ultramafics) emplaced as lenticular to ovoid bodies within the meta-sediments (Buba and Aboyeji, 2015).

Gold occurs in a mineral paragenesis with pyrite, chalcopyrite, galena and minor sphalerite, magnetite and bismuth telluride in a gangue of mainly quartz with some carbonates, sericite, chlorite and tourmaline (Garba, 2000). The gold veins are surrounded by a narrow zone of hydrothermal alteration in which a chlorite-tourmaline-pyrite carbonates association overprints a dominantly sericitic fabric of the hornfels wall rocks (Garba, 2000).

Both natural and anthropogenic activities are responsible for the abundant of heavy metals in the environment (Khan *et al*., 2008; Wilson and Pyatt, 2007). However, anthropogenic activities can effortlessly generate heavy metals in sediment and water that pollute the aquatic environment (Sánchez-Chardi *et al*., 2007).

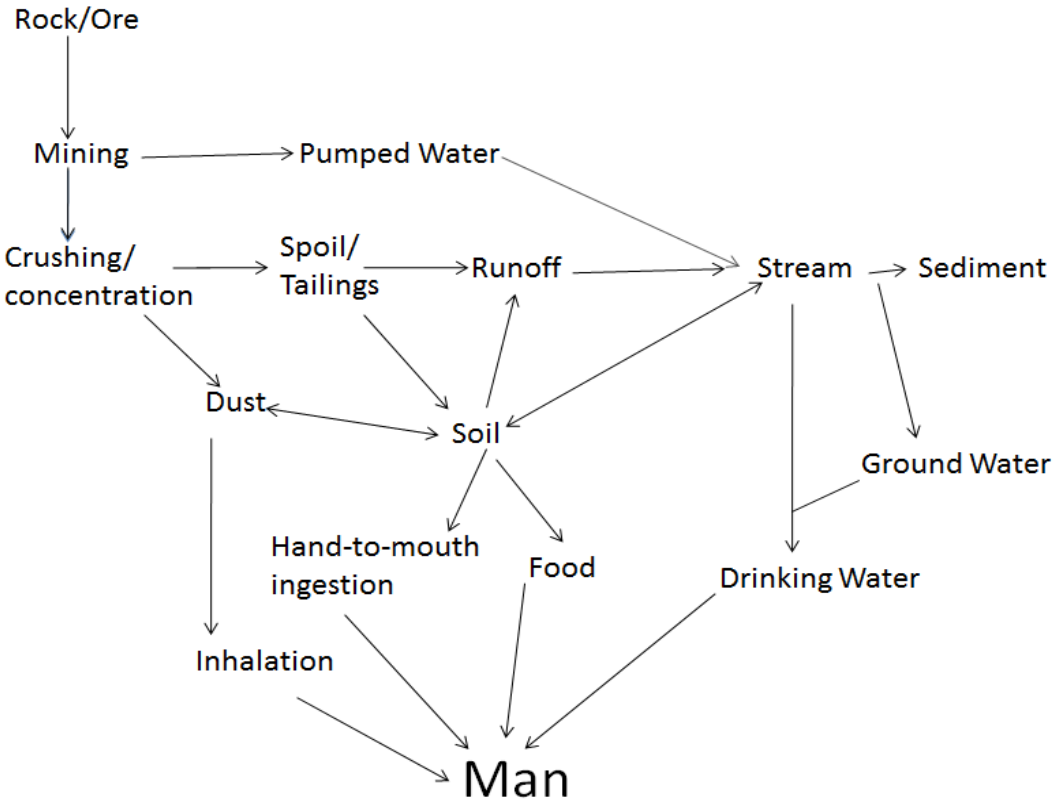
Chromium, arsenic, cadmium, mercury, and lead have the greatest potential to cause harm on account of their extensive use, the toxicity of some of their combined or elemental forms, and their widespread distribution in the environment (Baird and Cann, 2012). Hexavalent chromium, for example, is highly toxic as are mercury vapour and many mercury compounds (Kozin and Hansen, 2013).

Although heavy metals are naturally occurring elements that are found throughout the earth's crust, most environmental contamination and human exposure result from anthropogenic activities such as mining and smelting operations, industrial production and use, and domestic and agricultural use of metals and metal-containing compounds (Shallari *et al*., 1998; Herawati *et al*., 2000; He *et al*., 2005).

2.1.1 Source of heavy metal pollution

The type and abundance of contaminants from mines is directly linked to the geologic characteristics of the deposit being mined and type of host rock, local climatic conditions and the processing methods and chemicals used (Lottermoser, 2011; Plumlee and Morman, 2011). For example, in humid environments acid mine drainage (AMD) is generated by the oxidation of sulphide-bearing minerals in mine wastes exposed to weathering conditions, resulting in low quality effluents characterized by acidic pH and a high level of dissolved metals (Razo *et al*., 2004).

Irrespective of the transport mechanisms, mine-related contaminants will almost inevitably get to populations living in an area through a number of pathways as follow.



Transport to the Environment and Main Human Exposure Pathways for Potentially Toxic Elements in the Study Area (modified from Kelly, 1988)

Plumlee and Morman (2011) have summarized the pathways to include hand-to-mouth ingestion, inhalation and consumption of food grown on contaminated soils as well as drinking contaminated water. Exposure to heavy metals is normally chronic due to food chain transfer however; acute poisoning through ingestion or dermal contact though rare is possible (USDA, 2000).

In artisanal gold mining areas of the world, the indiscriminate use of metals for amalgamation to separate gold from associated minerals has been widely blamed for the introduction of mercury into the environment (Appleton *et al.*, 2001; Yongsheng *et al*., 2011). In drier climates however, the problem is not much about AMD, but the movement of contaminants through fluvial and aeolian processes (Razo *et al*., 2004).

Environmental contamination can also occur through metal corrosion, atmospheric deposition, soil erosion of metal ions and leaching of heavy metals, sediment re-suspension and metal evaporation from water resources to soil and ground water (Nriagu, 1989).

2.2 Heavy Metals of Environmental Concern

A lead contaminated site from artisanal gold mining in Nigeria was first reported in Zamfara state in 2010 (ACCLPP, 2012) while the subsequent one was reported in Niger State in 2013 (Emeka, 2015). The lead contaminated site was responsible for the monumental lead poisoning of children and animals reported in these states (Emeka, 2015). Artisanal gold mining is a livelihood strategy adopted primarily in rural areas by using simple tools and equipment (Veiga *et al*., 2006). It is sometimes called “informal sector”, which is outside the legal and regulatory framework (Azubike, 2011).

Artisanal gold mining was viewed negatively by governments and environmentalists when not formalized because of its potential for environmental damage, social disruption and conflicts (Opanfunso, 2010). Most artisanal miners work in difficult and often very hazardous conditions

in the absence of the required safe mining regulations to safeguard the operations (Veiga *et al*., 2006). This is because toxic materials can be released into the environment, posing large health risks to the miners, their families and surrounding communities (Azubike, 2011). This was exactly what happened in Zamfara and Niger States. The gold mining operations in these areas are particularly dangerous, as they often use mercury to extract gold from ores (Organization, 2014). Despite serious dangers posed by this activity, artisanal gold mining operations continue to spread due to rise in the demand for gold and unattractive nature of other means of livelihoods such as farming in the rural areas where the mineral is substantially available (WHO, 2014).

2.2.1 Lead

According to Needleman (2004), Lead is a metal; it is present in the 4^{th} group and period 6^{th} of the periodic table, with atomic number 82, atomic mass 207.2 and density11.4 gcm^{-3}. It has a very low melting point 327.40 ^{o}C and boiling point 17250 ^{o}C, it combined with Sulphur to give PbS, $PbSO_4$ and Oxygen to give $PbCO_3$ then ranges from 10 to 30 mg/kg in the earth's crust.

Lead is used as solders, bearings, cable covers, ammunition, plumbing, pigments and caulking. Ionic Lead, Pb(II) , lead oxides and hydroxides and lead-metal oxyanion complexes are the general forms of Pb that are released into the soil, ground water and surface waters. The most stable forms of lead are Pb (II) and lead hydroxyl complexes.

Lead (II) is the most common and reactives form of Pb, forming mononuclear and polynuclear oxides and hydroxides. Lead hydroxides, lead sulphide is the most stable solid form with in the soil matrix and forms under reducing conditions, the concentration of sulphide increased.

Lead (II) compounds are predominantly ionic forms i.e. Pb^{2+}, SO_4 while some such as PbO_2 are strong oxidants.

Lead forms several basic salts such as $Pb(OH)_2$, $2PbCO_3$ which is most widely used white paints pigment and the source of considerable chronic lead poisoning to children who ate peeling white paint.

Lead dioxide and lead sulphate are participants in the reversible reaction that occurs during the charge and discharge of lead storage battery. Today, the largest source of lead poisoning in children comes from dust and chips from deteriorating lead paint on interior surfaces (Lanphear, 1998).

Lead is the commonest of the heavy metals, accounting for 13 mg/kg of Earth's crust and is dispersed in small amounts into the environment by natural processes **(**WHO**,** 2014**)**. Lead exists in the Earth's crust, mainly as lead sulphide, and occurs naturally in the environment through a variety of mechanisms including volcanic emissions, geochemical weathering, sea spray emissions, and remobilization of historic sources such as lead in soil, sediment, and water from mining areas (Plumlee *et al*, 2013). Lead-zinc occurrence/mineralization in Nigeria is often associated with minor to significant amounts of copper and gold (MMSD, 2010).

Exposure to lead occurs mainly through inhalation of lead-contaminated dust particles or aerosols, and ingestion of lead-contaminated food, water, and paints (ATSDR, 1992; ATSDR, 1999). Adults absorb 35 to 50% of lead through drinking water and the absorption rate for children may be greater than 50%. Lead absorption is influenced by factors such as age and physiological status. In the human body, the greatest percentage of lead is taken into the kidney, followed by the liver and the other soft tissues such as heart and brain, however, the lead in the skeleton represents the major body fraction (Flora *et al*., 2006). The nervous system is the most vulnerable target of lead poisoning. Headache, poor attention spam, irritability, loss of memory

and dullness are the early symptoms of the effects of lead exposure on the central nervous system (ATSDR, 1999).

Since the late 1970's, lead exposure has decreased significantly as a result of multiple efforts including the elimination of lead in gasoline, and the reduction of lead levels in residential paints, food and drink cans, and plumbing systems (ATSDR, 1992; ATSDR, 1999). Despite the progress in these programs, human exposure to lead remains a serious health problem (Pirkle *et al*., 1998). Lead is the most systemic toxicant that affects several organs in the body including the kidneys, liver, central nervous system, hematopoetic system, endocrine system, and reproductive system (ATSDR, 1999).

Human evidence corroborates animal findings (Tchounwou *et al*., 2012), linking prenatal exposure to lead with reduced birth weight and preterm delivery and with neuro-developmental abnormalities in offspring (Andrews *et al*., 1994).

World Health Organization (2013) estimated that lead poisoning resulted in 143,000 deaths, and contributed to 600,000 new cases of children with intellectual disabilities", each year.

2.2.2 Chromium

Chromium (III) oxides are only slightly water soluble; therefore concentrations in natural waters are limited. Cr^{3+} ions are rarely present at pH values over 5, because hydrated chromium oxide ($Cr(OH)_3$) is hardly water soluble. Chromium (VI) compounds are stable under aerobic conditions, but are reduced to chromium (III) compounds under anaerobic conditions. The reverse process is another possibility in an oxidizing environment. Chromium is largely bound to floating particles in water. Lime or phosphate in soils may further decrease chromium susceptibility. Air-dried soil generally contains 2-100 ppm of chromium. Chromium solubility in soil water is lower than that of other potentially toxic metals. This explains the relatively low

plant uptake. Under normal conditions plants contain approximately 0.02-1 ppm chromium (dry mass), although values may increase to 14 ppm. Chromium (VI) compounds are toxic at low concentrations for both plants and animals. The mechanism of toxicity is pH dependent. These compounds are more mobile in soils than chromium (III) compounds, but are usually reduced to chromium (III) compounds within a short period of time, reducing mobility. Soluble chromates are converted to insoluble chromium (III) salts and consequently, availability for plants decreases. This mechanism protects the food chain from high amounts of chromium. Chromate mobility in soils depends on both soil pH and soil sorption capacity, and on temperature. The guideline for chromium in agricultural soils is approximately 100 ppm. Chromium (III) toxicity is unlikely, at least when it is taken up through food and drinking water. It may even improve health, and cure neuropathy and encephalopathy (Lenntech, 2013). Chromium (VI) compounds are toxics and known human carcinogens, breathing high levels can cause irritation to the lining of the nose; nose ulcers; running nose; and breathing problems, such as asthma, cough, shortness of breath, or wheezing. Long term exposure can cause damage to liver, kidney, circulatory and nerve disorders, as well as skin irritation (Lokeshappa *et al.*, 2012).

Chromium does not occur freely in nature. The main chromium mineral is chromite. Chromium compounds can be found in waters only in trace amounts. The element and its compounds can be discharged in surface water through various industries. It is applied in metal surface refinery and alloys. It may be polished but does not oxidize when it comes in contact with air (Lenntech, 2013). The human body contains approximately 0.03 ppm of chromium. Daily intake strongly depends upon feed levels, and is usually approximately 15-200 μg, but may be as high as 1 mg. Chromium uptake is 0.5-1%, in other words very small. The placenta is the organ with the highest chromium amounts. Trivalent chromium is an essential trace element for humans.

Together with insulin it removes glucose from blood, and it also plays a vital role in fat metabolism. Chromium deficits may enhance diabetes symptoms, and are very rare. Chromium is a dietary requirement for a number of organisms. This however only applies to trivalent chromium (Lenntech, 2013). Chromium water pollution is not regarded one of the main and most severe environmental problems, although discharging chromium polluted untreated wastewater in rivers has caused environmental disasters in the past.

2.2.3 Cadmium (Cd)

Cadmium can mainly be found in the earth's crust. It always occurs in combination with zinc. Cadmium also consists in the industries as an inevitable by-product of zinc, lead and copper extraction. After being applied it enters the environment mainly through the ground, because it is found in manures and pesticides. Cadmium occurs naturally in soils as a result of the weathering of parent rocks. It has a relatively low crustal abundance. Anthropogenic sources are much more significant than natural emissions and account for its ubiquitous presence in soil (Alloway, 2013). Cadmium is a by-product of mining and smelting of lead and zinc, and is number 7 on the ATSDR's "Top 20 list. Cadmium and solutions of its compounds are toxic. Environment agency gives the soil guideline values (SVGs) for Cadmium to be 10mg/kg for residential areas and 230mg/kg for commercial areas (ENT. AGENCY, 2009). Human uptake of cadmium takes place mainly through food. Foodstuffs that are rich in cadmium can greatly increase the cadmium concentration in human bodies. Examples are liver, mushrooms, shellfish, mussels, cocoa powder and dried seaweed.

The United States Environmental Protection Agency (USEPA, 2008) Maximum Permissible Limits (MPL) for Cadmium in soil is 3ppm (Mosana *et al*, 2011). The levels of Cadmium recorded in Udiba *et al*. (2012) study were below the soil guideline values and the USEPA

standards. Cadmium accumulates in the kidney and liver causing kidney dysfunction and liver failure, interferes with the metabolism of Calcium and Phosphorus, causing painful bone diseases, in addition to being a teratogenic and carcinogenic agent. Eating food or drinking water with high Cadmium concentration irritates the stomach causing vomiting and diarrhea. Chronic exposure can also cause irreversible damage to the lungs (Ogabiela *et al*., 2011). Other health effects that can be caused by cadmium are: Reproductive failure and possibly even infertility, Damage to the central nervous system, Damage to the immune system, Psychological disorders, Possibly DNA damage or cancer development(Lenntech, 2013).

2.2.4 Mercury (Hg)

Mercury is a naturally occurring metal which has several forms. The most common one, methyl mercury, is produced mainly by microscopic organisms in the water and soil. More mercury in the environment can increase the amounts of methyl mercury that these small organisms make. Metallic mercury is used to produce chlorine gas and caustic soda, and is also used in thermometers, dental fillings, and batteries. Mercury salts are sometimes used in skin lightening creams and as antiseptic creams and ointments (Joint and Unit, 2010). Exposure to mercury occurs from breathing contaminated air, ingesting contaminated water and food, and having dental and medical treatments. Mercury, at high levels, may damage the brain, kidneys, and developing fetus. Inorganic mercury (metallic mercury and inorganic mercury compounds) enters the air from mining ore deposits, burning coal and waste, and from manufacturing plants. It enters the water or soil from natural deposits, disposal of wastes, and volcanic activity. The nervous system is very sensitive to all forms of mercury. Methyl mercury and metallic mercury vapors are more harmful than other forms, because more mercury in these forms reaches the brain (Joint and Unit, 2010). Exposure to high levels of metallic, inorganic, or organic mercury

can permanently damage the brain, kidneys, and developing fetus. Effects on brain functioning may result in irritability, shyness, tremors, changes in vision or hearing, and memory problems. Short-term exposure to high levels of metallic mercury vapors may cause effects including lung damage, nausea, vomiting, diarrhea, increases in blood pressure or heart rate, skin rashes, and eye irritation. Very young children are more sensitive to mercury than adults (Joint and Unit, 2010).

The chemical mercury is used in the extraction of gold from ore. It is very toxic to humans and animals. When the chemical enters the body, it suppresses the central nervous system causing respiratory failure and death. The mercury used in gold mining can get into the soil, and through the process of erosion can make its way into lakes and streams. This in turn can pollute local water supplies (Kendall, 2013).

2.3 Heavy Metal Toxicity in Zamfara-State

In March 2010, an unusually high number of deaths, primarily among children under age 5 in Bukkuyum and Anka Local Government Areas (LGAs) of Zamfara State were reported by Médecins sans Frontières (MSF, 2012) to state health authorities.

Further study of blood samples taken by MSF revealed that the increased mortality was the result of acute lead poisoning, determined to be caused by massive environmental contamination from artisanal mining and processing of gold found in lead-rich ore.

Gold ore, sourced from mines throughout Zamfara State, is crushed by hand to gravel consistency using scrap hammers or mortars and pestles, ground to a fine powder in modified flour-mills, sluiced by water to separate heavy particles, amalgamated with mercury, and burned over open flame to obtain a low grade “sponge” gold that is sold to local traders for eventual refining for Dubai or Chinese markets. Grinding produces large quantities of dust, which settle

on soils and surfaces. Sluicing results in water source contamination and large piles of ore tailings. Because of religious and cultural practices include sequestration of married women, ore crushing, washing, and gold recovery were undertaken within the homes "residential compounds" to utilize the women's labor. During the rapid increase in mining activities, a vein of ore exceeding 10% lead (Pb) was processed, resulting in severe residential exposures.

The grinding of the ore into fine particles resulted in extensive dispersal of lead dust in the villages concerned, including within family compounds.

Ingestion and inhalation of the fine lead particles was determined to be the major reason for high blood lead levels in victims' bodies. Blood lead levels (BLLs) were "unprecedented" for human beings, according to the CDC.

Following the identification of the mass acute lead poisoning situation in Zamfara State, an immediate, two-pronged response approach was developed, consisting of a medical component and an environmental component.

Medical treatment led by MSF and in collaboration with the World Health Organization (WHO) includes use of chelating agents to reduce blood lead levels. The Zamfara State Government is leading environmental remediation efforts, with technical advice provided by the Blacksmith Institute and its implementing partner, TerraGraphics Environmental Engineering.

Initial remediation of two villages (Dareta and Yargalma) was funded by the State Government.

Phase two of remediation of five additional villages is funded under the auspices of UNICEF.

The environmental remediation process involves removal of contaminated soil from home compounds and village common areas where processing has taken place, followed by burial in landfills.

It is essential that medical treatment and environmental remediation are carefully coordinated: crucial extended care (chelation therapy) cannot be provided for children who come from polluted villages, since villages must be remediated for their safe return and continued treatment.

Meanwhile, several advisory and coordination bodies were established by the Federal and State authorities to address the lead poisoning crisis, namely the Inter-Ministerial Committee, created by the President and chaired by the Minister of Mines and Steel Development; the Inter-Ministerial Task Force, established and chaired by the Federal Ministry of Health and the Zamfara State Rapid Response Team inaugurated and chaired by the State Commissioner of Health following approval by the State Governor.

At the time of this mission, only two villages had been remediated, and the list of villages suspected to be contaminated continued to grow. Efforts to temporarily settle children in "clean" villages that are not their own have had limited success.

The Joint UNEP/OCHA Environment Unit (JEU) is the UN mechanism that mobilizes and coordinates international assistance to countries affected by environmental emergencies and natural disasters with significant environmental impact. It is a 16 year-old partnership between UNEP and OCHA, combining the technical expertise of UNEP with the rapid humanitarian response and coordination mechanisms of OCHA. It serves as the UN mechanism to respond to environmental emergencies, which can be defined as a sudden onset disaster or accident resulting from natural, technological or human-induced factors, or a combination of these, that cause or threaten to cause severe environmental damage as well as harm to human health and/or livelihoods. The Unit is integrated into the Emergency Services Branch of OCHA (Joint and Unit, 2010).

According to Joint UNEP/OCHA Environment Unit, 2010 contaminated water is less of a concern than contaminated soil, due to the levels and extent of contamination, meaning that priority should be given to soil in remediation efforts.

Contamination is coming from 'above', meaning that lead has been introduced into the wells from the top during processing of ore and from run-off during the rainy season.

Lead pollution remains confined to areas (wells and ponds) where processing has taken place, and has not spread through the groundwater aquifer.

High concentrations of lead (up to more than 1,000 μg/l – 10 times higher than the exposure limit suggested by FAO for livestock) were often found in ponds, rivers and lakes sampled by the mission. It was not in the mission's Terms of Reference to assess the risk of consuming animal products. However, as it is common practice to use most or the entire animal after it has been slaughtered, including using bones for soup, it is reasonable to suspect that the consumption of such meat might also be an important exposure route for humans.

Further study of food pathways (livestock, crops) should be undertaken by Federal and State experts, with support from international partners, as livestock was seen to be drinking from contaminated ponds, and crops were found to be growing in contaminated soil near affected wells.

Until complete remediation of polluted villages takes place, and as long as ore processing continues in sensitive areas – home compounds and villages, wells and ponds used for drinking water by humans and livestock – there remains an alarming, continuing health risk.

2.4 Effect of Toxic Heavy Metals to Living Things

The main threats to human health from heavy metals are associated with exposure to lead, cadmium, mercury, and arsenic. These metals have been extensively studied and their effects on human health regularly reviewed by international bodies such as the WHO.

Heavy metals have been used by humans for thousands of years. Although several adverse health effects of heavy metals have been known for a long period, exposure to heavy metals continues, and is even increasing in some parts of the world, in particular in less developed countries, though emissions have declined in most developed countries over past several years.

In biological systems, heavy metals have been reported to affect cellular organelles and components such as cell membrane, mitochondrial, lysosome, endoplasmic reticulum, nuclei, and some enzymes involved in metabolism, detoxification, and damage repair (Wang and Shi, 2001).

Metal ions have been found to interact with cell components such as DNA and nuclear proteins, causing DNA damage and conformational changes that may lead to cell cycle modulation, carcinogenesis or apoptosis (Wang and Shi, 2001; Beyersmann and Hartwig, 2008).

Several studies have demonstrated that reactive oxygen species (ROS) production and oxidative stress play a key role in the toxicity and carcinogenicity of metals such as arsenic (Tchounwou *et al*., 2004), cadmium (Tchounwou *et al*., 2001), chromium (Patlolla *et al*., 2009), lead (Tchounwou *et al*., 2004; Brown *et al*., 2008) and mercury (Sutton *et al*., 2002; Sutton and Tchounwou, 2007) Because of their high degree of toxicity, these five elements rank among the priority metals that are of great public health significance. They are all systemic toxicants that are known to induce multiple organ damage, even at lower levels of exposure. According to the United States Environmental Protection Agency (U.S. EPA), and the International Agency for

Research on Cancer (IARC), these metals are also classified as either “known” or “probable” human carcinogens based on epidemiological and experimental studies showing an association between exposure and cancer incidence in humans and animals.

Heavy metal-induced toxicity and carcinogenicity involves many mechanistic aspects, some of which are not clearly elucidated or understood. However, each metal is known to have unique features and physicochemical properties that confer to its specific toxicological mechanisms of action. This review provides an analysis of the environmental occurrence, production and use, potential for human exposure, and molecular mechanisms of toxicity, genotoxicity and carcinogenicity of arsenic, cadmium, chromium, lead, and mercury.

Cadmium is biopersistent and once absorbed remains resident for many years. High exposure can lead to obstructive lung diseases and has been linked to lung cancer. Cadmium may also cause bone defects in humans and animals while long term exposure is associated with renal dysfunction.

Low exposure to chromium can irritate the skin and cause ulceration while long term exposure can cause kidney and liver damage as well as damage to circulatory and nerve tissues.

Aluminium toxicity is associated with the development of bone disorders including fractures, osteopenia and osteomalacia.

Monomethylmercury causes damage to the brain and the central nervous system while fetal and post-natal exposure has given rise to abortion, congenital malformation and development changes in young children.

Exposure to high levels of arsenic can cause death. All types of arsenic exposure can cause kidney and liver damage and in the most severe exposure there is erythrocyte hemolysis.

High doses of copper can cause anemia, liver and kidney damage, and stomach and intestinal irritation.

Excessive amounts of nickel can be mildly toxic. Long term exposure can cause decreased body weight, heart and liver damage and skin irritation.

Manganese is known to block calcium channels and with chronic exposure results in CNS dopamine depletion (Mulvihill and Pritchard 2010).

2.5 Bagega Remediation

2.5.1 The concept of remediation

Remediation is the removal of hazardous contaminants from soil, groundwater, sediment and surface water, provides an opportunity to reduce pollution and thereby, pollution-related deaths (Landrigan *et al*., 2018; Santé, 2018). Although remedial efforts have occurred in developing communities, such as the clean-up of lead contamination in Nigeria in 2010, most efforts have been confined to developed communities due to the difficulty in overcoming the above mentioned barriers (e.g., social, economic, etc.).

According to O'Brien *et al*. (2020) remedial strategies have four main categories which are excavation, encapsulation, bioremediation and informational campaign. The most common remedial strategy applied was excavation and safe, where contaminated soil was physically removed and stored in an alternate location, typically off-site but disposal location selection is critical to the success of the projects that utilize excavation and safe storage. Encapsulation on the other when soil is surrounded by impermeable barriers in situ, was the only method that applied isolation and containment as a remedial strategy but has a shortcoming of event where the containment fails, locating the hazardous waste facility away from people reduces the risk of contaminant exposure. However, a hazardous waste disposal facility may not be available. For

example, during the remediation of mercury-contaminated soils in Kyrgyzstan, contaminated soil was stored at a nearby tailings facility (Earth, 2017). A source and plume treatment option is known as bioremediation or in-situ chemical oxidation. Many projects implemented institutional controls alongside other remedial strategies. Institutional controls included dissemination of information through mass media outlets, informational pamphlets or children's books, and educational programs and workshops created for communities and schools. Institutional controls rely on the adoption and compliance of local communities to be effective, necessitating adequate stakeholder participation efforts (US EPA, 2012). For example, during the Nigeria Lead Poisoning Crisis of Zamfara-State, two institutional controls were implemented (Tirima *et al*., 2016).

2.5.2 The actual remediation activity

The Phase I cleanup work was conducted by the ZMoE (Zamfara-state ministry of Environment) with the technical guidance and assistance of TG. The work was funded by a combination of Zamfara State, TG and BI (Blacksmith Institute). The cleanup continued until work was suspended due to the onset of the rainy season in mid-July. As a result of Phase 1 activities, MSF was able to provide chelation treatment for nearly 1000 children commencing in mid-June and continuing through the rainy season (Blacksmith Institute, 2014). At the end of the remediation exercise a total of 282 residential compounds, 107 exterior areas and 23 processing ponds have been remediated in the Bagega and other villages around it. A large landfill has been constructed and prepared to accept contaminated soils and industrial waste; and residential areas, common area village exteriors, brick-making ponds and the Bagega Industrial Site have been characterized (Girigisu *et al*., 2014). The response action undertaken in Bagega Lead Remediation Project by Blacksmith Institute was based on this successful US model of health

intervention, emergency removal, advocacy, clinical treatment, and follow-up (Galadima and Garba, 2012). All of the measures aim to reduce exposure to the population by reducing the intake of lead along the main exposure routes. A similar pathways model was utilized in Zamfara, identifying and removing soil/dust pathways to mitigate lead exposures (Blacksmith Institute 2014). The primary exposure routes for children and adults identified in the village are (Girigisu *et al*., 2014).

1) Incidental ingestion of contaminated soils and dusts

2) Consumption of food contaminated by soil and dust sources

3) Ingestion of contaminated water

4) Inhalation of contaminated dusts

Based on the review conducted, the artisanal gold mining exercises in Bagega and environs are likely to have immediate and long term health risks to the exposed populations if left unchecked. The hazard is not limited to the miners only, due to unprofessional practice of the miners, the villages and its visitors may be equally at risk.

Preliminary characterization in Bagega was suspended from March 2011 until February 2013, due to lack of funding and security concerns related to the Nigerian presidential election. MSF initiated blood lead screening and chelation therapy as the remediation program progressed (Greig *et al*., 2014).

However, in May 2011, MSF noted increasing BLLs in a small number of individual chelation patients and suspected lead poisoning in the deaths of two children in remediated villages. Follow-up environmental investigations by TG and ZMOE revealed resumption of mineral processing and recontamination in isolated locations in two villages. Out of concern for recontamination issues, MSF and TIFO initiated an advocacy campaign to persuade the Nigerian

Federal, State, and Local governments to undertake Phase III remediation of Bagega and establish programmes to sustain the remedy and promote safer mining.

A three-part proposal advocating;

a) MSF establishes an outpatient chelation clinic for the children of Bagega

b) Remediation of Bagega by the Nigerian Federal Government under TIFO guidance and certification

c) Development of a safer mining program in Zamfara

The proposal was presented to representatives of both Zamfara State and Federal Ministries of Health, Environment, Mining and Solid Minerals, and LGA officials at a conference sponsored by MSF and TIFO, originally scheduled for January 2012 in Abuja, but delayed until May 2012 due to civil unrest in the country (MSF, 2012). Numerous delays in the release of cleanup funds postponed the start of Phase III remediation. Significant media attention and pressure came from international and Nigerian nongovernmental organizations (NGOs) (Murdock, 2012). MSF and TIFO maintained permanent staff in Nigeria to conduct negotiations regarding project roles and responsibilities, and to secure the release of funds. In late January 2013, Nigerian President Goodluck Jonathan released $3.2 million to FMOE to undertake the Bagega cleanup, with the bulk of the work to be accomplished by the newly established Zamfara Environmental Sanitation Agency (ZESA), LGA, and local village labor. TIFO provided technical guidance and assistance. Upon certification of completion by TIFO, MSF opened clinics and began BLL testing and treatment. In addition, the Nigerian government allocated $1.1 million to initiate a safer mining program (Abatu, 2014).

Bagega remediation was the phase III which involved (February–July 2013), an estimated population of 7,323 and one base of operations. Remediation within each village was carried out in three steps: Characterization, excavation of contaminated media then replacement with clean soils or concrete and waste disposal.

The social and technical context of the cleanup required adaptability and remedial protocols were re-evaluated and modified based on experience during all three phases. Examples include developing health messaging for males and females as well as community engagement efforts; employing village tailors in the production, repair, and laundering of work uniforms; and having excavation hoes manufactured from scrap metal by local blacksmiths.

2.5.3 Characterization

Common areas and residential compounds were assessed for lead and other metals *in situ* by modifying BHSS protocols for hand-held X-ray fluorescence (XRF) and by laboratory XRF of bulk and sieved samples of surface soils, dusts, and mining wastes (Bartrem *et al*., 2014). Innov-X Alpha 4000 (Olympus), Innov-X (Olympus) Delta 4000, Innov-X (Olympus) DS 4000, and Niton XL3 (Thermo Fisher Scientific Inc.) models were used. A subset of soil samples was sent to four U.S. laboratories (U.S. EPA Region X, U.S. Geological Survey, University of Idaho Analytical Laboratory Services and Anatek Laboratories, Moscow, ID) for confirmatory analyses by inductively coupled mass spectrometry. Sharia traditions were amended by the local emirate, granting special permission to male staff and village workers to enter the compounds. Hand-drawn maps of homes and common areas included key features and XRF readings. Maps were modified to delineate areas requiring excavation, clean soil and concrete placement, and materials to be cleaned or replaced. Every residence and common area in all villages was sampled. Sample locations focused on the areas identified by the residents, with the objective of

identifying locations requiring removal. Typically, 30–150 XRF readings were obtained within a single compound or common area. Sample-site selection was biased to avoiding false negatives (i.e., falsely identifying areas as not requiring removal).

2.5.4 Excavation and replacement

Before compound remediation, residents were required to remove, clean, and store utensils, bedding, and clothing. During Phase I, sleeping mats and carpets were collected, destroyed, and replaced. Areas with surface soil lead concentrations > 1,000 mg/kg were excavated to 5 cm depth. The exposed surface was retested by XRF and excavation continued until criteria (≤ 400 mg/kg Pb) were met (U.S. EPA, 2008). Unexcavated areas with soil concentrations > 400 mg/kg and < 1,000 mg/kg were capped with ≥ 8 cm of clean soil obtained from landfill or borrow area excavations. Depending on drainage considerations and clean soil availability, unexcavated soils with ≤ 400 mg/kg Pb were covered with clean soil at the discretion of the project manager. All clean soils were confirmed ≤ 25 mg/kg lead by XRF. No delineation of the clean/contaminated soil interface was provided because foot and animal traffic quickly compacted the surface. Local agricultural hoes were used to scrape the surface backwards (to prevent recontamination) from the walls inward, starting at the rear of each compound and ending at the main entrance. If needed, interior compound walls were brushed to remove contaminated dust before excavation. Contaminated cement floors were capped with new concrete. Excavated soils were shoveled into grain sacks, removed by wheelbarrow, and trucked to landfills by village laborers. Heavy equipment was leased from foreign mining companies operating in the region to construct the waste disposal facilities and clean soil sources, and to excavate public areas. Landfill and health and safety protocols are described below. In Phases I and II, most exterior removals were done by hand labor due to stability concerns for the mud walls surrounding the compounds and a lack

of suitable mechanized equipment. In Phase III, the government obtained small skid-steer loaders that could safely maneuver the narrow streets, facilitating exterior area excavations and waste disposal. Both heavy equipment and hand labor were used to clean several contaminated human-made village ponds. By long-standing practice, village residents had constructed ponds to provide water for livestock and for clay to make bricks for residential compounds in the dry season. These ponds had been exploited for ore sluicing/amalgamation and were severely contaminated with lead and mercury. Bricks produced from the contaminated muck often had lead concentrations exceeding 1%. All bricks, mortar, and plaster were tested by XRF. Most contaminated bricks were identified before being used and were purchased by the ZMoE from the home owner and disposed of in landfills. A small number of contaminated bricks and clay plaster that had been incorporated in homes were capped or removed. The ponds were excavated when completely dry in late February 2011 and April 2013, and were closed or lined with clean soil. Clean soil was delivered to the villages for brick making and other construction purposes. Phase III included remediation of a large mining encampment, the Industrial Area, adjacent to the Bagega reservoir. More than 1,000 migrant miners had used several dozen crushing/grinding operations that sluiced ore in the regional water supply reservoir. Several thousand tons of highly contaminated tailings were removed from the Industrial Area. Much of this waste material, which regularly exceeded 10% lead, was relocated to area *dabas* (mining sites located remote from the villages) for reprocessing to recover additional gold. The reservoir, which was also highly contaminated, was drained and dredged.

2.5.5 Disposal

Contaminated soil and mine wastes not designated for reprocessing were disposed of in a series of constructed landfills outside each village. Excavated soil from the landfills was used for clean

cover material; fill for ponds, and repair of village roads. Landfills were cited in consultation with ZMoE and village elders familiar with seasonal groundwater levels, water holding capacity, and the structural characteristics of local soils. Landfills were typically 10 m wide and 5 m deep, and extended 30 to > 50 m in length. Those landfills containing contaminated soil < 1% lead were bottom-lined with compacted clay and permanently closed with a 1-m compacted clay cap. Phase III landfills accepting highly contaminated wastes from the Industrial Area were additionally bottom-lined with a polyvinyl chloride (PVC) liner of undetermined thickness purchased and provided by the FMoE. The landfills were delineated by global positioning system (GPS) and closed with permanent monuments dedicated to the children who died in the epidemic (Tirima *et al*., 2016).

2.6 Post-Remediation

The fact remains that unless the homes are fully decontaminated and the Lead removed from the environment, the risk of continued poisoning and death remains (Gale, 2006). Complete resolution of the situation also demands sustained changes to mining practices to prevent further contamination (Sertx, 2011).

Lead was detected according to the order below; grinding mills > drinking water points > market place> residential compounds (Udiba *et al*., 2012). The concentration ranged from 81.65 - 684.27mg/kg. There was a significant reduction in soil Lead levels ($p< 0.05$) compared to the pre-remediation levels reported (Joint and Unit, 2010; Organization, 2016). The emergency cleanup therefore had a positive impact on the environment with over 95% reduction in soil Lead levels achieved.

Udiba *et al*. (2012) also noted that two out of five of the residential compounds studied recorded Lead levels above 400mg/kg and will therefore be misleading to conclude that all the residential

compounds are save. Two out of three soils around wells examined exceeded the US-EPA guidelines of 400mg/kg. This could be attributed to the fact that most of the processing are carried out in compounds around water sources and may not have been properly cleaned up. Residents of compounds with high soil Lead levels are exposed to serious health risk particularly young children who spend most of their time in the contaminated compounds and get infected chronically through their normal hand to mouth behavior, as they play in the dust (Joint and Unit, 2010). Such residential compounds may not have been properly cleaned up or further processing activities are still being carried out even after the cleanup exercise.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

Bagega Community is located in Anka Local Government Area of Zamfara State, which is one of the seven states that form the Northwest geopolitical zone of Nigeria (Barkan, 2007). Bagega Community is located between Longitude 5.999E - 6^{o}.04IE and Latitude 11^{o}.873N - 11^{o}.861N (Fig 3.1).

Bagega is a community with a settlement of over 5,000 people and a district among the eleven districts in Anka Local Government Area of Zamfara State.

Agriculture is the main occupation of the people in the study area until recent time when artisanal gold mining becomes important socio-economic activity of the people due to rise in worldwide gold prices (Joint and Unit, 2010). The major agricultural produce includes carrot, sweet potatoes, millet, guinea corn, maize, rice, groundnut, cotton, vegetables, tobacco and beans.

Anka is a Local Government Area in Zamfara State, Nigeria. It lies between 12°06′30″N 5°56′00″E, with area of 2,746 km² and a population of 142,280 according to 2006 census (Buba and Aboyeji, 2015).

The climate of Anka is warm tropical with temperature rising up to 38^{o}C between March and May. Rainy season starts in late May to September while the dry season known as harmattan lasts from December to February. Two major soil types, ferruginous tropical soils and lithosols, dominate the local government (Udiba *et al*., 2012).

The geology of Anka is characterized by the Anka schist belt that hosts the lead mineralization, and the lead-copper-silver-gold (Pb-Cu-Ag-Au) poly-metallic association (MMSD, 2010). Lead (Pb) mineralization in Zamfara State occurs in veins and as stringers in wall rocks, in a variety of rocks like quartz-schists, and quartzitic-phyllitic schists within the N-S trending Anka schist belt.

According to Uriah *et al*. (2013) Anka mining district lies within the Anka Schist Belt composed of meta-conglomerates, meta-sandstones, phyllites inter-layered with acid volcanic rocks (rhyolite-dacite) (Holt, 1983).

Gold mineralization in the Anka Schist belt occurs in association with lead-zinc-copper sulfide mineralization in the form of quartz-sulfide veins of about 1.5 m wide in places and stockworks hosted by the country rock (phyllites) (Garba and Akande, 1992).

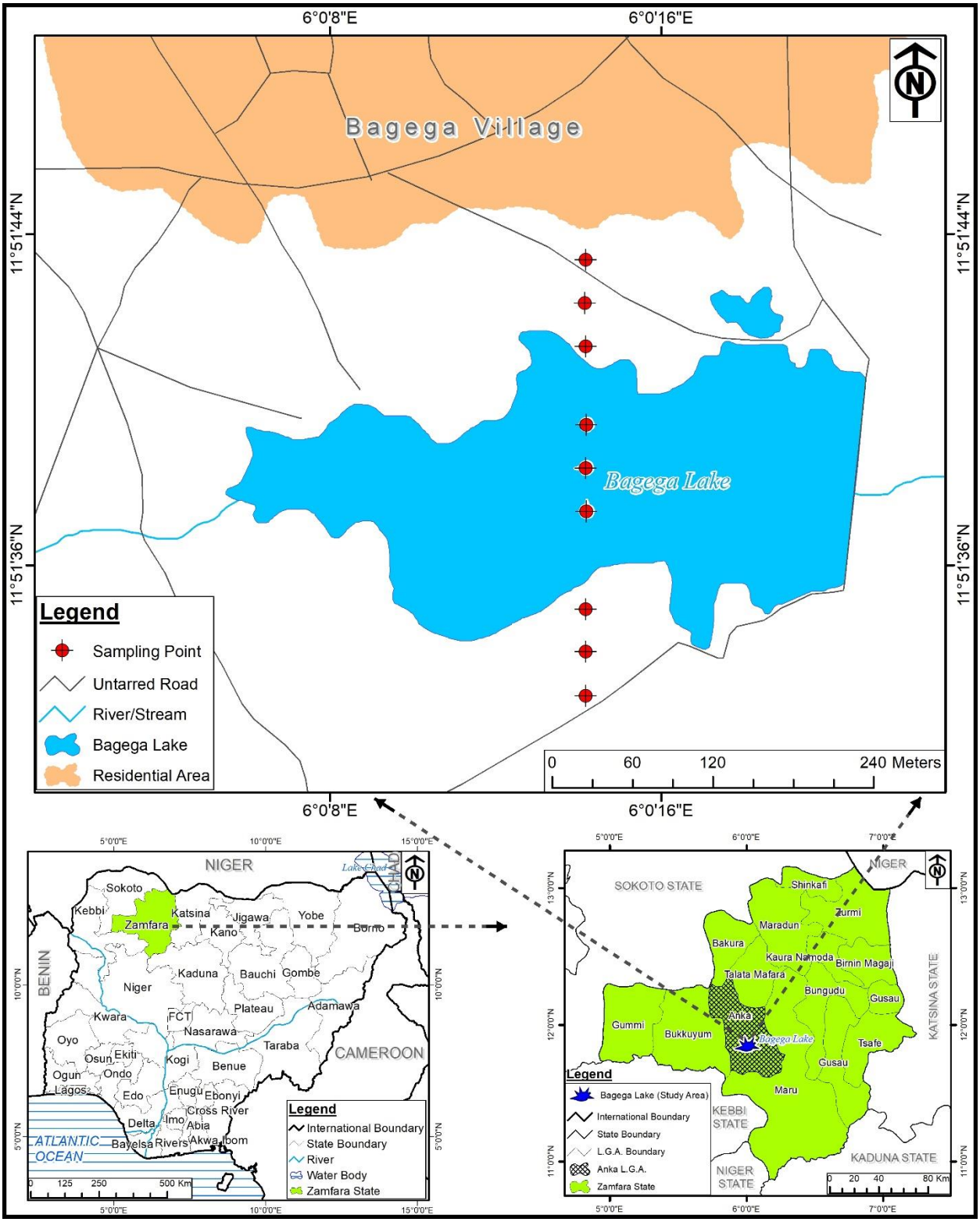


Figure 3.1: Map of Study Area in Bagega Town

3.2 Sample Collection

Samples of soil, water and commonly dominant plants and fish were collected on 21st February, 2020 during the peak of dry season (harmattan) as follow.

3.2.1 Sediment and Soil collection

Top soil (0-15cm) samples were collected using soil auger from each 30m by 30m quadrat. The first quadrat was located at previously remediated bank 06^{o} 00’ 15. 10 E - 06^{o} 00’ 13. 80 E and 11^{o} 51’40.70 N - 11^{o} 51’41.20 N co-ordinates, the second quadrat which is the drawback section of the lake reservoir lies between 06^{o} 00’09.80 E - 06^{o} 00’05.75 E and 11^{o} 50’70.30 N - 11^{o} 48’20.58 N while the third quadrat is the bank that was not remediated 05^{o} 90’ 56.40 E - 05^{o} 90’ 54.20 E and 11^{o} 40’ 36. 18 N - 11^{o} 40’ 38. 58 N. Each 30x30m quadrat was divided into 3 (10 × 30m) sub plots from which replicate samples were taken.

3.2.2 Water collection

The water samples were collected in triplicate pooled sections from the Bagega Lake near the remediated bank, through the middle of the Lake and to the unremediated bank respectively within the following coordinates 06^{o} 00’09.80 E - 06^{o} 00’05.75 E and 11^{o} 50’70.30 N - 11^{o} 48’20.58 N to have a uniform and adequate representative portion of the water body.

3.2.3 Fish collection and identification

With the help of the local fishermen present at the lake during the time of samples collection, dominant fish species in the lake were collected and identified.

3.2.4 Plant collection

The common plant species within the soil sampling area (remediated land before the lake and unremediated land after the lake) were collected using a garden scissors to cut the leaf stem to fruit portion, then wrapped in a paper sheet for a temporary preservation before getting to the laboratory for further examinations.

3.3 Sample Preparation

3.3.1 Plant sample preparation

The plant samples collected were identified in the Herbarium laboratory of Botany Department, A.B.U., Zaria and then dried at room temperature over a period of two weeks and was grinded using mortar and pestle and sieved into fine powder

3.3.2 Soil sample preparation

Sediment/Soil samples were air dried for 48h and then homogenized to fine powder and sieved using 2 mm stainless steel sift

3.3.3 Fish Sample preparation

The fish samples were dissected, using stainless steel knife. Liver, gills and muscles were removed and each organ was oven dried at 85^{o}C for 24hrs. (Azcue and Mudroch, 1994) The dried samples were homogenized to fine powder using ceramic mortar and pestle.

3.4 Sample Analyses

3.4.1 *In-Situ* physicochemical analysis

Physicochemical parameters of the water samples were measured *in-situ*. Temperature, pH, Electrical conductivity and Total Dissolved Solid were determined using a Microprocessor (HANNA Instruments) and a pH meter.

3.4.2 Sample digestion

All samples (water, plants, fish and soil) were digested in Centre for Dry Land Agriculture (CDA) Bayero University Kano using the Advanced Microwave Digestion System model (Ethos of easy) Milestone Connect Company. The samples were prepared and all added to each vessel as programmed by the equipment;

For water samples HNO_3 (10ml) and HCL (5ml) were added to 80ml of water sample then heated from 50^o to 200 ^oC for 20 to 40minutes.

For dry plant digestion HNO_3 (6ml) and H_2O_2 (2ml) were added to 200 mg of the sample then heated from 0^o to 200 ^oC for a period of 25 to 40minutes.

For the fish sample HNO_3 (7ml) and H_2O_2 (1ml) were added to 200mg of each fish parts then from heated 50^o to 200 ^oC for 20 to 35minutes.

For both the sediment/soil H_2SO_4 (10ml) and H_2O_2 (2ml) were added to 1g of sediment/soil sample then heated from 40^o to 250 ^oC for 20 to 40minutes.

After digestion, the samples stands for one hour (1h), which was allowed to cool from the 200 ^oC to approximately 50^oC or lower before it was handled. The digested samples was transferred to a

50ml volumetric flask; the solution volume was adjusted to 50ml with deionised water and filtered for mental analysis (Ozbek, 2018; Gebeyehu and Bayissa, 2020).

3.5 Determination of Metal Concentrations

Metal concentrations Cd, Cr and Pb were determined using Microwave Plasma Atomic Emission Spectroscopy_ MP-AES model 4210 (Agilent Technology) machine which uses gaseous nitrogen extracted straight from the air to sustain the plasma and detection of metal as well as what concentration is available. The sample introduction system consisted of PVC peristatic pump tubing (white/white and blue/blue), a single pass cyclonic spray chamber and the oneNeb nebulizer. The Agilent MP Expert software was used to automatically subtract the background signal from the analytical signal. A background spectrum from a blank solution was recorded and automatically subtracted from each standard and sample solution that was analysed. The software was also used to optimize the nebulization pressure and the viewing position for each wavelength selected to maximize sensitivity. Because of this optimization, and considering that all determinations were carried out sequentially, each analyte was determined under optimized conditions. A standard reference solution was used to quickly and easily optimize the parameters. The plasma of the 4210 MP-AES operates at around 5000k which results in improved detection limits when compared to Flame Atomic Absorption Spectrometry (FAAS).

3.6 Bioaccumulation Factor Determination

The bioaccumulation factors (BAF) of heavy metal concentrations were determined for plants and fish species.

The BAF formula is expressed as follow:

BAF = $\frac{\text{Cnplant}}{\text{Cnsoil}}$ where Cnplant is the concentrations of heavy metal in each plant species, Cnsoil is the concentrations of heavy metals in the plant location.

BAF = $\frac{\text{Cnpelagic fishparts}(Oreochromis\ niloticus\ )}{\text{Cnwater}}$ where Cnpelagic fish parts (*Oreochromis niloticus)* is the concentrations of heavy metals in pelagic fishes, Cn water is the concentrations of heavy metal in water.

BAF = $\frac{\text{Cnbenthic fishparts}(Clarias\ anguillaris\ )}{\text{Cnsediments}}$ where Cnbenthic fish parts (*Clarias anguillaris*) is the concentration of heavy metals in benthic fish, and Cnsediments are the heavy metal concentrations in sediments.

3.7 Data Analyses

The data generated were described statistically using the ggplots2 package of R statistical analysis software. Data was evaluated for homogeneity of variance and normality using Levene's homogeneity of variance and Shapiro-Wilk tests, respectively. Differences between metal content in water, fish and plants were determined per metal type and sampling location using two-way analysis of variance (ANOVA). A post hoc test to separate significantly different means was performed using Bonferroni test. Statistical analysis was performed at 5% significant level using the R statistical analysis program version 3.6.3 for macOS Big Sur.

CHAPTER FOUR

4.0 RESULTS

4.1 Physicochemical Analyses

The *in-situ* physicochemical analysis of the water from Bagega Lake at points across the lake, were evaluated for some parameters like electrical conductivity mean concentrations between 114.0 ± 1.0^{a} to 117.5 ± 0.5^{a} μ∫/cm, total dissolved solid 54.5 ± 2.5^{a} and 59.0 ± 2.0^{a} ppm, pH 7.5 ± 0.5^{a} and 8.0 ± 0.0^{a} while temperature ranges between 27.0 ± 0.0^{a} and 28.0 ± 0.0^{a} ^{o}C. There was no significant difference ($p>0.05$) in the mean concentrations across the Lake from points near remediated site through the middle of the Lake down to points near unremediated site.

4.2 Metal Concentration of Water from Bagega Lake Zamfara-State

The concentrations of Cr (0.12, 0.13 and 0.53mg/l) and Pb (0.72, 0.73 and 0.90mg/l) in the water samples increased in accordance to distance from remediated segments. Cd concentration was below detectable level and statistically not significantly different from one sampling site to another.

The lead (Pb) has concentrations range between 0.72-0.90mg/l which was above W.H.O, (2011) 0.1mg/l maximum permissible range and minimal range of chromium (Cr) between 0.12 - 0.53mg/l which were also above the acceptable limit of 0.15mg/l (W.H.O., 2011) (Figure 4.1)

Table 4.1; *In-situ* Physicochemical Paramaters on Bagega Lake, Zamfara-State, Nigeria

Sample	EC(µʃ/cm)	TDS(ppm)	pH	Temperature (^{o}C)
Near remediated	117.5±0.5[a]	59.0±2.0 [a]	7.5±0.5 [a]	27.5±0.5 [a]
Middle of Lake	114.0±1.0 [a]	54.5±2.5 [a]	8.0±0.0 [a]	27.0±0.0 [a]
Near unremediated	115.5±0.5 [a]	57.0±1.0 [a]	8.0±0.0 [a]	28.0±0.0 [a]

Data = Mean ± SEM: (p>0.05) means with same superscripts there is no significant no difference.
EC = Electrical conductivity, TDS = Total dissolved solids

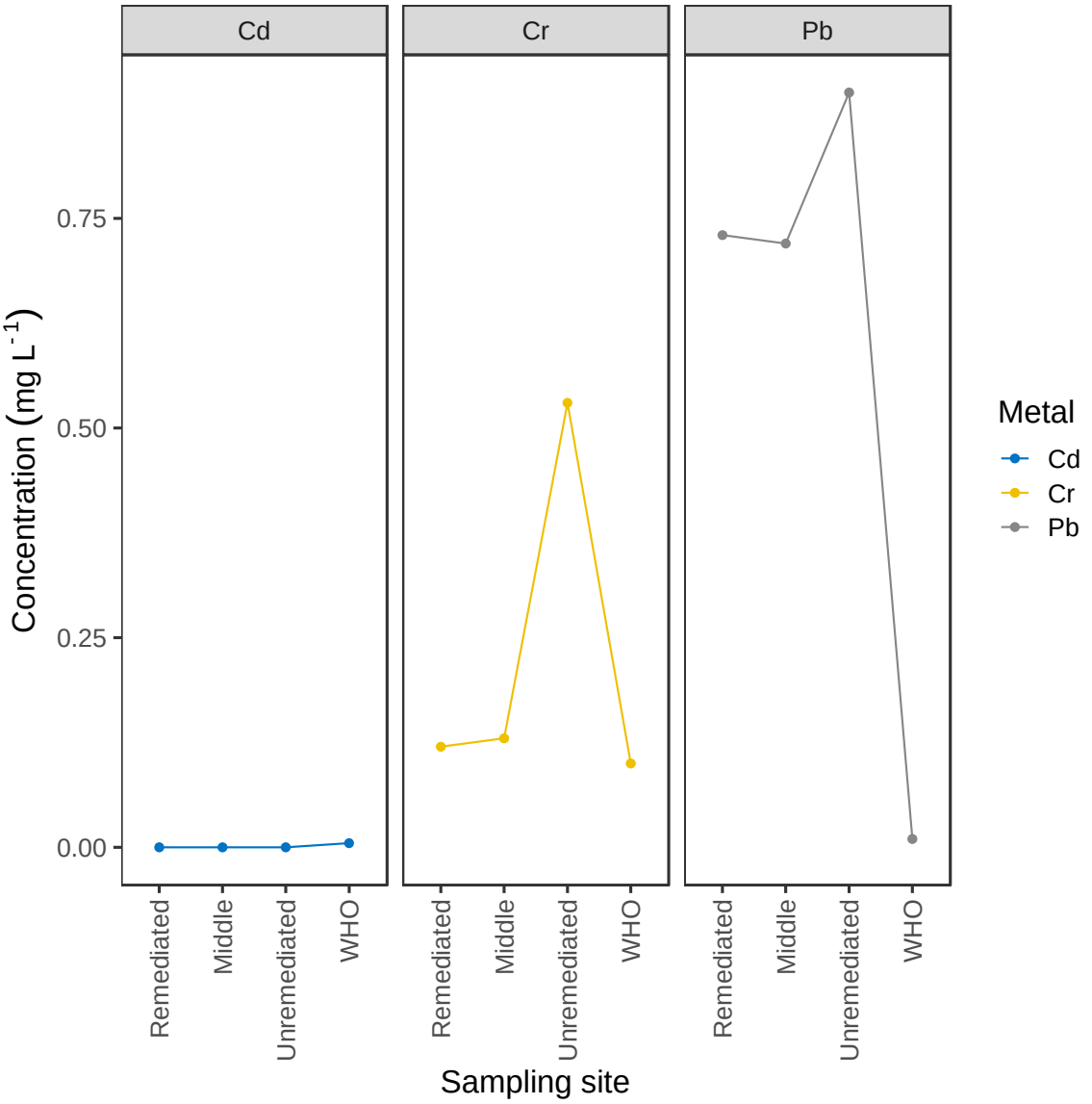


Figure 4.1: Cadmium, Chromium and Lead concentration in water from Bagega Lake Zamfara-State, Nigeria

4.3 Metal Concentration of Soil Samples in and around Bagega Lake Zamfara-State

Cadmium (Cd) concentrations in soil samples across the locations followed the order; sediment in middle of Lake (0.0mg/kg) < sediment near the unremediated (0.060mg/kg) < soil from unremediated site (0.065mg/kg) < sediment near the remediated (0.070mg/kg) < soil from the remediated (0.080mg/kg) (Figure 4.2a). Chromium (Cr) concentrations in soil samples across the locations followed the order; sediment in middle of Lake (0.940mg/kg) < sediment near the unremediated (1.660mg/kg) < sediment near the remediated (1.720mg/kg) < soil from unremediated site (1.810mg/kg) < soil from the remediated (4.333mg/kg) (Figure 4.2b). Lead (Pb) concentrations in soil samples across the locations followed the order; sediment in middle of Lake (3.350mg/kg) > sediment near the remediated (3.110mg/kg) > sediment near the unremediated (3.080mg/kg) > soil from remediated site (2.587mg/kg) > soil from the unremediated (0.446mg/kg) (Figure 4.2c). There was no significant difference ($p>0.05$) within the concentration of cadmium in unremediated, sediment and remediated soil. There was a significant difference ($p<0.05$) in the concentrations of lead and chromium in sediments and remediated soils. Highest mean lead concentration 3.18±0.08mg/kg was recorded in Bagega Lake sediment while lowest mean lead 0.44±0.26mg/kg in soil from unremediated soil segment. The highest mean chromium 4.39±1.08mg/kg was recorded in soil from remediated soil segment while lowest mean chromium 1.44±0.25mg/kg was recorded in sediment.

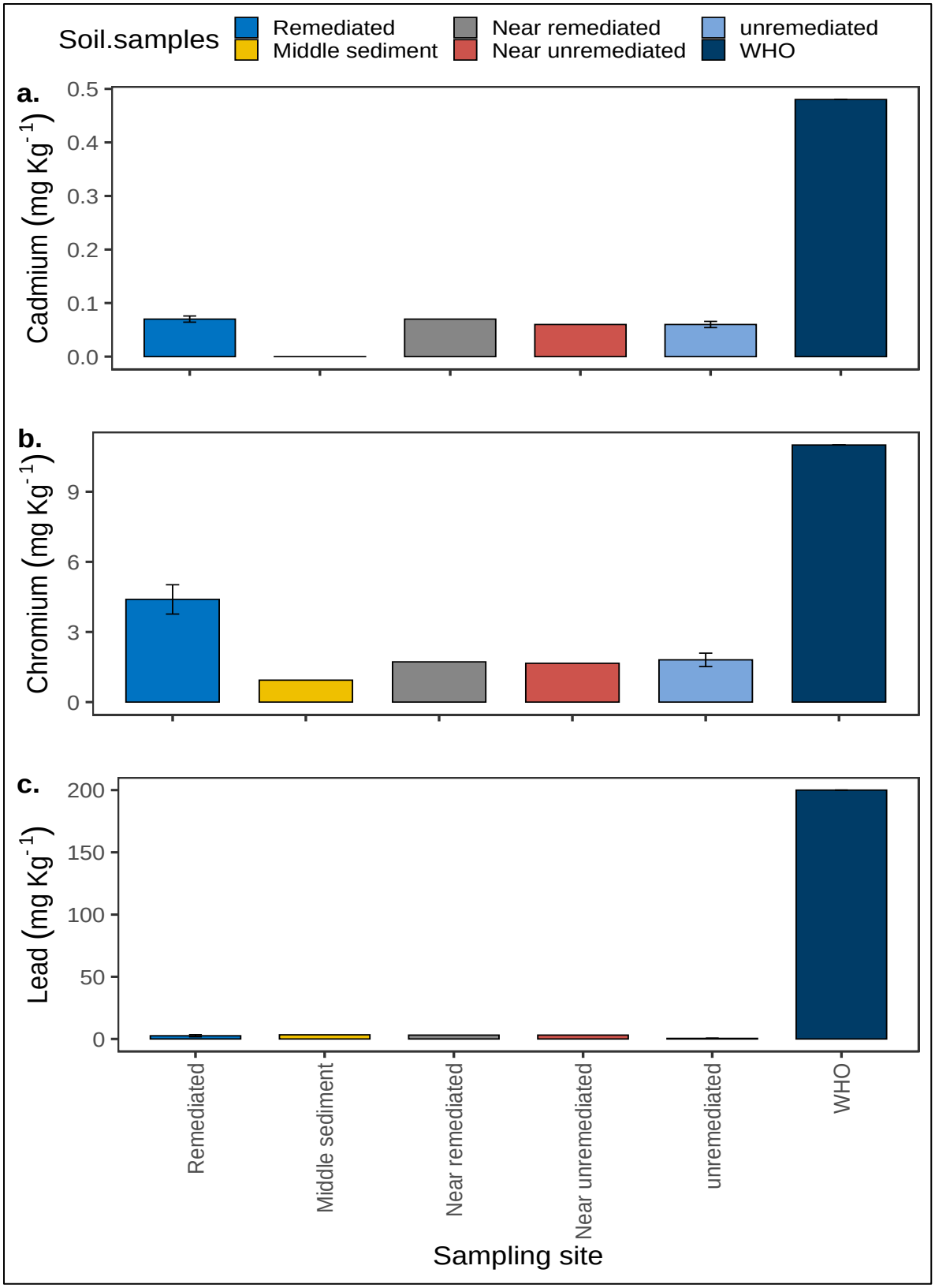


Figure 4.2: Cadmium, Chromium and Lead concentration of soil samples in and around Bagega Lake

4.4 Identified Plant Species Around Bagega Lake Zamfara-State

A total of 13 plant species were collected, belonging to 7 families' Convulvulaceae (*Ipomoea eriocarpa),* Ebenaceae (*Diospyros mesipiliformis),* Fabaceae (*Acacia ataxacantha, Crotalaria falcata, Isoberlina doka, Piliostigma thoningii & Senna alata)* Lamiaceae (*Hyptis spacigera),* Malvaceae (*Azadirachta indica, Sida acuta & Urena lobata)* Rubiaceae (*Naudea latifolia)* and Sterculiaceae (*Waltheria indica),* with Fabaceae having the highest number of collected species (5) followed by Malvaceae having (3) species. Some of the identified plant species that were found dominant to specific area as well as some also commonly found on both sides of the Lake (remediated and unremediated areas).

Fabaceae family had a uniform distribution of its species across the remediated and unremediated sites but Malvaceae species were more in abundance in the unremediated sites.

Table 4.2: Identified Plant Species and Their Locations Around Bagega Lake Zamfara-State, Nigeria

Family	Species	Voucher number	Remediated land	Unremediated land
Convulvulaceae	*Ipomoea eriocarpa*	ABU1042	+	-
Ebenaceae	*Diospyros mesipiliformis*	ABU8669	+	+
Fabaceae	*Acacia ataxacantha*	ABU75261	+	-
Fabaceae	*Crotalaria falcate*	ABU7811	+	-
Fabaceae	*Isoberlina doka*	ABU07878	+	+
Fabaceae	*Piliostigma thoningii*	ABU90076	-	+
Fabaceae	*Senna alata*	ABU01184	-	+
Lamiaceae	*Hyptis spacigera*	ABU08370	-	+
Malvaceae	*Azadirachta indica*	ABU900151	-	+
Malvaceae	*Sida acuta*	ABU7871	+	+
Malvaceae	*Urena lobata*	ABU0547	+	+
Rubiaceae	*Naudea latifolia*	ABU825	-	+
Sterculiaceae	*Waltheria indica*	ABU07451	+	-

+=presence, -=absence

4.5 Metal Concentration of the Plant Species Collected Around Bagega Lake Zamfara-State

The heavy metal concentrations in plant samples gotten from the (remediated and unremediated) areas around Bagega Lake for Cadmium (Cd) concentration was below detectable level in all the plants, while chromium (Cr) and Lead (Pb) concentrations in the same plant samples across the sites were within the W.H.O, (2011) acceptable limit (1.3 and 0.3mg/l) for Cr and Pb respctively. *Ipomoea eriocarpa* from remediated site had highest concentration 0.23mg/kg for Cr and *Senna alata* from unremediated site had 0.12mg/kg for Cr (Figure 4.3). All plants sampled from the remediated area of Bagega Lake had Lead (Pb) concentrations (Figure 4.3) but not all plant samples from unremediated area of the Bagega Lake had Lead (Pb) concentration (Figure 4.3)

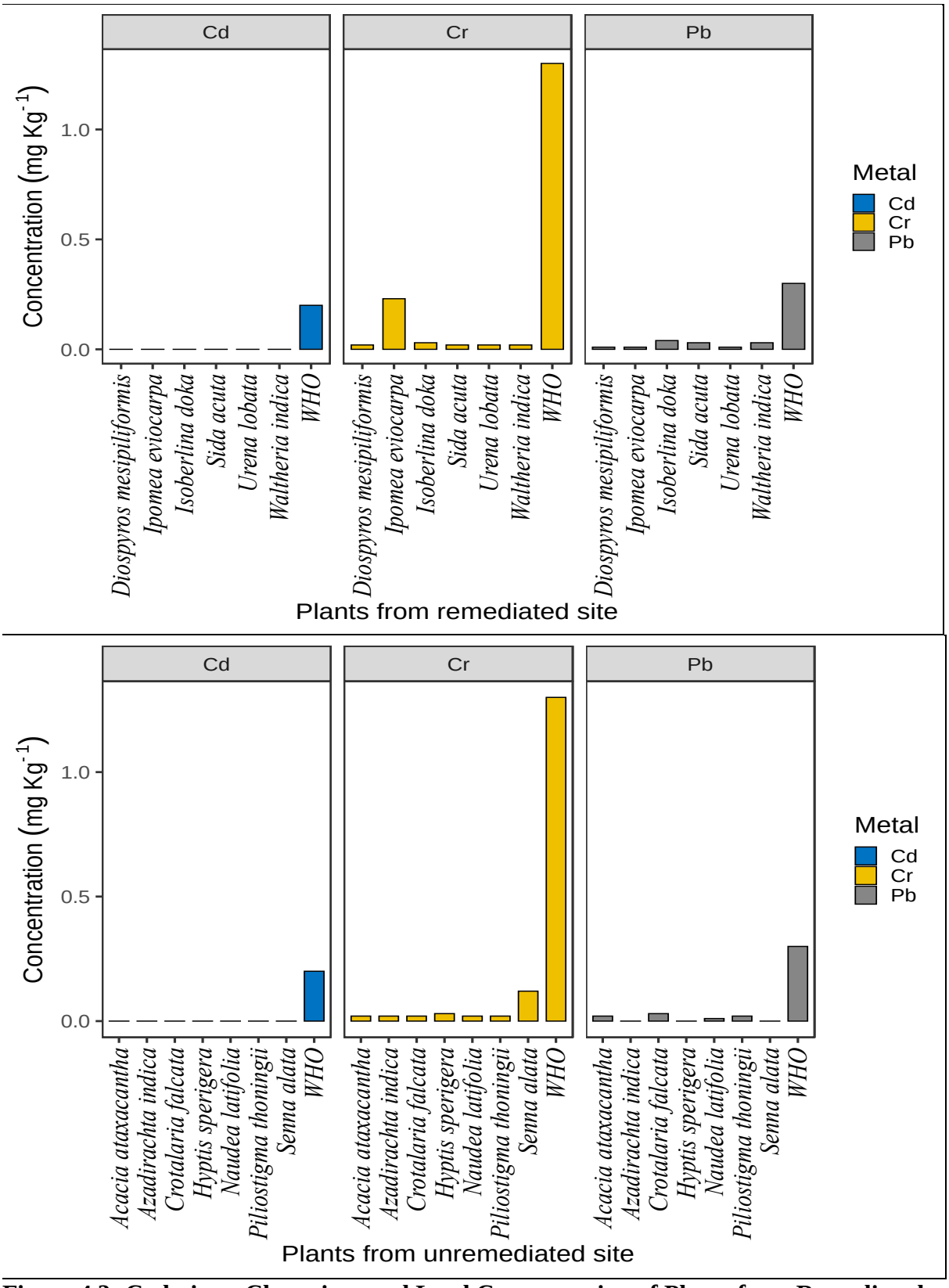


Figure 4.3: Cadmium, Chromium and Lead Concentration of Plants from Remediated and Unremediated Segments Around Bagega Lake Zamfara-State, Nigeria

4.6 Dominant Fish Species in Bagega Lake Zamfara-State, Nigeria

During the time of study, two (2) fish species were identified namely *Clarias anguillaris* (Plate Ia and Ib) and *Oreochromis niloticus* (Plate Ic) commonly known as mudfish and tilapia respectively in Bagega Lake

Cadmium (Cd) concentrations were completely absent or below detectable levels in all the fish species sampled, while chromium (Cr) concentrations were low 0.03mg/kg in gills while flesh and liver had concentrations of 0.02mg/kg present across the fish species. Lead (Pb) concentrations were higher in fish gills (0.09±0.03mg/kg) than the other parts (flesh and liver) (0.03±0.03mg/kg) of the fish species. But were all within the W.H.O, (2011) acceptable limit (0.15 and 0.5mg/kg) for Cr and Pb respectively (Figure 4.4). There was a significant difference ($p<0.05$) between the fish parts i.e the gills had higher concentrations heavy metals than the flesh (Figure 4.4).



Plate Ia: *Clarias anguillaris* from Bagega Lake Zamfara-State. (Burchell, 1822)



Plate Ib: Gills of *Clarias anguillaris* from Bagega Lake Zamfara-State.



Plate Ic: *Oreochromis niloticus* from Bagega Lake Zamfara-State. (Linnaeus, 1758)

Plate I: Identified fish from Bagega Lake Zamfara-State.

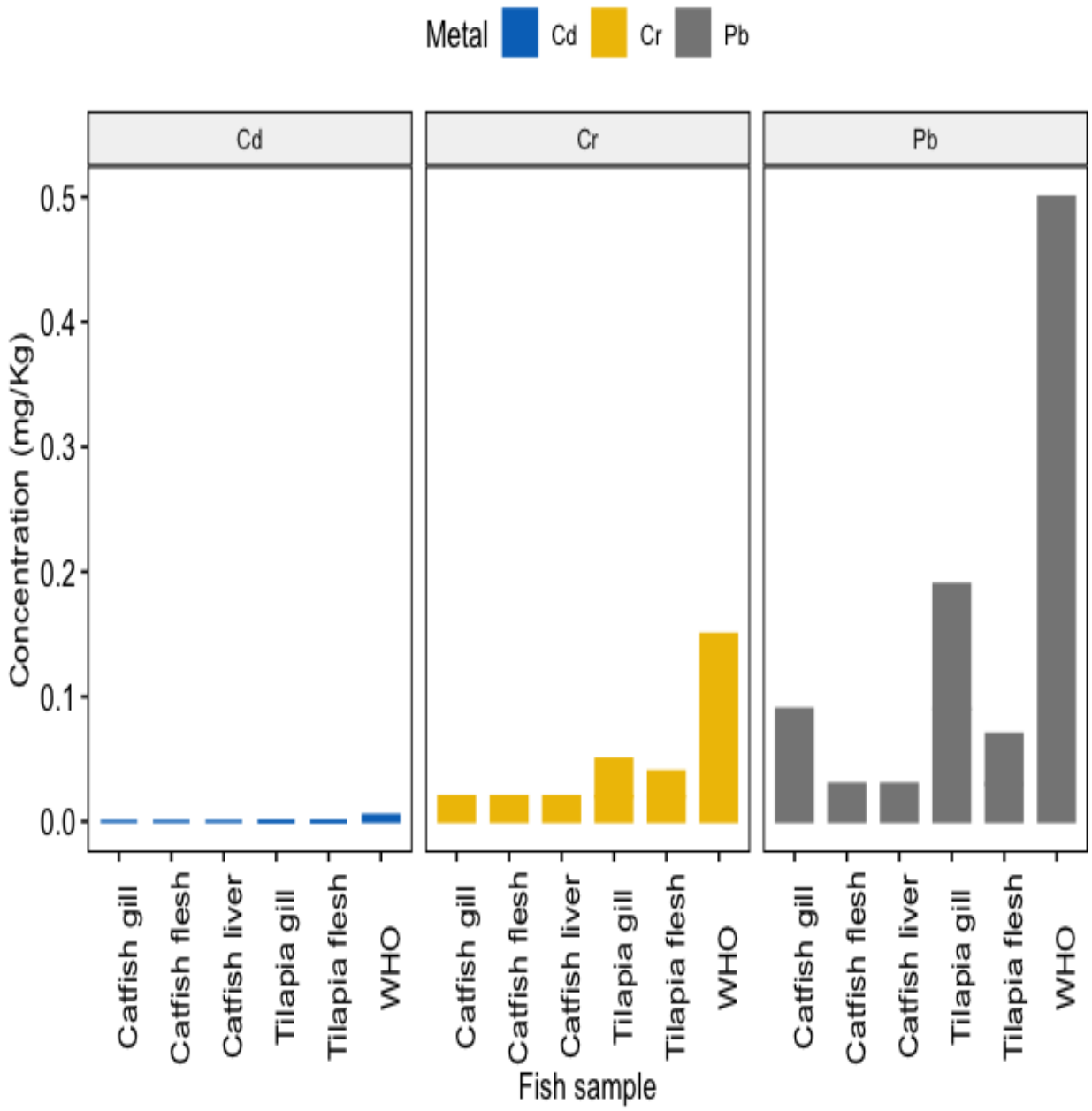


Figure 4.4: Cadmium, Chromium and Lead Concentration in Parts of Fish Samples from Bagega Lake Zamfara-State, Nigeria

4.7 Bioaccumulation Factor of Plant Species in Remediated Site and Unremediated Site

Bioaccumulation factors (BAFs) of heavy metals in plant sampled across the sites is shown in Figures4.6 and 4.7. These figures show the specific BAFs of heavy metals (Cd, Cr and Pb) in each plant per location and further revealed that the highest BAFs for Cr was observed in the *Ipomoea eriocarpa* (0.0524) and *Isoberlina doka* (0.0154) for Pb. Plant samples from remediated sites (Figure 4.6) while *Senna alata* had highest BAFs (Cr=0.0663) and *Crotalaria falcata* was highest (Pb=0.0667) for plant samples from the unremediated sites (Figure 4.7). BAFs of all the sampled plants across the location were < 1

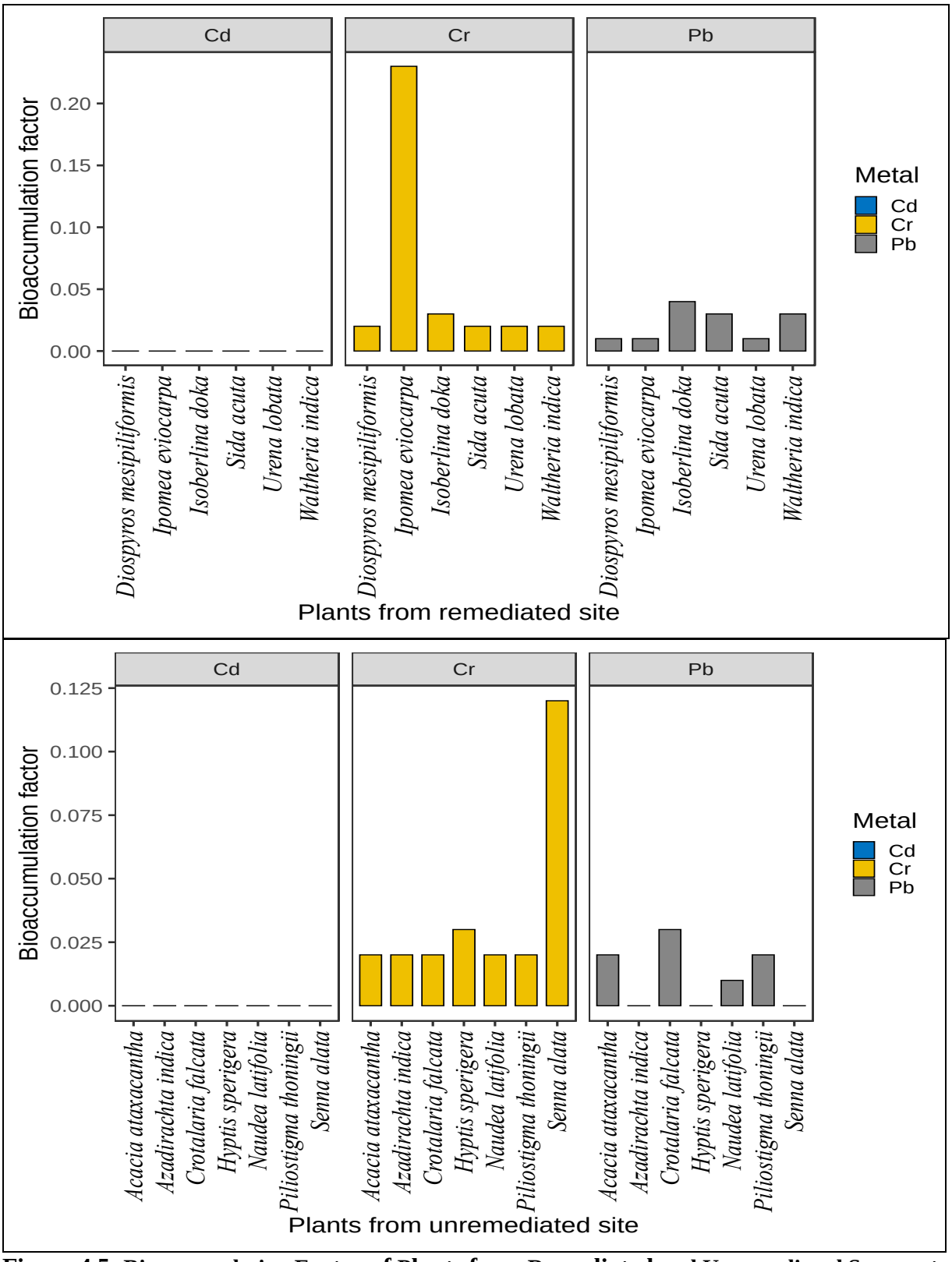


Figure 4.5: Bioaccumulation Factor of Plants from Remediated and Unremediated Segments Around Bagega Lake Zamfara-State, Nigeria

4.8 Bioaccumulation Factor of Fish Species in Bagega Lake

Bioaccumulation factors (BAFs) of heavy metals in parts of the fish samples collected from Bagega Lake Zamfara-State, Nigeria pattern of accumulation was as follow in Lead (Pb) tilapia gill 0.128 > catfish gill 0.115 > tilapia flesh 0.051 > catfish flesh and liver had BAFs of 0.038 while chromium (Cr) tilapia gill 0.115 > tilapia flesh, catfish gill, flesh and liver had 0.076 BAFs and cadmium (Cd) concentration was below detectable limit in both the water and parts of the fish sample (Figure 4.6).

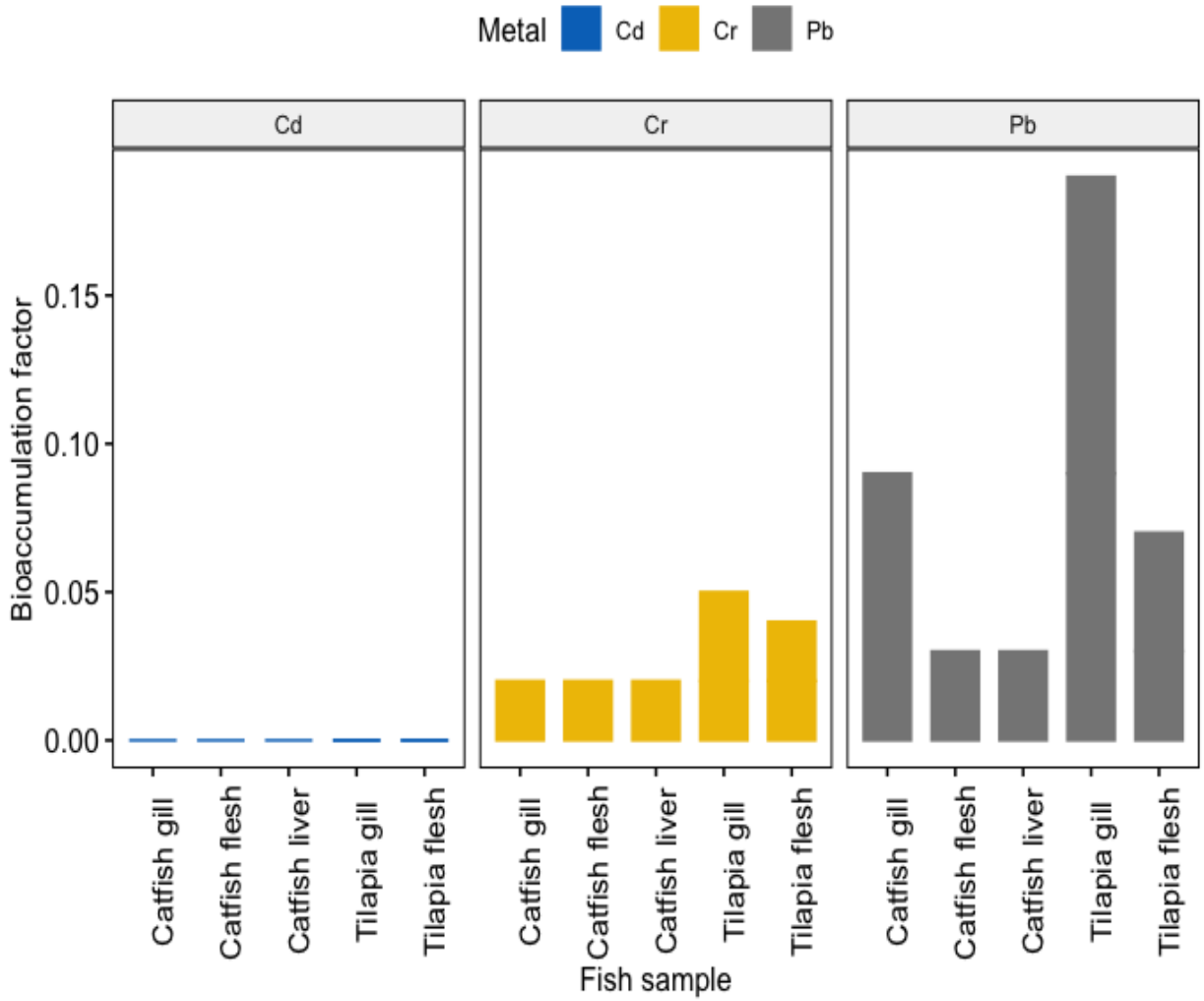


Figure 4.6: Bioaccumulation factor of some fish parts from Bagega Lake

CHAPTER FIVE

5.0 DISCUSSIONS

The surface water *In-situ* physicochemical analysis on water from Bagega Lake Zamfara-State, Nigeria mean concentration for Temperature 27.5^{o}C, pH 7.8, Electrical Conductivity 115.7μ∫/cm and Total Dissolved Solids 56.8ppm were found to be within the range suitable for domestic use and irrigation FAO, (1983) (pH 6.5-8.5, EC 3000μ∫/cm and TDS 2000ppm) (Nukpezah *et al*., 2017).

5.1 Concentration of Heavy Metal in Water from Bagega Lake

The high Pb concentration obtained from this study may be attributed to the fact that some individuals still perform sluicing (washing of the gold ore material) in the Lake (Appendix Ia) as well as workers from both the mining and ore processing site frequent the lake often either to get water to work on site or clean themselves on the water bodies or even both (Appendix Ib) and that surface water is more easily subjected to environmental contamination than underground water. Surface water remains the primary source of water in Bagega for their animal consumption while humans (the community dwellers) are still at risk of being affected by lead poisoning in the long run, by consuming on the animals and water. Tijjani *et al*., (2019) whose post remediation assessment on the Bagega Lake in 2014 recorded a much higher Pb concentration of (31.49 ± 7.1ppm) as well as the results of Olayinka-Olagunju *et al.*, (2021) whose Pb concentration obtained in water samples from Ogbese river of Ondo state were higher than the regulatory limits 0.1 ppm (W.H.O, 2003).

In this study the heavy metal concentration in water from Bagega Lake followed the order Pb>Cr>Cd, as it corresponds with the earlier findings of Pb, Cd, Cr, As and Hg heavy metals been the predominant elements that contaminated the Bagega environment during the 2010

pollution saga (M.S.F., 2012). The pattern in this study is similar to the findings of Islam *et al*., (2015) and Ali *et al*., (2016) who reported a high concentration of heavy metals in their findings Olayinka-Olagunju *et al*. (2021).

Chromium (Cr) which is above the acceptable limit from this present study was observed to be more in water samples from the unremediated bank of the Lake meaning due to several dilutions and various contacts reduced the available already high concentration of Cr in the middle to near the remediated bank of the Lake, where the community dwellers interacts. This is similar to the studies of Olayinka-Olagunju *et al.* (2021) whose Chromium concentrations ranged from 0.10 to 0.21 ppm and Maurya *et al*. (2019) concentrations in water samples from River Ganga Basin with the Cr values (0.28–0.31 ppm) that were higher than the permissible limit (FAO, 1983). Cadmium (Cd) concentration observed was below detectable limits and this could result from the fact that Cd had least percentage (31%) among the elements as reported Batrem *et.al*, (2014). This was in line with the work of Nuhu *et al*. (2014) whose water samples from the Bagega Lake in the study of the environmental impact of artisanal gold mining on Bagega village, discovered that cadmium concentration was below the WHO, (2011) permissible limit but lead (Pb) concentration was above the maximum permissible level and contradicted the studies of Olayinka-Olagunju *et al.* (2021) whose Cd concentration from water samples of Ogbese River which ranged from 0.001 to 0.004 ppm but revealed that those mean concentrations were within the W.H.O. (2003) permissible limit of 0.003 ppm.

5.2 Heavy Metals in Sediment/Soil Around Bagega Lake

The order of heavy metals detected in sediment sample from Bagega Lake is Pb>Cr > Cd. High concentration of Pb in the sediment sample from Bagega Lake is similar to the pattern from its water sample, which could be attributed to the fact that sediment is the soil sample beneath a

water body that receives all that goes in the water. Cr concentration in sediment sample from the Bagega Lake was also high and higher than the WHO, (2011) regulatory limits of 0.1 ppm. Long term exposure to Cr is capable of causing kidney and liver damage as well as disruptions in circulatory and nerve tissue functions (ATSDR, 2000). Bioaccumulation of Cr in aquatic life is hazardous and may contribute to the danger of eating fish. This is similar to Olayinka-Olagunju *et al.* (2021) sediment of the Ogbese River concentrations of Pb ranged from 0.24 to 0.57 ppm and Cr ranged from 0.31 to 0.45 ppm.

Soils sampled from remediated land around Bagega Lake had higher concentration of Pb than those in sampled from unremediated land. This could be attributed to the facts excavation was remedial style adopted to clean the then polluted land in Bagega community while the unremediated must have been verified not to have metal levels detriment to the people and community entirely. High concentration of Cr in soil samples from the remediated land than unremediated is likely to have the same pattern as the remedial area. The results from this study indicate that there is still have high heavy metal concentrations on remediated areas when compared to the concentrations recorded from unremediated area. This said soils with the highest concentration Cr and Pb heavy metal are used to mold bricks (Appendix IIa) that are in turn going to be used to build house for animals breeding or even human domestic purpose. Furthermore, the remediated area along the Lake where soil samples with the highest metal concentration are gotten as well as the water in the Lake is where children play and some community dwellers wash their cloths (Appendix IIb). In the long run there is going to be a gradual absorption of the metals either by inhaling, skin surface contact or ingestion with food and water. On the other hand Pb, a well-known toxicant, has several harmful effects on human health even at low concentrations. Bioaccumulation of Pb may be due to long-term exposure and

sometimes cause death or permanent damage to the central nervous system, the brain, kidneys and liver as well as being genotoxic (Olatunji-Ojo *et al*. 2020). In children, Pb is considered a serious health threat as its poisoning effect can last a lifetime. Cd also had more concentrations in soil sample from excavated land than those in soil sample from unexcavated land. Cadmium is usually grouped as a toxic trace element, found in low concentration in rocks, coal and petroleum and sometimes combines with Zn (Sobha *et al*., 2016). However, no previous study has shown any beneficial effects of Cd. It is also important to know that Cd bioaccumulates with age and it affects the kidney and liver, and also causes cardiovascular diseases (Obahiagbon and Olowojoba, 2007). This result has contradicted the findings of Venkateswarlu and Venkatrayulu (2020) who reported high concentrations of Cd in soil samples from coastal areas of Nellore India. Exposure to cadmium, for example, at a very minimal concentration may result in kidney injury and may also affect the bones (Maurya and Malik, 2016). There was a significant difference ($p<0.05$) between heavy metals in different locations i.e soil samples from remediated land has higher metal concentrations than those from unremediated land, even though the values were far below the W.H.O, (2011) regulatory limits. All the heavy metal concentration of soil samples recorded so far on Bagega remediated land have shown that, there is a gradual and consistent reduction in metal concentration of the pollution that occurred years back followed by the soil excavation method of remediation that was done. This evidence suffice from the works of Alaba and Abdulraman (2017) and Alaba *et al*. (2018) who evaluated the remedial options effectiveness and made a health risk model for lead contaminated sites in Bagega. The studies showed a decline in Pb concentration from 5000ppm to 46.87ppm. This could be attributed to the adoption of new methods for safer mining and ore-processing activities than the previous in-

house ore-processing method that was used as well as increased education and awareness on lead poisoning (Alaba and Abdulraman, 2017).

5.3 Heavy Metal in Plants around Bagega Lake

The grown plant sampled from both remediated and unremediated site had its highest concentration of heavy metals in *Ipomoea eriocarpa* species from the remediated site and also *Senna alata* species from the unremediated site for chromium, which were all still within the W.H.O., (2011) permissible metal limit with little concentration of lead. This signifies that there is either no reasonable amount of lead in the corresponding soil or the available plant species does not bioaccumulate elements present in its corresponding soil (BAFs < 1) (Figure 4.5). In northern Nigeria, the stem, leaf, and root decoctions of *Senna alata* are used in the treatment of wound, skin and respiratory tract infection, burns, diarrhoea, and constipation (Oladeji *et al*., 2020).

BAFs of all the sampled plants across the locations were < 1. Therefore indicating that none of the plant sampled species is suitable for phytoremediation. Bako *et al*. (2014) who worked on heavy metals deposition in soils and plants impacted by anthropogenic modification of two sites in the Sudan Savanna of North Western Nigeria explains that plants suitable for phytoextraction must have BCF of metals >1.0. Lead (Pb), a poisonous heavy metal, at a high or low dose, may cause different disruptions in plant physiological processes (Yadav *et al*., 2018). Cadmium being completely absent in Bagega plants was in line with the study of Abubakar *et al*. (2015) whose post-remediation assessment in soil and plants of Dareta gold mining area, Zamfara State, Nigeria reported that Cadmium, Nickel and Manganese were not detected in their plant samples.

5.4 Heavy Metal in Fish of Bagega Lake

The higher concentration of heavy metal in gills more than flesh and above the maximum permissible limits (WHO, 2011 0.05mg/kg for Pb) indicates that fish takes in heavy metals from the river through their respiratory organs and assimilation depends on the concentration level in the environment (Maurya and Malik, 2019). This also confirms the findings of Kaoud and El-Dahshan, (2010), Shivakumar *et al*. (2014) and Kaoud, (2015) whose findings revealed that fish muscle is not always a good indicator of whole fish body contamination compared to the gills and liver. This is in line with the studies of Olayinka-Olagunju *et al.* (2021) who worked on bioaccumulation of heavy metals in pelagic and benthic fish of Ogbese River, Ondo State, South-Western Nigeria. Concentration of Pb in gill samples ranges from 0.004 to 0.030 ppm, but contradicted the findings of Abalaka *et al*., (2020) who had high Pb (lead) in fish muscles (*Clarias gariepinus*) sold in Kado Fish Market Abuja. Cr concentrations in gills were higher in than the flesh but were all below the W.H.O., (2011) acceptable limit (0.15mg/kg). The gill (Pb = 0.1282) has the highest BAFs than the other parts (flesh and liver) (Cr = 0.0139), because the gills are widely opened to the water body; hence, it is predisposed more to the heavy metals in the aquatic environment. Results from this study observed that metabolically active tissues, i.e. gills, liver and kidneys, showed higher accumulations of heavy metals than other tissues such as muscles and skin (Ali *et al*., 2019; Olayinka-Olagunju *et al*., 2021). These results, however, showed no probability of accumulation has all the values were below the limits of NCRP, 1996 (200, 200 and 300) for Cd, Cr and Pb respectively.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSION

Bagega Lake Zamfara-State, Nigeria Pb and Cr concentrations in water were found to be above the W.H.O., (2011) acceptable limits but Cd was below detectable limits. This presents health risks to humans and other animals as the metals contaminate both aquatic and terrestrial ecosystems.

The concentrations of Cr, Cd and Pb of sediment/soils in and around Bagega Lake were below the W H O, (2011) acceptable limits.

A total of thirteen (13) plant species belonging to seven (7) families were identified to be dominant around the Bagega Lake during the time of study and their metal concentrations were within the maximum permissible limits. These plants include; *Isoberlina doka, Diospyros mesipiliformis, Piliostigma thoningii, Sida acuta, Urena lobata, Naudea latifolia, Hyptis spacigera, Senna alata, Azadirachta indica, Ipomoea eriocarpa, Crotalaria falcata, Waltheria indica* and *Acacia ataxacantha* with Fabaceae family having the highest species uniformly across the sites followed by Malvaceae family which have its species more abundance in the unremediated sites.

Two (2) fish species were sampled from Bagega Lake during the study and identified as *Clarias anguillaris* and *Oreochromis niloticus.* The Pb concentration was higher in the gills than other parts (flesh and liver). While other metals analysed (Cr and Cd) concentrations were within the W H O, (2011) maximum permissible limits.

6.2 Recommendations

Miners, ore processors and sluices (washing of gold ore material) should neither be allowed nor have direct contact on Bagega Lake Zamfara-State, Nigeria but adopt the use of pumping machine in which farmers used for their irrigation to fetch water from the Lake.

Public enlightenment should be carried out with the view to discourage people from consuming fish gills together with the fish flesh. Since heavy metals seems to accumulate more that organ than other parts.

Further studies on abundance and types of fish and plant species available in and around the Bagega Lake should be encouraged.

REFERENCES

Abalaka, S. E., Enem, S. I., Idoko, I. S., Sani, N. A., Tenuche, O. Z., Ejeh, S. A. and Sambo, W. K. (2020). Heavy metals bioaccumulation and health risks with associated histopathological changes in *Clarias gariepinus* from the Kado fish market, Abuja, Nigeria. *Journal of Health and Pollution*, *10*(26) 1-6.

Abatu, A. (2014). *Accountability a serious challenge in the environmental sector. Daily Trust*.

Abubakar, D. L., Bagudo, B. U., Birnin Yauri, U. A., Sahabi, D. M. and Garba, I. (2015). Post remediation assessment of trace Elements level in soils and plants of Dareta gold mining area, Zamfara State, Nigeria. *Journal Environment Analytical Chemistry*, *2*(131), 2.

ACCLPP. (2012). *CDC Response to Advisory Committee on Childhood Lead Poisoning Prevention Recommendations in "Low Level Lead Exposure Harms Children: A Renewed Call of Primary Prevention".* Centers for Disease Control and Prevention Atlanta.

Ajumobi, O. O., Tsofo, A., Yango, M., Aworh, M. K., Anagbogu, I. N., Mohammed, A., Umar-Tsafe, N., Mohammed, S., Abdullahi, M. and Davis, L. (2014). High concentration of blood lead levels among young children in Bagega community, Zamfara–Nigeria and the potential risk factor. *The Pan African Medical Journal*, *18* (Suppl 1).

Alaba, O. C., and Abdulraman, S. O. (2017). Evaluation of Remedial Option's Effectiveness of Lead Contaminated Site in Bagega Community, Zamfara State, Nigeria. *Ethiopian Journal of Environmental Studies Management*, *10*(10), 1257–1271.

Alaba, O. C., Opafunso, Z. O. and Agyei, G. (2018). Health risk assessment model for lead contaminated soil in Bagega Community, Nigeria. *Journal of Applied Sciences and Environmental Management*, *22*(5), 719–724.

Ali, M. M., Ali, M. L., Islam, M. S. and Rahman, M. Z. (2016). Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh. *Environmental Nanotechnology, Monitoring & Management*, *5*, 27–35.

Alloway, B. J. (2013). Sources of heavy metals and metalloids in soils. In *Heavy metals in soils* (pp. 11–50). Springer.

Andrews, K. W., Savitz, D. A. and Hertz-Picciotto, I. (1994). Prenatal lead exposure in relation to gestational age and birth weight: a review of epidemiologic studies. *American Journal of Industrial Medicine*, *26*(1), 13–32.

Appleton, J. D., Williams, T. M., Orbea, H. and Carrasco, M. (2001). Fluvial contamination associated with artisanal gold mining in the Ponce Enriquez, Portovelo-Zaruma and Nambija areas, Ecuador. *Water, Air, and Soil Pollution*, *131*(1), 19–39.

Agency for Toxic Substances and Disease Registry (ATSDR). Case Studies in Environmental Medicine - Lead Toxicity. Atlanta: Public Health Service, U.S. Department of Health and HumanServices; 1992.

Agency for Toxic Substances and Disease Registry (ATSDR. Public Health Service. Atlanta: U.S. Department of Health and Human Services; 1999. Toxicological Profile for Lead

ATSDR, T. (2000). ATSDR (Agency for toxic substances and disease registry). *Prepared by Clement International Corporation, under Contract*, *205*, 88–608.

Azcue, J. and Mudroch, A. (1994). Comparison of different washing, ashing, and digestion methods for the analysis of trace elements in vegetation. *International Journal of Environmental Analytical Chemistry*, *57*(2), 151–162.

Azubike, O. C. (2011). Update on the lead poisoning incident in Zamfara State Nigeria. *Regional Multi-Stakeholders Workshop, Anglophone West Africa, Sub-Regional Action Planning on Mercury Use in Artisanal and Small Scale Gold Mining*.

Baird C. & Cann M. 2012, *Environmental Chemistry*, 5th ed., W. H. Freeman and Company, New York, ISBN 978-1-4292-7704-4.

Bako, S. P., Ezealor, A. U. and Tanimu, Y. (2014). Heavy metal deposition in soils and plants impacted by anthropogenic modification of two sites in the Sudan Savanna of North Western Nigeria. In *Environmental Risk Assessment of Soil Contamination*. IntechOpen.

Barkan JD. (2007) State and Local Governance in Nigeria, Public Sector and Capacity Building Program: Africa Region; 2007.

Bartrem, C., Tirima, S., von Lindern, I., von Braun, M., Worrell, M. C., Mohammad Anka, S., Abdullahi, A. and Moller, G. (2014). Unknown risk: co-exposure to lead and other heavy metals among children living in small-scale mining communities in Zamfara State, Nigeria. *International Journal of Environmental Health Research*, *24*(4), 304–319.

Bello, O., Naidu, R., Rahman, M. M., Liu, Y. and Dong, Z. (2016). Lead concentration in the blood of the general population living near a lead–zinc mine site, Nigeria: Exposure pathways. *Science of the Total Environment*, *542*, 908–914.

Betts, K. S. (2012). *CDC updates guidelines for children's lead exposure*. National Institute of Environmental Health Sciences.

Beyersmann, D. and Hartwig, A. (2008). Carcinogenic metal compounds: recent insight into molecular and cellular mechanisms. *Archives of Toxicology*, *82*(8), 493–512.

Bishir umar (2015) Estimation Of Lead And Other Elements In Contaminated Soil Of Bagega In Anka Local Government Area Of Zamfara State, Nigeria International Journal of Advances in Science Engineering and Technology, ISSN: 2321-9009 Volume- 3, Issue-3

Bischoff, K., Thompson, B., Erb, H. N., Higgins, W. P., Ebel, J. G. and Hillebrandt, J. R. (2012). Declines in blood lead concentrations in clinically affected and unaffected cattle accidentally exposed to lead. *Journal of Veterinary Diagnostic Investigation*, *24*(1), 182–187.

Brathwaite, R. L. and Rabone, S. D. C. (1985). Heavy metal sulphide deposits and geochemical surveys for heavy metals in New Zealand. *Journal of the Royal Society of New Zealand*, *15*(4), 363–370.

Brown, E., Yedjou, C. G. and Tchounwou, P. B. (2008). *Molecular basis for arsenic-induced oxidative stress and genotoxicity in human liver carcinoma (HepG2) cells*. AACR.

Buba, F. N. and Aboyeji, O. S. (2015). Geospatial analysis of lead concentration in the soil of Anka, Zamfara State, Nigeria. *Greener Journal of Environmental Management Public Safety*, *4*(3), 28–36.

Emeka A. 28 Children Die of Lead Poisoning in Niger State; Guardian newspaper; 5 May 2015.

Earth, P. (2017). Mercury Cleanup Project Naiman, Kyrgyzstan. *Project Completion Report. Https://Www. Pureearth. Org/Wp-Content/Uploads/2017/08/PCR_Naiman_ Kyrgyzstan_2017_07_18. Pdf*.

El-Moselhy, K. M., Othman, A. I., Abd El-Azem, H. and El-Metwally, M. E. A. (2014). Bioaccumulation of heavy metals in some tissues of fish in the Red Sea, Egypt. *Egyptian Journal of Basic and Applied Sciences*, *1*(2), 97–105.

Environment Agency, 2009 Soil Guideline Value .for cadmium in soil Science Report SC050021/Cadmium SGV. Bristol: (Environment Agency).(Accessed 3 May 2018)

FAO. (1983). Compilation of legal limits for hazardous substances in fish and fishery products. FAO fisheries circular No. 764 (p. 102). FAO: Rome.

Flora, S. J. S., Flora, G. and Saxena, G. (2006). Environmental occurrence, health effects and management of lead poisoning. In *Lead* (pp. 158–228). Elsevier.

Galadima, A. and Garba, Z. N. (2012). Zamfara Lead Poisoning. Elixir pollution, 45, pp. 7917-7922.

Gale Encyclopedia of Children's Health. 2006 , Heavy metal poisoning , The Gale Group, Inc

Garba, I. (2000) Origin of Pan-African mesothermal gold mineralization at Bin Yauri, Nigeria, Journal of African Earth Sciences (31) 433-449.

Garba, I. and Akande, S. O. (1992). The origin and significance of non-aqueous CO_2 fluid inclusions in the auriferous veins of Bin Yauri, northwestern Nigeria. *Mineralium Deposita*, *27*(3), 249–255.

Gebeyehu, H. R. and Bayissa, L. D. (2020). Levels of heavy metals in soil and vegetables and associated health risks in Mojo area, Ethiopia. *PloS One*, *15*(1), e0227883.

Girigisu, S., Ibeanu, I. G. E., Adeyemo, D. J., Onoja, R. A., Bappah, I. A. and Okoh, S. (2014). Assessment of radiological levels in soils from artisanal gold mining exercises at Awwal, Kebbi state, Nigeria. *Research Journal of Applied Sciences, Engineering and Technology*, *7*(14), 2899–2904.

Goyer, R. A. (1990). Lead toxicity: from overt to subclinical to subtle health effects. *Environmental Health Perspectives*, *86*, 177–181.

Greig, J., Thurtle, N., Cooney, L., Ariti, C. and Ahmed, A. O. (2014). *Association of Blood Lead Level with Neurological Features in 972 Children Affected by an*.

He, Z. L., Yang, X. E. and Stoffella, P. J. (2005). Trace elements in agroecosystems and impacts on the environment. *Journal of Trace Elements in Medicine and Biology*, *19*(2–3), 125–140.

Herawati, N., Suzuki, S., Hayashi, K., Rivai, I. F. and Koyama, H. (2000). Cadmium, copper, and zinc levels in rice and soil of Japan, Indonesia, and China by soil type. *Bulletin of Environmental Contamination and Toxicology*, *64*(1), 33–39.

Holt, R. W. (1983). The geotectonic evolution of the Anka Belt in the Precambrian Basement Complex of NW Nigeria. *Dissertation Abstracts International. C. European Abstracts*, *44*(4), 830–831.

Islam, M. S., Ahmed, M. K. and Habibullah-Al-Mamun, M. (2015). Determination of heavy metals in fish and vegetables in Bangladesh and health implications. *Human and Ecological Risk Assessment: An International Journal*, *21*(4), 986–1006.

Jaishankar, M., Mathew, B. B., Shah, M. S. and Gowda, K. R. S. (2014). Biosorption of few heavy metal ions using agricultural wastes. *Journal of Environment Pollution and Human Health*, *2*(1), 1–6.

Joint, U. and Unit, O. E. (2010). Lead pollution and poisoning crisis. *Environmental Emergency Response Mission, Zamfara State, Nigeria*.

Kaoud, H. A. and El-Dahshan, A. R. (2010). Bioaccumulation and histopathological alterations of the heavy metals in Oreochromis niloticus fish. *Nature and Science*, *8*(4), 147–156.

Kaoud, H. A. (2015). Article review: heavy metals and pesticides in aquaculture: health problems. *European Journal of Academic Essays*, *2*(9), 15–22.

Kaur, T. and Sinha, A. K. (2019). Pesticides in Agricultural Run Offs Affecting Water Resources: A Study of Punjab (India). *Agricultural Sciences*, *10*(10), 1381.

Kazaure, M. B. (2018). Distribution of bacteria in lead contaminated soil in Anka local government area, Zamfara state, Nigeria. *Acta Scientific Microbiology*, *1*(7), 53–60.

Kendall, O. (2013). *Types of Pollution Generated by Gold Mining: ehow health. Demand Media, Inc*.

Kevin, T. (2011). Assessment of the Artisanal and Small Scale Gold Mining in Anka and Bukkuyum LGAs. Zamfara State, Nigeria, Artisanal Gold Council.

Khan, S., Cao, Q., Zheng, Y. M., Huang, Y. Z. and Zhu, Y. G. (2008). Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. *Environmental Pollution*, *152*(3), 686–692.

Kozin, L. F. and Hansen, S. C. (2013). *Mercury handbook: Chemistry, Applications and Environmental Impact*. Royal Society of Chemistry.

Lambert, M., Leven, B. A. and Green, R. M. (2000). New methods of cleaning up heavy metal in soils and water. *Environmental Science and Technology Briefs for Citizens. Kansas State University, Manhattan, KS.*

Landrigan, P. J., Fuller, R., Acosta, N. J. R., Adeyi, O., Arnold, R., Baldé, A. B., Bertollini, R., Bose-O'Reilly, S., Boufford, J. I. and Breysse, P. N. (2018). The Lancet Commission on pollution and health. *The Lancet*, *391*(10119), 462–512.

Lanphear, B. P. (1998). *The paradox of lead poisoning prevention*. American Association for the Advancement of Science.

Lenntech, B. V. (2013). *Water treatment solutions. Rotterdamseweg 402 M 2629 HH Delft, Netherland*.

Lenntech, W. (2004). Water Treatment and Air Purification, published by Lenntech. Rotterdamseweg, Netherlands.

Lokeshappa, B., Shivpuri, K., Tripathi, V. and Dikshit, A. K. (2012). *Assessment of Toxic Metals in Agricultural Produce. Food and Public Health, 2 (1): 24-29.*

Lottermoser, B. G. (2011). Recycling, reuse and rehabilitation of mine wastes. *Elements*, *7*(6), 405–410.

Maiti, P. and Banerjee, S. (2012). Fate of metals in fish under variable sewage input in fish ponds. *International Journal of Science Resource Publication*, *2*(6), 1–13.

Marriott, A. L., Kelly, T. J., Sarkar, S. K., Chenery, S. R. N., Rakshit, D., Bhattacharya, B. D. and Watts, M. J. (2020). Elemental composition of aquaculture fish from West Bengal, India: nutrition versus food safety. *Environmental Geochemistry and Health*, *42*(4), 1211–1228.

Maurya, P. K. and Malik, D. S. (2016). Distribution of heavy metals in water, sediments and fish tissue (Heteropneustis fossilis) in Kali River of western UP India. *International Journal of Fisheries and Aquatic Studies*, *4*(2), 208–215.

Maurya, P. K. and Malik, D. S. (2019). Bioaccumulation of heavy metals in tissues of selected fish species from Ganga river, India, and risk assessment for human health. *Human and Ecological Risk Assessment: An International Journal*, *25*(4), 905–923.

Maurya, Pradip Kumar, Malik, D. S., Yadav, K. K., Kumar, A., Kumar, S. and Kamyab, H. (2019). Bioaccumulation and potential sources of heavy metal contamination in fish species in River Ganga basin: Possible human health risks evaluation. *Toxicology Reports*, *6*, 472–481.

Meche, A., Martins, M. C., Lofrano, B. E. S. N., Hardaway, C. J., Merchant, M. and Verdade, L. (2010). Determination of heavy metals by inductively coupled plasma-optical emission spectrometry in fish from the Piracicaba River in Southern Brazil. *Microchemical Journal*, *94*(2), 171–174.

Medecins Sans Frontieres (MSF) (2012). Lead Poisoning Crisis in Zamfara State Northern Nigeria. *MSF Brief Pap.* Available at http://www.msf.org/sites/msf.org/files/old-cms/fms/articledocuments/MSF-Nigeria-Lead.pdf. [Accessed 15 November, 2019].

Medeiros, R. J., dos Santos, L. M. G., Freire, A. S., Santelli, R. E., Braga, A. M. C. B., Krauss, T. M. and Jacob, S. C. (2012). Determination of inorganic trace elements in edible marine fish from Rio de Janeiro State, Brazil. *Food Control*, *23*(2), 535–541.

Mosana C., Mapfaire L., Mapurazi S. and Makanda R. (2011), Assessement of Heavy MetalAccumulation in waste Water Irrigated Soil and Uptake by maize plant (Zea mays) at Firle Farm in Harare, Zimbaqwe. Journal of sustainable development, vol. 4, No. 6

Mulvihill G & Pritchard J (2010). 'McDonald's Recall: 'Shrek' Glasses Contain Toxic Metal Cadmium', Huffington Post, 4 June, viewed 24 April 2018.

Murdock H. (2012). Activists Use Facebook to Fight Nigeria Lead Poisoning. Voice of America. Available: http://www.voanews.com/content/ nigerian-activists-facebook-for-lead-poisoningcleanup/1559716.html [accessed 31 January 2018].

MMSD (2010). Lead-Zinc: Exploration Opportunities in Nigeria. Abuja, Ministry of Mines and Steel Development. Available: http://www.mmsd.gov.ng/downloads/Lead%Zinc.pdf. [Accessed 15 November, 2019].

Nagajyoti, P. C., Lee, K. D. and Sreekanth, T. V. M. (2010). Heavy metals, occurrence and toxicity for plants: a review. *Environmental Chemistry Letters*, *8*(3), 199–216.

Najeeb, U., Ahmad, W., Zia, M. H., Zaffar, M. and Zhou, W. (2017). Enhancing the lead phytostabilization in wetland plant Juncus effusus L. through somaclonal manipulation and EDTA enrichment. *Arabian Journal of Chemistry*, *10*, S3310–S3317.

NCRP, 1996. Screening models for releases of radionuclides to atmosphere, surface water, and ground. NCRP report No. 123 I. National Council on Radiation Protection and Measurements, USA

NNP. New Nigerian Politics. Lead poison kills 400 infants in Zamfara. March 7th, 2011.

Nriagu, J. O. (1989). A global assessment of natural sources of atmospheric trace metals. *Nature*, *338*(6210), 47–49.

Nuhu, A. A., Sallau, M. S. and Majiya, M. H. (2014). *Research Journal of Pharmaceutical, Biological and Chemical Sciences*. 5(6),306-312

Nukpezah, D., Rahman, F. A. and Koranteng, S. S. (2017). The impact of small scale mining on irrigation water quality in Asante Akim Central Municipality of Ghana. *West African Journal of Applied Ecology*, *25*(2), 49–67.

O'Brien, R. M., Phelan, T. J., Smith, N. M. and Smits, K. M. (2020). Remediation in developing countries: A review of previously implemented projects and analysis of stakeholder participation efforts. *Critical Reviews in Environmental Science and Technology*, 1–22.

Obahiagbon, K., & Olowojoba, G. (2007). Metal toxicity in mammals: Chemical toxicity of metals and metalloids. New York: Plenum press, (2).

Ogabiela, E. E., Okonkwo, E. M., Udiba, U. U., Oklo, D. A., Hammuel, C., Ade-Ajayi, A., Abdullahi, M. and Nwobi, B. (2011). Trace metal level of hang dug well in Dareta village, Anka, Nigeria. *Journal of Basic and Applied Science Research*, *1*(9), 981–984.

Oladeji, O. S., Adelowo, F. E., Oluyori, A. P. and Bankole, D. T. (2020). Ethnobotanical description and biological activities of Senna alata. *Evidence-Based Complementary and Alternative Medicine, 2*,1-6.

Olatunji-Ojo, A. M., Alimba, C. G., Adenipekun, C. O. and Bakare, A. A. (2020). Experimental simulation of somatic and germ cell genotoxicity in male Mus musculus fed extracts of lead contaminated Pleurotus ostreatus (white rot fungi). *Environmental Science and Pollution Research*, *27*(16), 19754–19763.

Olayinka-Olagunju, J. O., Dosumu, A. A. and Olatunji-Ojo, A. M. (2021). Bioaccumulation of Heavy Metals in Pelagic and Benthic Fishes of Ogbese River, Ondo State, South-Western Nigeria. *Water, Air, & Soil Pollution*, *232*(2), 1–19.

Opanfunso ZO. Overview of Best practices and field experience in artisanal and small scale gold mining in Nigeria. UNEP Project, 2010. Opanfunso 2010Available:www.unep.org/.../Mercury/.../ASGM/Nigeria/.../Overview%20of%20Best%20Practice... (Accessed 30 January 2019)

Ozbek, N. (2018). Elemental analysis of henna samples by MP AES. *Journal of Turkey Chemistry Society*, *5*, 857–868.

Patlolla, A. K., Barnes, C., Yedjou, C., Velma, V. R. and Tchounwou, P. B. (2009). Oxidative stress, DNA damage, and antioxidant enzyme activity induced by hexavalent chromium in Sprague-Dawley rats. *Environmental Toxicology: An International Journal*, *24*(1), 66–73.

Pirkle, J. L., Kaufmann, R. B., Brody, D. J., Hickman, T., Gunter, E. W. and Paschal, D. C. (1998). Exposure of the US population to lead, 1991-1994. *Environmental Health Perspectives*, *106*(11), 745–750.

Plumlee GS, Durant JT, Suzette AM, Neri A, Wolf RE, and Dooyema CA (2013). Linking geological and health sciences to assess childhood lead poisoning from artisanal gold mining in Nigeria. Environmental Health Perspect 121:744–750

Plumlee, G. S. and Morman, S. A. (2011). Mine wastes and human health. *Elements*, *7*(6), 399–404.

Rajeswari T. R and Sailaja, N (2014). "Impact of Heavy metals on environmental pollution", Journal of Chemical and Pharmaceutical Sciences, Special Issue 3, pp. 175-181

Razo, I., Carrizales, L., Castro, J., Díaz-Barriga, F. and Monroy, M. (2004). Arsenic and heavy metal pollution of soil, water and sediments in a semi-arid climate mining area in Mexico. *Water, Air, and Soil Pollution*, *152*(1), 129–152.

Sánchez-Chardi, A., Peñarroja-Matutano, C., Ribeiro, C. A. O. and Nadal, J. (2007). Bioaccumulation of metals and effects of a landfill in small mammals. Part II. The wood mouse, Apodemus sylvaticus. *Chemosphere*, *70*(1), 101–109.

Santé, O. mondiale de la. (2018). *World Health Statistics 2018: monitoring health for the SDGs sustainable development goals*. World Health Organization.

Shallari, S., Schwartz, C., Hasko, A. and Morel, J.L. (1998). Heavy metals in soils and plants of serpentine and industrial sites of Albania. *Science of the Total Environment*, *209*(2–3), 133–142.

Shiloh, (2010) Lead poisoning in kills over 160 people in Nigeria's Northern zamfara state.

Shivakumar, C. K., Thippeswamy, B., Tejaswikumar, M. V. and Prashanthakumara, S. M. (2014). Bioaccumulation of heavy metals and its effect on organs of edible fishes located in Bhadra River, Karnataka. *International Journal of Research in Fisheries and Aquaculture*, *4*(2), 90–98.

Singh, J., Yadav, P., Pal, A. K. and Mishra, V. (2020). Water pollutants: Origin and status. In *Sensors in Water Pollutants Monitoring: Role of Material* (pp. 5–20). Springer.

Sobha, V. V, Sapna Varma, N. K. and Ajith, V. V. (2016). *Comparative evaluation of laser etching and acid etching: an in vitro study*.

Sola Ogundipe (2010) lead poisoning kills over 200 people in Nigeria's Northern Zamfara state, Pathfinder http://www.vanguardngr.com/2010/07/1...-brain-damage.

Srivastava, S. and Goyal, P. (2010). *Novel biomaterials: decontamination of toxic metals from wastewater*. Springer Science & Business Media.

Sutton, D. J. and Tchounwou, P. B. (2007). Mercury induces the externalization of phosphatidyl-serine in human renal proximal tubule (HK-2) cells. *International Journal of Environmental Research and Public Health*, *4*(2), 138–144.

Sutton, D. J., Tchounwou, P. B., Ninashvili, N. and Shen, E. (2002). Mercury induces cytotoxicity and transcriptionally activates stress genes in human liver carcinoma (HepG2) cells. *International Journal of Molecular Sciences*, *3*(9), 965–984.

Tacon, A. G. J., Lemos, D. and Metian, M. (2020). Fish for health: improved nutritional quality of cultured fish for human consumption. *Reviews in Fisheries Science & Aquaculture*, *28*(4), 449–458.

Tanimu, Y., Bako, S. P. and Tiseer, F. A. (2013). Effects of sewage pollution on water quality of Samaru stream, Zaria, Nigeria. *WASTE WATER*, 189.

Tchounwou, Paul B, Centeno, J. A. and Patlolla, A. K. (2004). Arsenic toxicity, mutagenesis, and carcinogenesis–a health risk assessment and management approach. *Molecular and Cellular Biochemistry*, *255*(1), 47–55.

Tchounwou, Paul B, Yedjou, C. G., Patlolla, A. K. and Sutton, D. J. (2012). Heavy metal toxicity and the environment. *Molecular, Clinical and Environmental Toxicology*, 133–164.

Tchounwou, Paul Bernard, Ishaque, A. B. and Schneider, J. (2001). Cytotoxicity and transcriptional activation of stress genes in human liver carcinoma cells (HepG2) exposed to cadmium chloride. *Molecular and Cellular Biochemistry*, *222*(1), 21–28.

Tijjani, M. B., Agaie, B. M., Onifade, K. I., Mainasara, A. S., Yusuf, I. L. and Tijjani, A. O. (2019). Post-epidemic lead exposure to animals following a decontamination exercise in gold mining village of Bagega, Zamfara State, Nigeria. *Journal of Toxicology and Environmental Health Sciences*, *11*(3), 32–37.

Tirima, S., Bartrem, C., von Lindern, I., von Braun, M., Lind, D., Anka, S. M. and Abdullahi, A. (2016). Environmental remediation to address childhood lead poisoning epidemic due to artisanal gold mining in Zamfara, Nigeria. *Environmental Health Perspectives*, *124*(9), 1471–1478.

Udiba, U. U., Ogabiela, E. E., Hammuel, C., Magomya, A. M., Yebpella, G. G., Ade-Ajayi, A. F., Odey, M. O. and Gauje, B. (2012). Post remediation assessment of contaminants levels in soil, Dareta Village, Zamfara, Nigeria. *Trends Advanced Science Engineer*, *4*(1), 70–79.

Uriah, L., Kenneth, T., Gusikit, R. and Ayuba, M. (2013). *Lead and Mercury Contamination Associated with Artisanal Gold Mining in Anka, Zamfara State, North Western Nigeria: The Continued Unabated Zamfara Lead Poisoning.*

UNICEF Programme Cooperation Agreement,(2011) Environmental Remediation – Lead Poisoning in Zamfara FINAL REPORT September 2010 – March 2011.

United States Environmental Protection Agency. Allowable limits for lead in soil. US EPA; c2008. Available: http://www.epa.gov/lead/pubs/learn-about-lead.html (Accessed 29 November 2019)

US EPA. (2012). Institutional controls: A guide to planning, implementing, maintaining, and enforcing institutional controls at contaminated sites (EPA-540-R-09-001). United States Environmental Protection Agency Office of Solid Waste and Emergency Response (OSWER). https://www.epa.gov/sites/production/files/documents/final_pime_guidance_december_2012.pdf

Veiga, M. M., Metcalf, S., Baker, R. F., Klein, B., Davis, G., Bamber, A., Siegel, S., Singo, P. and Investments, G. L. (2006). Manual for training artisanal and small-scale gold miners. *Global Mercury Project. UNIDO, Vienna, Austria*.

Venkateswarlu, V. and Venkatrayulu, C. (2020). Bioaccumulation of heavy metals in edible marine fish from coastal areas of Nellore, Andhra Pradesh, India. *GSC Biological and Pharmaceutical Sciences*, *10*(1), 18–24.

Wang, S. and Shi, X. (2001). Molecular mechanisms of metal toxicity and carcinogenesis. *Molecular and Cellular Biochemistry*, *222*(1), 3–9.

W. H. O., (2003). *Atrazine in Drinking-Water: Background Document for Development of WHO Guidelines for Drinking-Water Quality*. World Health Organization.

W. H. O., (2014). P*ublic Health Events of Initially Unknown Etiology: A Framework for Preparedness and Response in the African Region*. World Health Organization.

W. H. O., (2016). *World Health Statistics 2016: Monitoring Health for the SDGs Sustainable Development Goals*. World Health Organization.

Wilson, B. and Pyatt, F. B. (2007). Heavy metal dispersion, persistance, and bioccumulation around an ancient copper mine situated in Anglesey, UK. *Ecotoxicology and Environmental Safety*, *66*(2), 224–231.

WHO. (2011). Guidelines for drinking water quality. (4th ed.p. 564). Geneva: World Health Organization.

Wong, S. L. and Lye, E. J. D. (2008). Lead, mercury and cadmium levels in Canadians. *Health Reports / Statistics Canada, Canadian Centre for Health Information = Rapports Sur La Santé / Statistique Canada, Centre Canadien d'information Sur La Santé*, *19*(4), 31–36.

Yadav, K. K., Gupta, N., Kumar, V., Khan, S. A. and Kumar, A. (2018). A review of emerging adsorbents and current demand for defluoridation of water: bright future in water sustainability. *Environment International*, *111*, 80–108.

Yongsheng, W., Qihui, L. and Qian, T. (2011). Effect of Pb on growth, accumulation and quality component of tea plant. *Procedia Engineering*, *18*, 214–219.

Yousif, N. (2007). *Geochemistry of stream sediment from the state of Colorado using NURE data*. The University of Texas at El Paso.

APPENDICES



Appendix 1a: Sluicing of gold ore material in Bagega Lake (February 21, 2020)



Appendix 1b: Gold ore processor fetching water to the processing site

Appendix 1: Common Activities Occuring in Bagega Lake Zamfara-State



Appendix II: Industrial Utilization of Water from Bagega Lake Zamfara-State, Nigeria

⟷ =Double egde arrow indicating the Remediated sites



Appendix III: Domestic Utilization of Water from Bagega Lake Zamfara-State, Nigeria

⟷ =Double egde arrow indicating the unremediated sites