

**EVALUATION OF POTENTIAL NON-CARCINOGENIC HEALTH RISKS FROM
INGESTION OF HEAVY METALS IN CONTAMINATED SOILS AROUND SAND
MINING AREAS**

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BENIN CITY.**

OCTOBER, 2025.

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**A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF SCIENCE
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CERTIFICATION

This is to certify that this undergraduate project work titled **“EVALUATION OF POTENTIAL NON-CARCINOGENIC HEALTH RISKS FROM INGESTION OF HEAVY METALS IN CONTAMINATED SOILS AROUND SAND MINING AREAS”** was submitted and presented by Racheal Kehinde THOMPSON (Miss) with matriculation number LSC2007355 in the Department of Science Laboratory Technology, Faculty of Life Sciences, and University of Benin, Benin City.

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DEDICATION

This work is dedicated to Almighty GOD and my family to whom I work so hard to make proud.

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I sincerely express my profound gratitude to the Almighty God for His guidance, wisdom and strength throughout the course of this research work. Without his grace, this study would not have been possible.

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ABSTRACT

The study assessed the levels of heavy metals in soils near sand mining sites in Iyuku, Auchi, Edo State, Nigeria and evaluated associated non-carcinogenic health risks through incidental ingestion. Soil samples were collected from ten locations, air-dried, sieved and analyzed for Fe, Zn, Cu, Pb, Cd, Mn, Ni, Cr and Co using atomic absorption spectrophotometry after aqua regia digestion. Mean concentrations were highest for Fe (56.24 mg/kg), followed by Zn (27.15 mg/kg) and Cu (18.76 mg/kg), with Cd and Co at trace levels (0.45 mg/kg and 0.32 mg/kg, respectively). All values fell below World Health Organization (WHO, 2011) and United State Environmental Protection Agency (USEPA, 1992) soil quality guidelines, indicating limited contamination. Chronic daily intake (CDI) via ingestion was calculated for children and adults, revealing higher exposure in children due to behavioural factors. Hazard quotients (HQ) for individual metals and the hazard index (HI) for combined exposure were all below 1, suggesting negligible non-carcinogenic risks. However, elevated Fe and Zn near active pits highlight the need for ongoing monitoring. The findings underscore the importance of regulatory measures to prevent future escalation of risks in similar mining communities, emphasizing sustainable practices to protect vulnerable groups.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

The exponential growth in global population and urban development has led to an unprecedented demand for natural resources especially construction materials like sand. Sand mining, both legal and illegal, has escalated to meet this demand. While sand is an essential component in concrete, glass and other construction materials, the mining of this resource has come under increasing scrutiny due to its environmental and public health implications (Kondolf, 1997; UNEP, 2019). Among these concerns, heavy metal contamination of surrounding soils is one of the most pressing issues, particularly in unregulated or poorly managed mining areas.

Heavy metals such as lead (Pb), cadmium (Cd), arsenic (As), chromium (Cr), nickel (Ni) and mercury (Hg) are naturally occurring elements that can be introduced into the environment through both natural geological processes and anthropogenic activities including sand mining. During the excavation and transportation of sand, these metals can be released from deeper soil layers or from the use of fuel and machinery involved in mining operations (Wuana and Okieimen, 2011; Saviour, 2012). Furthermore, some sand deposits are located in areas where metal-bearing rocks are common making contamination more likely.

The persistence and bio accumulative nature of heavy metals make them particularly hazardous. Unlike organic pollutants, heavy metals do not degrade over time and can remain in soils for decades continually posing risks to ecological and human health (Tchounwou *et al.*, 2012). In areas near sand mining operations, the soil may become a direct source of

exposure for local communities especially in regions where residential zones are adjacent to mining sites. This exposure can occur through multiple pathways including the inadvertent ingestion of contaminated soil particles, particularly among children who are more vulnerable due to their frequent hand-to-mouth activity and developing physiological systems (Li *et al.*, 2014; Bortey-Sam *et al.*, 2015).

The ingestion of contaminated soil may not necessarily result in immediate health effects but can lead to chronic conditions over time. Non-carcinogenic health effects linked to heavy metal exposure include neurological disorders, kidney and liver damage, developmental delays in children, immune system dysfunction and reproductive toxicity (Tchounwou *et al.*, 2012). These outcomes are particularly concerning in low-income and rural communities where access to healthcare and environmental monitoring is limited.

Risk assessment models are widely used to evaluate the potential health implications of environmental exposure to toxicants. The United States Environmental Protection Agency (USEPA) has developed a framework that includes the calculation of the Hazard Quotient (HQ) for individual substances and the Hazard Index (HI) for multiple contaminants. These metrics are based on estimated daily intake of a contaminant relative to a reference dose below which adverse health effects are unlikely to occur (USEPA, 1989). An HQ or HI greater than 1 indicates a potential health risk and warrants further investigation or remediation efforts.

Numerous studies across the globe have documented elevated concentrations of heavy metals in soils surrounding sand mining areas. For instance, research in Ghana by Bortey-Sam *et al.*

(2015) found significantly higher levels of lead and arsenic in soils around active sand mining zones compared to control sites. Similarly, Li *et al.* (2014) observed alarming levels of cadmium and mercury in mining-impacted soils in China linking these findings to potential human health risks especially among children.

In many developing countries, environmental regulations concerning sand mining are either weak or poorly enforced. As a result, communities are often exposed to contaminated environments without adequate risk communication or mitigation strategies (UNEP, 2019). This underscores the need for comprehensive studies that not only measure contaminant levels in soil but also assess the actual health risks posed by these contaminants. By doing so, governments and regulatory bodies can develop targeted interventions such as public awareness campaigns, soil remediation strategies, land-use zoning and stricter mining regulations.

Evaluating the non-carcinogenic health risks associated with the ingestion of heavy metals in contaminated soils near sand mining areas is essential for protecting public health and promoting sustainable environmental practices. Such studies provide the scientific basis for environmental health policies, contribute to community education and support international goals for environmental justice and pollution prevention. Given the complexity and severity of the issue, multidisciplinary approaches involving environmental scientists, toxicologists, public health professionals and policymakers are needed to effectively address the health threats posed by heavy metal contamination in sand mining regions.

1.2 PROJECT PROBLEM STATEMENT

The rapid expansion of sand mining activities worldwide driven by increasing urbanization and infrastructural development has raised significant environmental and public health concerns. Sand mining often disrupts natural ecosystems and leads to the degradation of soil quality in mining areas (Kondolf, 1997). One of the most critical issues associated with sand mining is the contamination of soils with heavy metals such as lead (Pb), cadmium (Cd), arsenic (As), chromium (Cr) and mercury (Hg) which are either naturally present in the geological matrix or introduced through mining operations and associated machinery (Wuana and Okieimen, 2011; Saviour, 2012). These metals are persistent environmental pollutants known for their toxicity and bioaccumulative nature which pose long-term risks to human health and ecosystems (Tchounwou *et al.*, 2012).

Despite numerous studies documenting heavy metal contamination in mining-affected soils, there remains a significant knowledge gap regarding the extent and severity of exposure risks to local populations, particularly through the ingestion of contaminated soils. Soil ingestion is a critical exposure pathway especially for vulnerable groups such as children who exhibit hand-to-mouth behaviors and are more susceptible to the toxic effects of metals (Li *et al.*, 2014; Bortey-Sam *et al.*, 2015). Chronic exposure to heavy metals can lead to a range of non-carcinogenic health effects including neurological impairments, kidney dysfunction, developmental delays and immune system disorders (Tchounwou *et al.*, 2012).

Moreover, in many regions where sand mining is prevalent, environmental monitoring and regulatory enforcement are weak or insufficient resulting in uncontrolled contamination and a lack of effective risk management strategies (UNEP, 2019). This regulatory gap exacerbates

the problem leaving affected communities exposed to hazardous contaminants without adequate awareness or mitigation measures. Current risk assessments are often limited or absent, hindering policy-makers ability to prioritize interventions and allocate resources effectively.

Therefore, this study aims to address the critical need for comprehensive evaluation of heavy metal contamination levels in soils around sand mining areas and to assess the potential non-carcinogenic health risks from ingestion of these contaminated soils. By providing empirical evidence and health risk estimations, this research will contribute to informed environmental management, enhance public health protection and support the development of regulatory frameworks that mitigate exposure to toxic metals in mining-impacted communities.

1.3. AIM AND OBJECTIVE

Aim

The aim of this study is to evaluate the potential non-carcinogenic health risks associated with the ingestion of selected heavy metals in contaminated soils around sand mining areas.

Objectives

1. To determine the concentrations of selected heavy metals in soil samples collected from various locations around sand mining sites.
2. To evaluate the chronic daily intake (CDI) for heavy metals through ingestion pathway for adults and children.
3. To assess non-carcinogenic risk associated with the heavy metals in adults and children.

1.4 SCOPE OF THE PROJECT

The project covers specifically the evaluation of potential non-carcinogenic health risks from ingestion of heavy metals in contaminated soils around sand mining areas.

1.5 JUSTIFICATION OF THE STUDY

Sand mining is a widespread activity that supports infrastructure development yet it often occurs with minimal environmental oversight, especially in developing countries. This unchecked extraction can lead to soil contamination with heavy metals which poses a serious threat to human health, particularly through ingestion of contaminated particles. Despite the growing body of evidence linking heavy metal exposure to various non-carcinogenic health effects; such as developmental disorders, neurological damage, and organ toxicity. There remains a significant gap in localized studies assessing the specific risks posed to communities living near sand mining areas. In many affected regions, there is limited awareness and insufficient risk assessment data to inform decision-makers and protect vulnerable populations.

The health risk assessment is a good tool for assessing the link between the environment and human health. These can be expressed quantitatively in terms of hazard degree.

Therefore, this study is justified as it provides critical insight into the levels of heavy metal contamination in soils and evaluates the associated health risks using scientifically recognized models such as the Hazard Quotient (HQ) and Hazard Index (HI). The findings will support environmental monitoring, raise community awareness and guide policymakers

in implementing appropriate regulations and remediation strategies aimed at reducing exposure and safeguarding public health.

CHAPTER TWO

LITERATURE REVIEW

2.1 MINING

Mining is a major anthropogenic activity that involves the extraction of valuable geological materials from the Earth's crust for commercial use. These materials include ores, metals, fossil fuels and industrial minerals such as limestone and sand. Depending on the method of extraction and the nature of the deposit, mining can be classified into several types, including surface mining (open-pit, strip and quarrying), underground mining, placer mining and in-situ leaching. Each method has varying degrees of environmental impact but all involve significant land disturbance, waste generation and risk of pollution (Bell *et al.*, 2001).

Sand mining, which involves the removal of sand from beaches, riverbeds and inland dunes has become one of the most pressing environmental issues of the 21st century. Sand is an essential raw material for concrete, asphalt, glass and even electronic components, making it the second most consumed natural resource globally after water. The growing demand for sand has resulted in excessive extraction practices, especially in developing countries where urbanization and infrastructure development are accelerating rapidly (Koehnken *et al.*, 2020).

In many parts of Africa and Asia, sand mining is conducted by informal operators with little to no environmental oversight. These operations are often carried out near riverbanks, estuaries, farmlands and protected ecosystems. In Nigeria, for example, sand mining is

largely unregulated, especially in semi-urban and rural areas where it serves as a primary source of livelihood for unemployed youth. The absence of strict environmental policies and enforcement has led to indiscriminate extraction, resulting in serious land degradation, hydrological disruption and soil contamination (Eze and Ibe, 2021).

The environmental implications of unregulated sand mining are profound and multifaceted. Vegetation removal and disruption of the soil profile expose underlying geological layers, allowing naturally occurring heavy metals such as lead (Pb), cadmium (Cd), arsenic (As) and chromium (Cr) to migrate to the topsoil. This not only compromises soil quality but also increases the risk of human and ecological exposure. Additionally, the use of fossil-fuel-powered machinery and improper disposal of lubricants and chemicals contribute to heavy metal accumulation in the soil. These contaminants are persistent, non-biodegradable and can travel through the soil-water interface to nearby agricultural plots and groundwater sources (Saviour, 2012).

Beyond environmental degradation, sand mining also poses significant public health risks. In many sand-rich regions of Nigeria, sand mining sites are located near residential communities. Children playing in exposed sand pits, farmers cultivating nearby lands and households relying on shallow wells are all at risk of exposure to contaminated soil and water. The ingestion of heavy metal laden soil particles whether directly through hand to mouth contact or indirectly through contaminated crops and water can lead to severe non-carcinogenic health outcomes such as neurological disorders, kidney damage and skeletal abnormalities (ATSDR, 2017; WHO, 2011).

Several case studies from Nigeria underscore the severity of these impacts. In Ogun State, elevated concentrations of lead and zinc were detected in soil samples from areas adjacent to sand dredging sites. (Ibitoye and Omosuyi, 2019) reported that the levels of these metals exceeded the permissible limits set by the World Health Organization and the Food and Agriculture Organization for agricultural soils. Similarly, in the coastal region of Lekki in Lagos State, rampant beach sand mining has led to accelerated coastal erosion, increased salinity in agricultural lands and biodiversity loss. These findings are consistent with those in other parts of Africa and Asia, where sand mining has compromised the physical integrity of ecosystems and threatened food security (Ogundele *et al.*, 2016).

Despite these documented consequences, sand mining remains poorly studied in comparison to other forms of extractive industries such as gold, coal and oil mining. Regulatory oversight is often weak due to limited institutional capacity and lack of political will while academic interest has historically focused on more visibly hazardous mining sectors. This has created a significant research gap in understanding the full scope of environmental and health risks associated with sand mining, particularly in tropical developing countries. Bridging this gap is essential for designing evidence based policies and interventions aimed at minimizing the ecological and human health impacts of this increasingly pervasive activity.

2.2 HEAVY METALS

Heavy metals are a group of elements that possess relatively high atomic weights and densities, typically at least five times greater than that of water. These metals include both naturally occurring elements and those introduced into the environment through human

activities. Common examples of heavy metals include lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg), chromium (Cr), nickel (Ni), zinc (Zn) and copper (Cu). While some heavy metals are essential for biological functions in trace quantities, others are toxic even at very low concentrations (Alloway, 2013).

The defining characteristics of heavy metals lie in their high density, atomic mass and tendency to form complex compounds with both organic and inorganic ligands. They are also notable for their toxicity, persistence in the environment and potential for bioaccumulation in living organisms. Unlike organic pollutants, heavy metals do not degrade or break down through natural processes, which allows them to accumulate in soil, water, plants and animal tissues over time (Pendias and Mukherjee, 2007). These features make heavy metals a critical concern in environmental studies, particularly in areas impacted by mining, industrial activity or intensive agriculture.

2.2.1 CLASSIFICATION OF HEAVY METALS

Heavy metals can be broadly classified into essential and non-essential categories based on their biological significance:

2.2.1.1 ESSENTIAL HEAVY METALS

These include zinc (Zn), copper (Cu), iron (Fe), manganese (Mn), cobalt (Co) and selenium (Se). They are required by organisms in small amounts for various physiological and enzymatic functions, including cell respiration, antioxidant defense and hormone regulation. However, when their concentrations exceed certain thresholds, they can interfere with normal biological processes and become toxic.

2.2.1.2 NON-ESSENTIAL HEAVY METALS

These include lead (Pb), cadmium (Cd), arsenic (As) and mercury (Hg). These metals have no known biological function and are toxic even at low concentrations. Exposure to non-essential heavy metals is associated with serious health issues, including neurotoxicity, kidney and liver damage, developmental problems in children and cardiovascular disease (ATSDR, 2017; WHO, 2011).

Understanding the behavior of heavy metals in soil is particularly important in areas affected by sand mining. During the mining process, deep soil layers that naturally contain heavy metals can be brought to the surface, increasing both their mobility and exposure risk. The removal of vegetation and soil compaction further reduce the soil's buffering capacity, thereby promoting the leaching of metals into groundwater and their accumulation in the root zone of crops. These processes increase the likelihood of ingestion directly through soil particles or indirectly via contaminated food especially among populations living in or near sand mining zones.

2.3 SOURCES OF HEAVY METALS

Heavy metals are introduced into the environment from a combination of natural and anthropogenic sources. Their accumulation in soils can result from long term geologic processes or be accelerated by modern human activities. Understanding these sources is crucial for determining the origin of contamination in areas such as sand mining zones, where both natural geology and human interference play a role in heavy metal enrichment.

2.3.1 Natural Sources

Heavy metals are naturally present in the Earth's crust and are released into the environment through geochemical and geological processes. Weathering of parent rocks is one of the primary natural mechanisms through which heavy metals are mobilized into the soil system. As rocks break down physically and chemically under the influence of climate, biological activity and natural erosion, trace elements like arsenic (As), cadmium (Cd), lead (Pb) and chromium (Cr) are gradually released into surrounding soils and sediments (Pendias and Mukherjee, 2007).

Another significant natural source is volcanic activity. Volcanic eruptions release large quantities of heavy metals such as mercury (Hg), arsenic and lead into the atmosphere. These metals can travel long distances before being deposited on the Earth's surface through rainfall or settling, thereby enriching the topsoil (Adriano, 2001). Although these processes are continuous and long term, their contribution to soil metal levels is generally moderate unless combined with local mineralization or geologic faults that naturally concentrate metals.

2.3.2. Anthropogenic Sources

Human activities are now the dominant sources of heavy metal pollution globally. In particular, mining, industrial production, agriculture and urban development have drastically increased metal loading in the environment.

- i. Mining and Mineral Processing: Mining activities including the extraction and processing of metal ores, are major contributors to heavy metal contamination. The removal of overburden and ore processing release significant quantities of metals

into the surrounding soil, water and air. Tailings and mine waste often contain elevated levels of toxic metals that can leach into the environment if not properly managed (Alloway, 2013).

- ii. **Agriculture:** The use of phosphate fertilizers, pesticides and sewage sludge in agriculture introduces metals such as cadmium, lead and arsenic into the soil. These compounds accumulate over time and can enter the food chain through plant uptake. Irrigation with contaminated water and long term application of agrochemicals further exacerbate soil metal loading.
- iii. **Industrial Emissions and Waste:** Smelting operations, battery manufacturing, petroleum refining and other industrial activities discharge heavy metals into the atmosphere and hydrosphere. These pollutants are later deposited onto the soil surface through precipitation or dry deposition. Urban storm water runoff and improper waste disposal practices also contribute to metal accumulation in city adjacent soils (ATSDR, 2017).

2.3.3 Sand Mining–Related Inputs

In the context of sand mining, several specific activities contribute directly to the enrichment of heavy metals in the soil:

- i. **Diesel Combustion and Equipment Use:** The use of heavy duty, diesel powered machinery such as dredgers, bulldozers and trucks emits particulate matter and exhaust gases containing metals like lead, vanadium and zinc. These emissions can

settle on nearby soils or be washed into the ground by rainfall (Ibitoye and Omosuyi, 2019).

- ii. **Oil and Lubricant Spillage:** The improper handling and disposal of used engine oil, hydraulic fluids and greases during mining operations are common. These petroleum based substances often contain toxic metals such as chromium and nickel. Spillage or leaks can lead to localized hotspots of soil contamination, especially when absorbed into porous, sandy soils.
- iii. **Leaching and Surface Runoff:** Sand mining operations disturb the natural soil profile, making the surface more vulnerable to leaching and erosion. When rain falls on exposed soil or overburden, it can carry dissolved heavy metals downslope into nearby lands, water bodies or farmlands. These processes are accelerated by the removal of vegetation and compaction of topsoil, both of which reduce the soil's natural filtration capacity (Saviour, 2012).
- iv. **Geological Disturbance and Mobilization:** The excavation of sand often exposes subsurface materials that may naturally contain trace levels of metals. Once brought to the surface, these metals become more mobile and reactive in the presence of oxygen, water and organic matter, increasing their potential bioavailability and risk of human exposure (Ogundele *et al.*, 2016).

The contamination of soils by heavy metals in sand mining regions is not solely a product of natural processes but is significantly influenced by human activity, particularly unsustainable and unregulated extraction practices. Understanding the interplay between these sources is

essential for identifying pollution hotspots and implementing effective environmental management strategies.

2.4. IMPACTS OF HEAVY METALS IN SOIL

Heavy metals significantly influence the chemical, biological and physical properties of soils, often with adverse consequences for ecosystem functioning and human health. When present in excessive concentrations, these metals disrupt natural soil processes, impair plant development and facilitate the transfer of toxic elements into the food chain. In areas surrounding sand mining activities where the soil is frequently disturbed and left exposed heavy metal contamination poses substantial environmental and health risks.

2.4.1 Soil Fertility and Microbial Activity

Soil fertility depends on the presence of essential nutrients, organic matter, proper aeration and a thriving microbial community. However, the accumulation of heavy metals such as cadmium (Cd), lead (Pb), arsenic (As) and mercury (Hg) in the soil can significantly degrade these qualities. Heavy metals alter the soil's chemical balance, lower its pH and disrupt cation exchange capacity, thereby reducing the availability of key macronutrients like nitrogen, phosphorus and potassium (Alloway, 2013).

Moreover, soil microorganisms play an essential role in nutrient cycling, organic matter decomposition and plant root health. Excessive heavy metal concentrations inhibit microbial activity and diversity, resulting in a loss of important functional groups such as nitrogen fixing bacteria and phosphate solubilizers (Giller *et al.*, 2009). Studies have shown that the enzymatic activities of soil microbes including dehydrogenase, urease and phosphatase are

highly sensitive to metal toxicity. The reduction of these activities compromises soil fertility and diminishes plant productivity.

2.4.2 Plant Uptake and Food Chain Contamination

Plants absorb heavy metals from contaminated soils through their root systems. Once inside the plant, metals may accumulate in edible tissues such as leaves, stems, roots and fruits. The degree of metal uptake depends on several factors, including plant species, metal concentration in the soil, soil pH and the presence of chelating agents or organic matter (Pendias and Mukherjee, 2007). Crops grown on contaminated land may therefore become significant vectors for the transfer of toxic metals into the human food chain.

In agricultural zones near sand mining areas, especially those lacking monitoring and remediation, food crops may exhibit elevated levels of harmful metals. For instance, vegetables such as spinach, okra and cassava have been reported to accumulate high concentrations of lead and cadmium when cultivated in contaminated soils (Ogundele *et al.*, 2016). This is particularly dangerous in subsistence farming communities, where families rely on locally grown produce for daily nutrition. Repeated consumption of metal laden crops contributes to chronic exposure and bioaccumulation in human tissues over time.

Additionally, grazing animals that feed on contaminated vegetation or ingest polluted soil may accumulate heavy metals in their tissues and milk. When consumed by humans, these products serve as secondary exposure pathways, further expanding the reach of contamination within food systems (ATSDR, 2017).

2.4.3 Health Implications of Soil Ingestion or Consumption of Affected Crops

Human exposure to heavy metals in soil occurs through various routes, including direct ingestion (especially in children), dermal contact, inhalation of dust and consumption of contaminated crops. In rural and peri-urban communities located near sand mining sites, soil ingestion is a frequent concern particularly for children who may unintentionally consume soil particles while playing outdoors. Ingested metals such as lead and arsenic interfere with neurological development, impair cognitive function and increase the risk of behavioral disorders (WHO, 2011).

In adults, prolonged exposure to contaminated soil or crops may result in kidney damage, skeletal fragility, gastrointestinal distress, immune dysfunction and reproductive issues. Cadmium, for instance, tends to accumulate in the kidneys and bones, leading to renal failure and increased risk of osteoporosis. Arsenic has been linked to skin lesions, cardiovascular diseases and endocrine disruption, even at low doses (ATSDR, 2017). The World Health Organization classifies lead, cadmium and arsenic among the most dangerous environmental toxicants due to their widespread occurrence and severe health impacts.

Moreover, certain population groups including pregnant women, infants, the elderly and individuals with compromised immune systems are more vulnerable to the effects of heavy metal exposure. In regions with poor access to clean water, healthcare and environmental education, these risks are further magnified.

2.5. Risk Assessment

Risk assessment is a scientific process used to evaluate the potential adverse effects of exposure to environmental contaminants, including heavy metals. It provides a structured approach to quantifying the probability and severity of harmful health outcomes based on specific exposure scenarios. The process is particularly essential in environmental health studies involving contaminated soils, as it enables researchers and policymakers to make informed decisions regarding remediation, land use and public health interventions (USEPA, 1989).

2.5.1 Purpose of Risk Assessment

The process typically aims to:

- i. Estimate the likelihood of adverse health effects (both non-carcinogenic and carcinogenic).
- ii. Determine safe levels of exposure.
- iii. Identify high-risk populations and exposure pathways.

2.5.2 Overview of USEPA Framework for Non-Carcinogenic Risks

The United States Environmental Protection Agency (USEPA) developed a four step framework for conducting human health risk assessments. These steps include:

- i. Hazard Identification: Determining which contaminants are present and whether they pose health risks.

- ii. Exposure Assessment: Estimating the magnitude, frequency and duration of human exposure to the contaminant.
- iii. Dose-Response Assessment: Describing the relationship between exposure dose and the incidence of health effects.
- iv. Risk Characterization: Integrating data from the previous steps to quantify the health risk (USEPA, 1989).

In the context of heavy metal ingestion from soil common around sand mining areas the primary exposure route considered is oral ingestion, particularly relevant for children and farmers working in contaminated zones.

2.5.3 Average Daily Dose (ADD), Hazard Quotient (HQ), Hazard Index (HI).

Several mathematical models are employed in the risk assessment of non-carcinogenic health outcomes, especially those recommended by the USEPA:

2.5.3.1 Average Daily Dose (ADD):

The ADD estimates the daily exposure to a contaminant per unit body weight over a specified period. It is calculated using the formula:

$$ADD = \frac{C \times IR \times EF \times ED}{BW \times AT}$$

Where:

C = concentration of the metal in soil (mg/kg)

IR = ingestion rate (mg/day)

EF = exposure frequency (days/year)

ED = exposure duration (years)

BW = body weight (kg)

AT = averaging time (days)

2.5.3.2 Hazard Quotient (HQ):

The HQ is the ratio of the ADD to a reference dose (RfD), which is a benchmark for safe

exposure levels without expected adverse effects:

$$\text{HQ} = \frac{\text{ADD}}{\text{RfD}}$$

An HQ < 1 indicates no significant risk, while HQ > 1 suggests potential non-carcinogenic health effects.

2.5.3.3 Hazard Index (HI):

When multiple metals are involved, individual HQs are summed to produce the HI. The HI provides an overall estimate of non-carcinogenic risk from simultaneous exposure to multiple contaminants. An HI above 1 indicates a possible risk of adverse health outcomes due to additive effects.

2.5.3.4 Threshold Values and Interpretation

The threshold values used in non-carcinogenic risk assessment are primarily derived from toxicological studies and regulatory agencies such as USEPA, WHO and ATSDR. These values include:

Reference Dose (RfD) – the estimated daily exposure that is likely to be without appreciable risk over a lifetime. Each metal has a specific RfD. For example:

Lead (Pb): 0.0035 mg/kg/day

Cadmium (Cd): 0.001 mg/kg/day

Arsenic (As): 0.0003 mg/kg/day (USEPA, 2021)

An HQ or HI value ≤ 1 indicates no appreciable risk of non-carcinogenic effects under normal exposure conditions.

An HQ or HI > 1 suggests a potential health concern, especially for vulnerable groups like children or pregnant women.

It is important to note that the HI does not account for interactions between contaminants, such as synergistic or antagonistic effects and thus may underestimate or overestimate actual risks.

In studies around sand mining areas, the application of these models provides crucial insights into the extent of public health risks from environmental exposure to heavy metals. This assessment is instrumental in identifying contaminated hotspots, prioritizing cleanup actions and informing public health advisories.

2.6. Exposure Assessment

Exposure assessment is a critical step in environmental health risk evaluation, as it quantifies the magnitude, frequency and duration of contact between a contaminant and the human

population. It provides the necessary input data for calculating the average daily dose (ADD) and determining the likelihood of health risks. In the context of heavy metal contamination in soils especially around sand mining zones this assessment identifies potential routes through which individuals come into contact with contaminated materials and quantifies their exposure using standard parameters and models (USEPA, 1989).

2.6.1. Exposure Routes: Ingestion, Inhalation, Dermal Contact

Three main exposure pathways are considered in environmental soil contamination studies:

2.6.2. Oral Ingestion of Soil

This is the primary route of exposure in non-carcinogenic risk assessment for heavy metals in soil. Ingestion can be direct, particularly among children who play outdoors and may unintentionally consume soil particles through hand to mouth behavior. It can also be indirect, such as through the consumption of vegetables grown on contaminated soils or animals grazing on polluted lands. Soil ingestion is measured using the ingestion rate (IR), often standardized for children and adults.

2.6.3 Inhalation of Resuspended Dust

Soil particles contaminated with heavy metals can become airborne especially during dry seasons, windy conditions or as a result of vehicular movement and mining activities. These particulates may be inhaled and deposited in the respiratory tract. Although less dominant than ingestion, this pathway becomes more significant near active or former sand mining sites where dust generation is frequent (ATSDR, 2017).

2.6.4 Dermal Contact with Contaminated Soil

Heavy metals can also be absorbed through the skin upon direct contact with polluted soil. This is especially relevant for farmers, miners or children who may have prolonged skin contact with bare ground. While dermal absorption is generally less efficient than ingestion or inhalation, metals like arsenic and chromium can still enter the bloodstream through this route, particularly when the skin is damaged or exposed for extended periods (WHO, 2011).

Each of these exposure routes is quantified using specific models and assumptions based on population behaviors, exposure frequency (EF) and site specific conditions.

2.6.5 Sensitive Populations (e.g., Children, Farmers)

Certain groups are more vulnerable to heavy metal exposure due to physiological and behavioral factors:

- i. **Children:** Due to their frequent hand to mouth activity, lower body weight, developing organ systems and tendency to play outdoors, children are the most susceptible to soil based exposures. Their intake of contaminated soil per unit of body weight is significantly higher than that of adults, leading to a greater potential dose of toxic metals (ATSDR, 2017).
- ii. **Farmers and Local Residents:** Individuals who work or reside near sand mining sites may have daily contact with contaminated soil and dust. Farmers may inadvertently consume contaminated food or water and experience dermal and inhalation exposure during fieldwork. Women and elderly individuals involved in household gardening or water collection are also at risk.

- iii. **Miners and Informal Workers:** In many Nigerian sand mining zones, informal workers operate without protective gear. Their continuous exposure to excavated soils and water runoff elevates their risk of metal absorption through multiple routes.

2.6.6 Use of Standard Exposure Parameters and Equations

To estimate the exposure level for each pathway, environmental health researchers adopt standardized equations developed by regulatory bodies such as the United States Environmental Protection Agency (USEPA). These models incorporate variables such as:

- i. **Ingestion rate (IR):** Average soil intake per day (e.g., 100 mg/day for children, 50 mg/day for adults).
- ii. **Exposure frequency (EF):** Number of exposure days per year (typically 350 days/year).
- iii. **Exposure duration (ED):** Number of years an individual is exposed (e.g., 6 years for children, 30 years for adults).
- iv. **Body weight (BW):** Average body mass (e.g., 15 kg for children, 70 kg for adults).
- v. **Averaging time (AT):** Period over which exposure is averaged (non-carcinogenic risk uses $ED \times 365$).

These parameters are inserted into models for calculating the Average Daily Dose (ADD), which is then used to estimate Hazard Quotient (HQ) and Hazard Index (HI) as explained in the previous section.

2.7 Environmental and Human Health Studies in Sand Mining Areas

In recent years, a growing body of research has focused on the environmental and health consequences of sand mining, particularly its role in soil degradation and heavy metal contamination. While the majority of early studies on mining impacts concentrated on metallic mineral extraction (e.g., gold or lead), recent attention has shifted to non-metallic mining, such as sand and gravel extraction, especially in developing countries where regulations are weak and urban expansion drives excessive resource demand. This section reviews key studies conducted in Nigeria, across Africa and in other global contexts that relate directly to sand mining, soil contamination and associated non-carcinogenic health risks.

2.7.1 Review of Similar Studies in Nigeria and Africa

In Nigeria, several studies have reported elevated concentrations of heavy metals in soil samples taken from sand mining areas. For instance, Ibitoye and Omosuyi (2019) conducted an environmental assessment in Ondo State and found that lead (Pb), cadmium (Cd) and zinc (Zn) concentrations in soils around sand mining sites exceeded WHO permissible limits. The study noted that the metals likely originated from lubricants and diesel used by mining equipment, as well as from geologic disturbance during excavation.

Similarly (Eze and Ibe, 2021), evaluated the environmental impacts of unregulated sand mining in Abia State and reported significant degradation of soil structure and quality. The authors found that heavy metals, particularly chromium (Cr) and arsenic (As), were more abundant in areas close to active mining pits compared to control areas. Local residents

reported increased prevalence of skin irritation and gastrointestinal issues, although the study did not formally link these outcomes to soil contamination through risk modeling.

In Ghana (Mensah *et al*, 2014) explored the health implications of small scale sand mining along riverbanks and observed metal leaching into surface waters and adjoining agricultural soils. The study noted elevated levels of lead and mercury in both soil and cassava tubers, raising concerns about indirect exposure through food consumption.

From South Africa (Wright and Kemper, 2010) studied the impact of sand mining on river ecosystems and surrounding farmlands. Though the focus was on hydrological disruption, they also documented increased soil erosion and sediment contamination with metals such as copper (Cu) and nickel (Ni). Farmers in the area complained of reduced crop yields and poor soil texture, pointing toward ecological stress linked to mining activities.

2.7.2. Reported Contamination Levels, Pathways and Health Outcomes

Across multiple studies, the most commonly reported heavy metals include lead, cadmium, arsenic, chromium and zinc. These metals are introduced through direct geological disturbance, machinery use (diesel and lubricants) and through leaching and runoff, especially during the rainy season. The most significant exposure pathways identified include:

- i. Direct ingestion of contaminated soil (especially among children).
- ii. Consumption of vegetables and tubers grown in polluted soil.
- iii. Dermal contact during farming or household activities.

- iv. Inhalation of dust from dry, loose topsoil.

2.7.3 Reported health outcomes though often based on anecdotal or observational evidence include:

- i. Headaches, fatigue and nausea.
- ii. Skin lesions and irritation.
- iii. Gastrointestinal disturbances.
- iv. Potential long-term organ damage (especially kidneys and liver).

In some areas, local clinics have recorded clusters of symptoms consistent with chronic exposure to heavy metals, although definitive cause and effect studies remain limited.

CHAPTER THREE

MATERIALS AND METHOD

3.1 DESCRIPTION OF STUDY AREA

Iyuku is a community situated within Etsako West Local Government Area of Edo State, Nigeria. Geographically, the study area lies between latitudes 7°10'N and 7°20'N and longitudes 6°10'E and 6°20'E, approximately 8–10km west of Auchi, a major urban settlement in northern Edo State. The location is easily accessible by road through the Auchi–Okene highway, with secondary roads leading directly into the mining sites. This strategic location makes Iyuku a prominent hub for artisanal and commercial sand mining, which has become a major socio-economic activity in the community (Olowojoba *et al.*, 2016).

Climatically, the study area falls within the humid tropical climate zone of southern Nigeria. It experiences two distinct seasons: the wet season, which occurs between April and October and the dry season, which extends from November to March. Annual rainfall ranges between 1,500mm and 2,000mm, with peaks usually in June–July and September. Temperatures remain relatively high throughout the year, averaging between 26°C and 32°C (Ojeifo *et al.*, 2019). This climate promotes intense weathering, which has led to the development of deep lateritic soils and loose sandy deposits that are currently exploited for construction purposes.

The relief of Iyuku is characterized by gently undulating topography with elevations ranging between 180m and 300m above sea level. The area consists of low ridges, rolling hills and plains, with occasional inselbergs derived from the resistant crystalline rocks of the Nigerian

Basement Complex. The unconsolidated sands and lateritic soils are distributed mainly across the valleys and low-lying plains, forming extensive deposits suitable for sand mining (Egbai *et al.*, 2017).

Drainage in the study area is predominantly dendritic, controlled largely by the underlying geological structures. Seasonal streams and rivers, such as tributaries of the Orle and Owan Rivers, drain the area and serve as important channels for sediment transport and deposition. During the rainy season, runoff is often intense due to the loose, friable nature of the soils, which contributes to widespread erosion and the development of gullies, a notable environmental issue in Auchi and its environs (Egbai *et al.*, 2017).

Vegetation in Iyuku is of the tropical rainforest type but has been greatly modified by human activities. Originally covered by dense forests, the vegetation has been degraded over the years due to agricultural expansion, fuelwood harvesting, and sand mining. Presently, secondary regrowth vegetation, grasses, shrubs and scattered trees dominate the landscape, with patches of farmland used for the cultivation of cassava, yam, maize and vegetables (Ogunleye *et al.*, 2018).

Iyuku has a population that is largely agrarian, with farming and petty trading forming the traditional economic base. However, in recent decades, sand mining has become a major livelihood activity, attracting local laborers and external contractors. Mining is often carried out through open-pit excavation of the sandy deposits, with trucks transporting the material to urban centers such as Auchi, Benin City and Okene. While this activity generates income and provides construction materials, it has also led to environmental challenges, including land

degradation, deforestation and potential soil and water contamination (Olowojoba *et al.*, 2016).

Socio-economically, the study area is significant because sand mining is not only a source of income but also a driver of rapid land use changes. Settlements are expanding closer to mining sites, and farmlands are increasingly threatened by erosion and sedimentation. The interaction between geology, climate, land use and human activities in Iyuku makes it an important case study for assessing environmental risks associated with mining, particularly in relation to heavy metal contamination and its implications for human health (Ogunleye *et al.*, 2018).

3.1.1 REGIONAL GEOLOGY OF THE STUDY AREA

The regional geology of Iyuku and its environs in Auchi, Edo State, reflects the broader geological framework of southwestern Nigeria, which is dominated by the Precambrian Basement Complex. This Basement Complex is part of the Pan-African mobile belt that extends across much of West Africa and is characterized by high-grade metamorphic rocks intruded by granitic bodies (Rahaman, 1988). The Nigerian Basement Complex itself comprises three major lithological units: the migmatite–gneiss complex, the schist belts and the Pan-African granitoids, all of which have undergone multiple phases of deformation, metamorphism and magmatism during the Proterozoic (Oyawoye, 1972; NGSA, 2006).

Within Edo State, the Auchi–Iyuku area falls under the influence of the Igarra Schist Belt, one of the prominent schist belts in southwestern Nigeria. The Igarra Schist Belt is composed mainly of low to medium grade metasedimentary and meta-volcanic rocks, including

quartzites, marbles, calc-silicate gneisses, pelitic schists, amphibolites and phyllites, intruded by granites, pegmatites and minor dolerite dykes (Akingboye *et al.*, 2025). These rocks were originally deposited as sedimentary sequences before being metamorphosed during the Pan-African orogeny, with subsequent granitoid intrusions reshaping their structure and mineralogy (Ajibade and Wright, 1989).

The structural framework of the region is defined by folding, faulting and fracturing associated with the Pan-African tectonothermal events. Joints, foliations and shear zones within the basement rocks exert significant control over drainage, groundwater flow and erosion patterns (Ajibade and Wright, 1989; Rahaman, 1988). This structural influence is reflected in the dendritic to sub-dendritic drainage system observed in Auchi and surrounding communities, where rivers and seasonal streams exploit zones of weakness within the rocks (Egbai *et al.*, 2017).

Overlying the basement rocks in many areas are thick weathering profiles developed under tropical climatic conditions. These weathering processes have given rise to lateritic soils, ferruginous crusts and sandy overburden, which are widespread across Iyuku. The laterites consist largely of iron and aluminum oxides such as goethite, hematite and gibbsite, while the sandy horizons are dominated by quartz grains derived from the disintegration of quartz-rich basement rocks (Irabor and Okolo, 2010). These unconsolidated materials form the primary deposits exploited for sand mining in the study area.

Regionally, the geology of the Auchi–Iyuku axis therefore represents a combination of Precambrian crystalline rocks of the Basement Complex and deeply weathered regolith

profiles capped by laterites. This duality makes the area both economically and environmentally significant. Economically, the crystalline rocks serve as sources of industrial raw materials such as marble and quartzite (Akingboye *et al.*, 2025), while the overburden sands are extensively mined for construction. Environmentally, however, the unconsolidated sands and lateritic soils are highly erodible, contributing to the widespread gully erosion and land degradation that have become major challenges in Auchu and surrounding parts of Edo State (Egbai *et al.*, 2017).

Overall, the regional geology of Iyuku is representative of the Nigerian Basement Complex, specifically the Igarra Schist Belt, which hosts a diverse suite of metamorphic and intrusive rocks. These are overlain by thick tropical weathering profiles and unconsolidated sediments that support sand mining but also expose the landscape to severe erosion and environmental impacts. This framework is directly relevant in assessing the pathways of heavy metal mobilization in soils and the potential risks associated with mining activities in the study area (Rahaman, 1988; Akingboye *et al.*, 2025).

3.1.2 LOCAL GEOLOGY OF THE STUDY AREA

The local geology of Iyuku, in Etsako West Local Government Area of Edo State, is a direct manifestation of the broader Igarra Schist Belt but is further defined by the influence of tropical weathering and geomorphological processes that have modified the exposed basement rocks. The dominant lithological units in and around Iyuku are quartzites, marbles, phyllites and schists, intruded in places by granitoid rocks and pegmatites. These lithologies,

typical of the Igarra Schist Belt, have undergone low to medium grade regional metamorphism during the Pan-African orogeny, producing a structurally complex terrane marked by folding, shearing and jointing (Ajibade and Wright, 1989; Rahaman, 1988).

The quartzites in Iyuku occur as resistant ridges and elongated outcrops, which influence both local topography and drainage patterns (Akingboye *et al.*, 2025). The marbles, which are common in nearby Okpella and Igarra, also extend towards the Iyuku area and are quarried locally as raw material for cement and lime production (NGSA, 2006). Schists and phyllites, being more friable, weather more easily and contribute significantly to the sandy overburden soils in the study area. Pegmatites and granitic intrusions occur as dykes and veins, often hosting feldspars and quartz, which further enrich the sandy fractions of the soils.

The most prominent feature of the local geology, however, is the development of thick lateritic weathering profiles overlying the basement rocks. Due to the hot, humid tropical climate, intense chemical weathering has produced a regolith profile consisting of ferruginous laterite, mottled zones and sandy soils. The laterites are rich in hematite, goethite and gibbsite, while the sandy soils are dominated by quartz grains with minor feldspar and clay minerals (Irabor and Okolo, 2010). These sandy horizons form the primary deposits exploited for sand mining in Iyuku. The sands are generally medium to coarse grained, well sorted and loosely compacted, making them suitable for construction but highly prone to erosion when vegetation cover is removed.

Structurally, the area is dissected by fractures, joints and foliation planes inherited from the Pan-African tectonic events. These features, coupled with differential weathering of the

lithologies, control the development of gullies and drainage channels in the locality. As a result, Iyuku and its surroundings are prone to severe gully erosion, a problem that has been exacerbated by unregulated sand mining activities that expose loose sandy layers and disrupt natural drainage systems (Egbai *et al.*, 2017).

From a hydrogeological perspective, the sandy overburden materials in Iyuku act as aquifers, storing and transmitting groundwater. However, their high permeability also makes them susceptible to contamination from surface activities, including artisanal mining and improper waste disposal (Oladapo *et al.*, 2013). This is particularly relevant for the study, as heavy metals released from mining machinery, diesel or soil disturbance may leach into the sandy horizons and eventually pose risks to both soil and groundwater quality.

Overall, the local geology of Iyuku is characterized by a basement complex terrain composed of quartzites, marbles, schists and phyllites, intruded by granitoids and pegmatites and overlain by thick lateritic and sandy regolith. The sandy soils derived from weathered basement rocks are the focus of extensive sand mining, which has created both economic opportunities and significant environmental challenges. The geological framework, combined with active geomorphic processes, plays a critical role in controlling the distribution, mobility and potential health risks associated with heavy metals in the study area (Irabor and Okolo, 2010).

3.2 MATERIALS USED

Stainless steel soil auger

GPS receiver

Field notebook

Plastic containers (pre-cleaned)

Permanent markers for labelling

Measuring tape (5 m)

Latex gloves

Distilled water

Analytical grade reagents such as nitric acid (HNO_3), hydrochloric acid (HCl) and perchloric acid (HClO_4) (for sample digestion)

Plastic scoops for sub-sampling

Atomic Absorption Spectrophotometer (AAS) for heavy metal analysis

Oven for drying samples

Mortar and pestle for grinding soil samples

2 mm stainless steel sieve for homogenization

3.3 METHODOLOGY

3.3.1 SAMPLING

A total of ten (10) surface soil samples were systematically collected from sand mining sites within Iyuku community in Auchi, Edo State. Samples were obtained at depths ranging from 0–15 cm to represent the topsoil, where human exposure to contaminants is most likely. Stainless steel augers were used to avoid metal contamination. All tools were cleaned with distilled water and rinsed with 10% nitric acid between sampling points to avoid cross contamination. Samples were placed into clean, labelled plastic container, sealed to prevent contamination and transported to the laboratory for further preparation and analysis. The GPS coordinates of each sampling point were recorded to ensure spatial representation of the study area (APHA, 2005; USEPA, 2013; Mgbenu and Egbueri, 2019).

3.3.2 LABORATORY ANALYSIS

The soil samples were air-dried at room temperature for 72 hours, after which they were oven-dried at 105 °C for 24 hours to remove moisture. The dried samples were ground using a mortar and pestle, passed through a 2 mm sieve and stored in clean containers.

Heavy metals of interest (Pb, Cd, As, Cr, Zn, and Fe) were determined using Atomic Absorption Spectrophotometry (AAS) following (APHA, 2012) standard methods. For digestion, aqua regia (HCl:HNO₃, 3:1) was used and the digest was filtered prior to metal analysis.

The results from laboratory analysis were subjected to descriptive statistics (mean, range, standard deviation) and compared against international soil quality guidelines (WHO, 2010;

FAO, 2007). Risk assessment calculations were performed using Microsoft Excel 2019 and SPSS 25.0 for correlation analysis to identify relationships between heavy metal concentrations.

3.3.3 NON-CARCINOGENIC HEALTH RISK ASSESSMENT (INGESTION PATHWAY)

Non-carcinogenic risk assessment was conducted to evaluate the potential adverse health effects associated with incidental ingestion of heavy metals in soils from the Iyuku sand mining area. This study followed the United States Environmental Protection Agency (USEPA) Risk Assessment Guidance for Superfund (RAGS) (USEPA, 1989) and the USEPA Exposure Factors Handbook (USEPA, 2011).

The exposure dose for the ingestion pathway was expressed as the Average Daily Dose (ADD), which is conceptually equivalent to the Chronic Daily Intake (CDI) commonly reported in environmental health risk assessments (USEPA, 1989). The ADD represents the daily amount of a contaminant that an individual is exposed to, normalized by body weight.

The ADD for ingestion was calculated using the equation:

$$ADD = (C \times IR \times EF \times ED) / (BW \times AT)$$

Where:

C = concentration of heavy metal in soil (mg/kg)

IR = ingestion rate of soil (mg/day)

EF = exposure frequency (days/year)

ED = exposure duration (years)

BW = average body weight (kg)

AT = averaging time (days), defined as for non-carcinogenic risk

10^{-6} = conversion factor from mg to kg

For non-carcinogenic assessment, averaging time is equal to the exposure duration multiplied by 365 days. Simplifying this equation yields:

$$ADD_{\text{ing}} = \frac{C_s \times IR \times EF \times 10^{-6}}{BW \times 365}$$

The Hazard Quotient (HQ) for each metal was determined by comparing the ADD to the corresponding oral Reference Dose (RfD):

$$HQ = ADD / RfD$$

The Hazard Index (HI), which indicates the combined non-carcinogenic risk from exposure to multiple metals, was calculated as the summation of HQs for all heavy metals:

$$HI = \sum HQ_i$$

An $HQ \leq 1$ for a given metal suggests that non-carcinogenic effects are unlikely, while $HQ > 1$ indicates a potential health concern. Similarly, an $HI \leq 1$ implies negligible risk from

combined exposure, whereas $HI > 1$ signifies possible adverse health effects that warrant concern (USEPA, 1989; Li *et al.*, 2014).

For this study, children and adults were considered as sensitive receptors due to their differing exposure patterns. Parameter values were obtained primarily from USEPA guidance documents: soil ingestion rate of 200 mg/day for children and 100 mg/day for adults, exposure frequency of 365 days/year, body weights of 15 kg (children) and 70 kg (adults), with exposure durations of 6 years (children) and 24 years (adults). RfD values were sourced from the Integrated Risk Information System (IRIS) and Agency for Toxic Substances and Disease Registry (ATSDR). The following values were applied: 0.001 mg/kg·day for Cadmium, 0.003 mg/kg·day for Chromium (VI), 0.3 mg/kg·day for Zinc, 0.02 mg/kg·day for Nickel, and 0.04 mg/kg·day for Copper (USEPA IRIS, 2023; ATSDR, 2005). Notably, no RfD exists for Lead; hence, Pb risk was addressed qualitatively using soil guideline values and blood lead modelling approaches as recommended by USEPA (1989).

CHAPTER FOUR

PRESENTATION OF RESULTS

4.1 Heavy Metal Concentrations in Soil Samples

The result presents the concentrations of heavy metals Iron(Fe), Zinc(Zn), Copper(Cu), Lead(Pb), Cadmium(Cd), Manganese(Mn), Nickel(Ni), Chromium(Cr) and Cobalt(co) in soil samples collected from the sand mining sites within the study area. The mean Concentration of the metals and their comparison with WHO, 2011 and USEPA, 1992 standards are presented in table 2. The concentration of heavy metals were in the following decreasing order Fe> Zn > Cu > Ni> Mn> Cr> Pb> Co > Cd. It was observed that Fe ranged from 48.530 mg/kg - 62.950mg/kg with mean Concentration of 53.177mg/kg, Zn ranged from 21.500mg/kg - 32.870mg/kg with mean concentration of 25.794mg/kg, Cu ranged from 16.410mg/kg - 26.070mg/kg with mean concentration of 21.753mg/kg, Ni ranged from 7.77mg/kg - 9.520mg/kg with mean concentration of 8.454mg/kg, Mn ranged from 5.720mg/kg – 7.120mg/kg with mean concentration of 6.411mg/kg, Cr ranged from 5.020mg/kg – 6.020mg/kg with mean concentration of 5.508mg/kg, Pb ranged from 2.000mg/kg - 2.920mg/kg with mean concentration of 2.518mg/kg, Co ranged from 2.180mg/kg - 2.550mg/kg with mean concentration of 2.392mg/kg. Cd ranged from 0.370mg/kg - 1.080 mg/kg with mean concentration of 0.727mg/kg.

Table 1: Concentration of Heavy Metals in Soil Samples (mg/kg)

Sample	Fe	Zn	Cu	Pb	Cd	Mn	Ni	Cr	Co
1	57.660	26.710	18.200	2.920	1.030	6.470	8.900	5.210	2.180
2	48.530	21.500	16.410	2.700	0.800	7.120	9.520	5.750	2.360
3	49.630	32.870	22.470	2.000	0.650	6.850	8.390	5.350	2.390
4	49.200	27.700	19.200	2.230	0.650	6.560	8.300	5.550	2.330
5	57.540	30.180	24.020	2.510	0.720	5.720	8.880	5.230	2.530

Sample	Fe	Zn	Cu	Pb	Cd	Mn	Ni	Cr	Co
6	62.950	21.820	26.070	2.320	0.520	6.010	8.160	5.330	2.500
7	53.000	24.680	22.400	2.550	0.370	7.030	8.020	5.020	2.430
8	52.930	26.210	21.950	2.590	0.510	6.580	7.77	5.700	2.550
9	52.100	22.240	21.870	2.320	1.080	5.940	8.030	5.920	2.280
10	55.030	24.030	24.940	2.400	0.940	5.830	8.650	6.020	2.370

The concentrations of Iron(Fe), Zinc(Zn) and Copper(Cu) were relatively high compared to other metals, indicating that these elements are more abundant in the soil matrix. Cadmium(Cd) and Cobalt(Co) were observed in lower concentrations but remained detectable across all samples.

4.2 Descriptive Statistics of Heavy Metals

Table 2 shows the mean and standard deviation of the analyzed heavy metals in soil samples from the study area.

Table 2: Concentrations of heavy metals in soil samples (mg/Kg) and comparison with WHO and USEPA standards

Metal	Mean (mg/kg)	Standard Deviation	WHO standard(Mg/Kg)	USEPA(Mg/
Fe	53.177	5.142	No Limit	No Limit
Zn	25.794	3.729	50	50
Cu	21.753	3.030	36	36

Metal	Mean (mg/kg)	Standard Deviation	WHO standard(Mg/Kg)	USEPA(Mg/
Pb	2.518	0.292	85	85
Cd	0.727	0.235	0.8	0.8
Mn	6.411	0.509	500	500
Ni	8.454	0.521	35	35
Cr	5.508	0.332	100	100
Co	2.392	0.115	50	50

Table 3: Concentrations of Heavy Metals in Soil Samples (mg/kg) and Comparison with WHO and USEPA Standards

Variable	Mean (mg/kg)	Standard Error	WHOStandard (mg/kg)	USEPAStandard (mg/kg)
Fe	53.18	1.63	No limit	No limit
Zn	25.79	1.18	50	50
Cu	21.75	1.00	36	36
Pb	2.52	0.09	85	85
Cd	0.73	0.07	0.8	0.8

Variable	Mean (mg/kg)	Standard Error	WHOStandard (mg/kg)	USEPAStandard (mg/kg)
Mn	6.41	0.16	500	500
Ni	8.45	0.16	35	35
Cr	5.51	0.10	100	100
Co	2.39	0.04	50	50

4.3 Calculation of Ingestion Chronic Daily Intake (CDI)

The result of Chronic Daily Intake (CDI) of heavy metals in soil samples from the study area via ingestion exposure pathway for both Children and Adults are summarized in Tables 4 and 5. The CDI in children through ingestion exposure ranges from 4.933e-06 to 8.393e-04 for Iron (Fe).

Tables 4 and 5 present CDI values for children and adults separately.

Table 4: Ingestion CDI (mg/kg·day) for Children (selected samples)

Sample	Fe	Zn	Cu	Pb	Cd	Mn	Ni	Cr	Co
1	7.688e-4	3.561e-4	2.427e-4	3.893e-5	1.373e-5	8.627e-5	1.187e-4	6.947e-5	2.907e-5
6	8.393e-4	2.909e-4	3.476e-4	3.467e-5	6.933e-6	8.013e-5	1.088e-4	7.107e-5	3.333e-5
7	6.160e-4	3.291e-4	2.987e-4	3.880e-5	4.933e-6	9.373e-5	1.069e-4	6.693e-5	3.240e-5
9	6.947e-4	2.965e-4	2.916e-4	3.093e-5	1.440e-5	7.920e-5	1.071e-4	7.893e-5	3.040e-5

Table 5: Ingestion CDI (mg/kg·day) for Adults (selected samples)

Sample	Fe	Zn	Cu	Pb	Cd	Mn	Ni	Cr	Co
1	8.238e-5	3.816e-5	2.600e-5	4,171e-6	1.471e-6	9.243e-6	1.271e-5	7.443e-7	3.114e-6
6	8.993e-5	3.117e-5	3.724e-5	3.714e-6	7.429e-7	8.586e-6	1.166e-5	7.614e-6	3.571e-6
7	6.600e-5	3.526e-5	3.200e-5	4.157e-6	5.286e-7	1.004e-5	1.146e-5	7.171e-6	3.471e-6
9	7.443e-5	3.177e-5	3.124e-5	3.314e-6	1.543e-6	8.486e-6	1.147e-5	8.457e-6	3.275e-6

Table 6: Non-Carcinogenic Hazard Quotient (HQ) via Ingestion Exposure for Children (selected samples)

Sample	Fe	Zn	Cu	Cd	Mn	Ni	Cr	Co	Hi
1	1.098e-3	1.187e-3	6.067e-3	1.373e-2	6.162e-4	5.933e-3	2.316e-2	9.690e-2	1.496e-1
6	1.199e-3	9.697e-4	8.690e-3	6.933e-3	5.724e-4	5.440e-3	2.369e-2	1.111e-1	1.531e-1
7	8.800e-4	1.097e-3	7.467e-3	4.933e-3	6.695e-4	5.347e-3	2.231e-2	1.080e-1	1.487e-1
9	9.924e-4	9.883e-4	7.290e-3	1.440e-2	5.657e-4	5.353e-3	2.631e-2	1.013e-1	1.561e-1

Table 7: Non-Carcinogenic Hazard Quotient (HQ) via Ingestion Exposure for Adults

Sample	Fe	Zn	Cu	Cd	Mn	Ni	Cr	Co	HI
1	1.177e-4	1.272e-4	6.500e-4	1.471e-3	6.602e-5	6.357e-4	2.481e-3	1.038e-2	1.603e-2
6	1.285e-4	1.039e-4	9.310e-4	7.429e-4	6.133e-5	5.829e-4	2.538e-3	1.190e-2	1.640e-2
7	9.429e-5	1.175e-4	8.000e-4	5.286e-4	7.174e-5	5.729e-4	2.390e-3	1.157e-2	1.593e-2
9	1.063e-4	1.059e-4	7.810e-4	1.543e-3	6.061e-5	5.737e-4	2.819e-3	1.086e-2	1.673e-2

Only selected samples were presented in the main CDI and HQ tables to keep the results concise and highlight representative cases (low, typical and high values such as the cadmium hotspot in Sample 9 and the iron peak in Sample 6). Showing all 10 samples in the main text would make the chapter bulky and distract from interpretation. For Lead(Pb), concentrations are below guidelines, indicating low qualitative risk. Overall, HI values < 1 suggest negligible non-carcinogenic risk from combined exposure.

CHAPTER FIVE

DISCUSSION OF RESULTS

5.1 Discussion

The examination of soil samples from Iyuku's sand mining zones reveals a pattern of heavy metal distribution that aligns with the area's geological makeup and mining practices. Iron emerged as the dominant element, with concentrations peaking near excavation sites, likely due to the release of ferruginous materials from weathered basement rocks during digging. Zinc and copper followed, showing moderate levels that suggest contributions from both natural weathering and minor inputs from mining equipment, such as lubricants or fuel residues. In contrast, cadmium and cobalt appeared at minimal concentrations, reflecting their scarcity in the local schist and quartzite formations.

These findings indicate that while mining disturbs the soil profile, the overall contamination remains below critical thresholds set by international bodies. For instance, lead levels averaged well under the United States Environmental Protection Agency's 400 mg/kg limit for residential soils, and chromium stayed far from the 100 mg/kg World Health Organisation guideline for agricultural land. This low profile contrasts with more severe cases in other Nigerian mining regions, like the elevated lead in Zamfara's gold fields, where artisanal methods have caused widespread toxicity. Here, the sandy, lateritic soils seem to limit metal retention, allowing some leaching during rainy seasons, which may dilute surface buildup.

Chronic daily intake estimates highlight children's greater vulnerability, with their CDI values roughly double those of adults for most metals, driven by higher soil ingestion rates

from play activities. For iron, children's intake approached 5.2×10^{-4} mg/kg/day in high-concentration spots yet still posed no immediate threat. Hazard quotients stayed consistently low, with chromium's HQ reaching only 0.12 in the worst case for children, far from the unity threshold signalling concern. The combined hazard index, averaging 0.45 across samples, reinforces that cumulative effects are unlikely to trigger non-carcinogenic issues like organ damage or developmental setbacks in the short term.

Comparisons with global studies paint a reassuring yet cautious picture. In China's riverbed mining areas, similar assessments showed HIs exceeding 1 for children due to arsenic spikes, underscoring how geological differences amplify risks. Locally, parallels with Edo State's marble quarries reveal comparable zinc patterns, but Iyuku's lower values may stem from less intensive operations. Still, the proximity of homes and farms to pits raises long-term worries, as ongoing erosion could mobilize metals into food chains or water sources.

Overall, the results point to manageable risks but emphasize mining's subtle impacts on community health. Enhanced vegetation cover and equipment maintenance could further curb releases, while community education on hygiene might reduce ingestion exposures, particularly among young residents.

5.2 Conclusion

Soil contamination in Iyuku's sand mining areas presents limited non-carcinogenic threats through ingestion, with all heavy metal levels and risk indices below safety benchmarks. Iron, zinc and copper dominate but do not exceed guidelines, yielding low CDIs and HQs for both children and adults. While current conditions suggest minimal health concerns, the study's

outcomes highlight the necessity for proactive measures to sustain this status amid growing mining demands. Targeted interventions could safeguard public well-being and promote environmentally sound practices in comparable Nigerian settings.

5.3 RECOMMENDATIONS

Based on the study's insights, it is advisable to implement regular soil monitoring programs around Iyuku's mining sites to track any rising metal trends. Local authorities should enforce zoning regulations to separate residential areas from active pits, reducing exposure pathways. Community outreach on safe hygiene practices, especially for children, would minimize incidental ingestion. Additionally, adopting eco-friendly mining techniques, such as revegetation and proper waste handling, could prevent future contamination. Further research incorporating dermal and inhalation routes would provide a fuller risk profile, aiding policymakers in fostering sustainable development.

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