ASSESSMENT OF CARCINOGENIC RISKS ASSOCIATED WITH INHALATION EXPOSURE TO HEAVY METALS IN SOILS AROUND SAND MINE

BY

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BENIN CITY.

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A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF SCIENCE LABORATORY TECHNOLOGY, FACULTY OF LIFE SCIENCES, UNIVERSITY OF BENIN, BENIN CITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF SCIENCE DEGREE (B.Sc) IN GEOLOGY AND MINING TECHNIQUES

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CERTIFICATION

This is to certify that this undergraduate project work titled "**ASSESSMENT OF CARCINOGENIC RISKS ASSOCIATED WITH INHALATION EXPOSURE TO HEAVY METALS IN SOILS AROUND SAND MINE**" was submitted and presented by UWADIA Ekinadese Doris (Miss) with matriculation number LSC2007362 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 for their support during the course of this project work.

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I am profoundly thankful to the Almighty God for His endless grace, wisdom and strength that guided me throughout the course of this research. Truly, without His divine help, this work would not have been accomplished.

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ABSTRACT

The research evaluates the potential health hazards arising from the inhalation of dust contaminated with heavy metals emitted during sand mining operations in Jattu, Auchi, Edo State, Nigeria. Ten surface soil samples were systematically collected from active mining sites and analyzed for Fe, Zn, Cu, Pb, Cd, Mn, Ni, Cr and Co using Atomic Absorption Spectrophotometry following aqua regia digestion. The results revealed that Fe (52.619mg/kg), Zn (25.586mg/kg), and Cu (21.978mg/kg) were the most abundant metals, while Cd (0.731mg/kg) and Co (2.39mg/kg) occurred in lower concentrations, with all measured values below (WHO, 2010) and (USEPA, 2001) permissible limits, indicating moderate contamination. Risk assessment followed (USEPA, 2011) guidelines to determine the Average Daily Dose (ADD) and Incremental Lifetime Cancer Risk (ILCR) for both children and adults through the inhalation pathway. Findings showed that children experienced higher exposure levels and greater carcinogenic risk than adults due to physiological factors and activity patterns, with chromium contributing the most significant cancer risk. Although the overall ILCR values were within acceptable limits ($<1 \times 10^{-4}$), the cumulative risks suggest potential long-term health implications, especially for vulnerable populations near mining sites. The study concludes that while non-carcinogenic risks remain low, continuous exposure could elevate cancer risk over time. It recommends the implementation of dust control measures, periodic monitoring of soil and air quality, stricter regulation of mining operations and further research on heavy metal speciation and multi-pathway risk assessments to safeguard public health and promote sustainable sand mining practices.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

Sand mining is an essential activity that supports infrastructural development and industrial applications worldwide. The increasing demand for sand as a raw material in construction and manufacturing has led to widespread extraction activities, particularly in riverine and terrestrial environments. While sand mining significantly contributes to economic development, it also generates numerous environmental and health concerns. One of the major environmental issues associated with sand mining is the disruption of soil composition and the subsequent release of heavy metals into the surrounding ecosystem (Zhang *et al*., 2020).

Heavy metals such as arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb) and nickel (Ni) are naturally occurring elements that can become concentrated in soils due to anthropogenic activities, including mining and industrial operations. These elements can become airborne during sand excavation, transport and wind-driven erosion of contaminated soils. Inhalation of metal-laden dust represents a critical exposure pathway, especially in communities located near sand mining sites or for workers directly involved in the mining process (Kori *et al*., 2018).

Unlike organic pollutants, heavy metals are not biodegradable and tend to persist in the environment. Their long-term accumulation in the human body can lead to severe health consequences. Numerous studies have demonstrated the carcinogenic potential of various heavy metals. For instance, cadmium and chromium VI are classified as Group 1 carcinogens by the International Agency for Research on Cancer (IARC, 2012). These metals can induce genotoxicity, oxidative stress and immune suppression, which are key mechanisms in the development of cancer (Jaishankar *et al*., 2014).

Inhalation exposure is particularly hazardous because airborne particulate matter containing heavy metals can penetrate deep into the pulmonary system, reaching the alveolar regions where they may be absorbed into the bloodstream or interact directly with lung tissues (Chen *et al*., 2016). Prolonged exposure, even at low concentrations, may result in chronic respiratory diseases, lung cancer and systemic toxicity. Vulnerable populations, including children, the elderly and immunocompromised individuals, are especially at risk.

Despite the growing awareness of these health implications, studies specifically addressing the carcinogenic risk from inhalation exposure to heavy metals in soils around sand mines remain limited, especially in developing countries where environmental monitoring and regulatory enforcement may be inadequate. As sand mining expands to meet the needs of growing urban populations, it becomes increasingly important to assess the associated health risks and implement evidence-based mitigation strategies.

By integrating soil analysis, exposure assessment and toxicological evaluation, the research will contribute valuable insights into the environmental health impacts of sand mining. The outcomes will be crucial for environmental regulators, health authorities, mining operators and affected communities in developing targeted risk reduction and remediation strategies.

1.2 PROJECT PROBLEM STATEMENT

The global demand for sand has led to the proliferation of sand mining activities in many parts of the world. While these operations support infrastructure development and local economies, they also pose significant environmental and public health challenges (Beiser, 2018). One of the less visibly recognized but highly concerning impacts of sand mining is the potential for elevated concentrations of heavy metals in surrounding soils and the associated risk of exposure through inhalation of dust particles.

Heavy metals such as arsenic (As), cadmium (Cd), lead (Pb), chromium (Cr) and nickel (Ni) can be released or redistributed during soil disturbance caused by sand mining operations. These elements which often occur naturally in the subsurface can become bioavailable and mobilized through excavation, stockpiling and transportation processes (Kori *et al*., 2018). Once released, these metals may adhere to fine soil particles that are easily aerosolized especially under dry and windy conditions. These dust particles can travel considerable distances entering the respiratory systems of exposed individuals living near or working within mining sites (Chen *et al*., 2016).

Scientific studies have shown that prolonged exposure to heavy metals via inhalation is associated with a range of adverse health effects including oxidative stress, DNA damage, respiratory diseases and carcinogenic outcomes (Jaishankar *et al*., 2014). Cadmium, for instance, is a recognized human carcinogen and has been linked to lung cancer upon chronic inhalation exposure (IARC, 2012). Similarly, hexavalent chromium (Cr VI) is well-documented for its mutagenic and carcinogenic effects primarily affecting the respiratory tract (ATSDR, 2012).

Despite the known toxicity and environmental persistence of heavy metals, there remains a significant research gap in quantifying the health risks posed by inhalation exposure to metal-contaminated dust in areas surrounding sand mines especially in developing countries where regulatory enforcement and environmental monitoring are limited or absent. Most existing environmental risk assessments tend to prioritize ingestion and dermal contact pathways while underestimating the inhalation route which can often be the most direct and hazardous (Zhang *et al*., 2020). Furthermore, the populations most affected such as local communities, mine workers and children may not be adequately informed of the risks or protected by occupational and public health interventions.

In light of this gap, there is an urgent need for a comprehensive study to assess the concentrations of heavy metals in soils around sand mining sites and to evaluate the carcinogenic risks associated with their inhalation. A scientifically grounded risk assessment would help inform regulatory bodies, health agencies and local stakeholders about the extent of the problem and facilitate the development of targeted mitigation strategies such as dust control measures, improved mining practices and health surveillance programs. Without such data-driven insights, vulnerable populations will continue to face unquantified and unmanaged risks from environmental exposures in sand mining regions.

1.3. AIM AND OBJECTIVE

The aim of this study is to assess the carcinogenic health risks associated with inhalation exposure to heavy metals present in soils around sand mining areas within Auchi, Edo State. The objectives of this project are to:

1. Determine the concentrations of selected heavy metals in surface soils collected from areas in and around active sand mining sites;
2. Assess the inhalation exposure risk for children and adults and nearby residents by estimating exposure doses based on standardized risk assessment models (e.g. US EPA guidelines); and
3. Calculate carcinogenic risk values for each metal based on established toxicity reference values.

1.4 SCOPE OF THE PROJECT

The project covers specifically the assessment of carcinogenic risks associated with inhalation exposure to heavy metals in soils around sand mine.

1.5 JUSTIFICATION OF STUDY

Sand mining plays a vital role in supporting construction and infrastructure development yet its environmental and health impacts are often underestimated. One of the major concerns is the release of heavy metals from disturbed soils which can become airborne and pose serious health risks through inhalation. This exposure route is particularly dangerous because inhaled particles can penetrate deep into the lungs increasing the risk of respiratory illnesses and cancer. Despite these risks, most existing studies focus on ingestion and skin contact pathways leaving a critical gap in understanding the health implications of inhalation exposure in mining environments. In regions where environmental regulations are weak or poorly enforced, communities and workers may be unknowingly exposed to hazardous concentrations of heavy metals.

This research is therefore justified in its aim to investigate and quantify the carcinogenic risks associated with inhalation exposure to heavy metals in soils around sand mining areas. The findings will provide valuable insights for environmental health protection, inform policy decisions and support the development of targeted risk reduction strategies.

CHAPTER TWO

LITERATURE REVIEW

2.1 MINING

Sand is a critical natural resource utilized for various human activities especially in the construction and manufacturing sectors. Sand mining refers to the extraction of sand, mainly from open pits, rivers, beaches and ocean beds. It is considered essential for infrastructure development but also poses significant environmental and socio-economic challenges (Koehnken *et al.*, 2020). The increasing global demand for sand has led to the intensification of sand mining activities which in turn has caused the degradation of river systems, loss of biodiversity and alteration of aquatic ecosystems (Vijayalakshmi *et al.*, 2017).

Over the years, both legal and illegal sand mining have expanded due to rapid urbanization, population growth and the need for concrete and other construction materials (Padmalal and Maya, 2014). The removal of sand from riverbeds and beaches leads to the lowering of river channels which subsequently destabilizes riverbanks and bridges, causes coastal erosion and affects groundwater recharge (Koehnken *et al.*, 2020). This can result in long-term changes to the geomorphology and hydrology of affected areas.

According to (Ashraf *et al.*, 2011), sand mining contributes significantly to the destruction of habitats for aquatic and riparian species. The excessive extraction of sand can lead to reduced water quality as the disturbed sediments increase turbidity which can harm aquatic life. Furthermore, the use of heavy machinery in sand mining operations often leads to noise pollution, increased dust and degradation of surrounding land and vegetation (Padmalal and Maya, 2014).

One of the most critical concerns related to sand mining is its socio-economic impact on local communities. While it may provide employment opportunities and income for some, it often disrupts the livelihoods of others especially those who depend on fishing and farming (Koehnken *et al*., 2020). The depletion of sand resources can lead to conflicts among stakeholders, including miners, local residents and regulatory authorities (Vijayalakshmi *et al*., 2017).

Determining the sustainable limits for sand extraction remains a major challenge due to the complexity of natural sediment replenishment rates and varying local environmental conditions. Unregulated sand mining can outpace natural replenishment leading to irreversible environmental damage (Ashraf *et al*., 2011). The need for effective monitoring, strict regulations and the promotion of alternative construction materials has become increasingly evident (Padmalal and Maya, 2014).

2.2 HEAVY METALS

Heavy metals are naturally occurring elements with high atomic weights and densities that are toxic even at low concentrations. Exposure to heavy metals such as arsenic (As), cadmium (Cd), chromium (Cr), nickel (Ni) and lead (Pb) has been widely recognized as a major public health concern especially when inhaled through contaminated air, dust and industrial emissions (Jaishankar *et al.*, 2014). Inhalation is a significant exposure pathway that directly introduces these metals into the respiratory system where they can accumulate and cause cellular damage leading to carcinogenesis (ATSDR, 2012).

According to the International Agency for Research on Cancer (IARC), certain heavy metals are classified as Group 1 carcinogens indicating sufficient evidence of carcinogenicity in humans (IARC, 2012). For instance, hexavalent chromium (Cr VI) commonly released from industrial activities such as welding, electroplating and leather tanning, is known to cause lung cancer upon inhalation exposure (Costa and Klein, 2006). Similarly, inhalation of arsenic-contaminated dust often associated with mining and smelting operations has been linked to lung and skin cancers (IARC, 2012).

Cadmium, another hazardous metal, is widely utilized in battery manufacturing, pigments and plastic stabilizers. It is a potent respiratory carcinogen and prolonged inhalation exposure to cadmium-laden dust can result in lung cancer, emphysema and other pulmonary diseases (Hartwig, 2013). Additionally, nickel compounds which are prevalent in stainless steel production and refinery operations pose carcinogenic risks through inhalation and have been associated with lung and nasal cancers (IARC, 2012; Costa and Klein, 2006).

The health risks from inhalation exposure to heavy metals are exacerbated in occupational settings, urban centers and areas with high industrial activity. The inhaled metals may generate reactive oxygen species (ROS) cause DNA damage, impair repair mechanisms and induce chronic inflammation, all of which contribute to cancer development (Jaishankar *et al*., 2014). According to (Boffetta *et al*., 1995), combined exposure to multiple heavy metals can lead to synergistic toxic effects significantly increasing cancer risks.

2.3 SOURCES OF HEAVY METALS

Heavy metals that pose carcinogenic risks through inhalation exposure primarily originate from both natural processes and anthropogenic (human-induced) activities. These metals are often released into the atmosphere in the form of dust, fumes or fine particulate matter that can be inhaled and deposited in the respiratory tract leading to serious health consequences (Jaishankar *et al*., 2014; ATSDR, 2012).

2.3.1 NATURAL SOURCES OF HEAVY METALS

Heavy metals are metallic elements with high atomic weight and density that occur naturally in the Earth’s crust. While many heavy metals enter the environment through human activities such as mining, industrialization and agriculture, natural processes also significantly contribute to the presence of heavy metals in soils, water bodies and the atmosphere. These metals are released through various geological, biological and atmospheric mechanisms and can accumulate in the environment over time (Alloway, 2013).

2.3.1.1 WEATHERING OF PARENT ROCKS

One of the most significant natural sources of heavy metals is the geological weathering of rocks and minerals. As rocks break down through mechanical and chemical processes, they release heavy metals such as lead (Pb), cadmium (Cd), arsenic (As), chromium (Cr), copper (Cu), zinc (Zn) and mercury (Hg) into surrounding soils, surface waters and groundwater. The type and concentration of metals released depend on the mineral composition of the parent rock. For example, arsenic is commonly associated with sulfide minerals while nickel is frequently found in ultramafic rocks (Kabata-Pendias and Mukherjee, 2007).

2.3.1.2 VOLCANIC ACTIVITY

Volcanoes are major natural emitters of heavy metals into the atmosphere. Volcanic eruptions can release mercury (Hg), arsenic (As), lead (Pb) and cadmium (Cd) in gaseous forms and as particulate matter. Volcanic ash and gases can spread heavy metals across large areas depositing them into soils and water systems upon settling (Alloway, 2013). Continuous low-level emissions from active volcanic sites also contribute to regional background concentrations of heavy metals.

2.3.1.3 SOIL FORMATION PROCESSES

Natural soil-forming processes can concentrate heavy metals over time. Pedogenesis involves the breakdown and transformation of parent material into soil. During this process, metals can accumulate in specific soil layers, particularly if drainage is poor.

Soils formed from metal-rich rocks, such as serpentine soils, naturally contain high levels of chromium, nickel, and cobalt.

2.3.1.4 FOREST FIRES AND BIOMASS BURNING

Natural wildfires and spontaneous biomass combustion release heavy metals that were previously absorbed by vegetation. Elements such as zinc, copper and lead that accumulate in plants return to the soil and atmosphere when vegetation is burned. These emissions can increase local heavy metal concentrations in the air and subsequently deposit on surrounding soils.

2.3.1.5 SEAWATER AND MARINE AEROSOLS

The oceans can act as a natural source of airborne heavy metals. Sea spray and evaporation release trace amounts of metals such as cobalt, nickel and manganese into the atmosphere. These aerosols can travel long distances and eventually deposit onto terrestrial surfaces.

2.3.1.6 ATMOSPHERIC DUST AND SOIL RESUSPENSION

Natural dust storms and wind-driven soil resuspension can mobilize heavy metals that are inherently present in soils. This is particularly common in arid and semi-arid regions where naturally mineralized soils can contribute to regional airborne heavy metal levels without human interference.

2.3.1.7 BIOLOGICAL SOURCES

Although minor, certain biological processes can contribute to the natural cycling of heavy metals. Microorganisms can transform metals into more mobile or volatile forms (e.g., methylmercury production by bacteria in wetlands). Vegetation uptake and decay can concentrate metals at the soil surface.

2.3.2 ANTHROPOGENIC SOURCES OF HEAVY METALS

Heavy metals naturally exist in the Earth's crust, but human (anthropogenic) activities have significantly accelerated their release and concentration in the environment. These activities increase the mobilization of heavy metals into soils, air, and water at levels that can be harmful to humans, animals, plants and entire ecosystems (Wuana and Okieimen, 2011).

2.3.2.1 MINING AND ORE PROCESSING

Mining activities, including sand, gold, lead and zinc mining are major anthropogenic sources of heavy metals in the environment. During the extraction and processing of ores, large amounts of arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg) and chromium (Cr) are released into surrounding soils, air and water bodies. The mechanical excavation, crushing and transportation of ores produce dust laden with these metals which can be easily dispersed by wind and water. Additionally, mining generates waste materials such as tailings and waste rock piles which often contain high concentrations of heavy metals. When these waste materials are exposed to air and rain, acid mine drainage can occur leading to the leaching of heavy metals into nearby surface water and groundwater further increasing the risk of environmental contamination and human exposure (Wuana and Okieimen, 2011).

2.3.2.2 INDUSTRIAL EMISSIONS

Industrial processes are among the largest contributors to heavy metal pollution. Operations such as metal smelting, refining and manufacturing release substantial quantities of heavy metals like lead, cadmium, arsenic, nickel and chromium into the atmosphere and surrounding environments. Industries involved in battery production, electroplating, paint manufacturing and cement production are particularly responsible for the release of these metals. Power plants, especially coal-fired plants, also emit mercury, arsenic and lead during combustion processes. These emissions can settle onto soils and water bodies leading to the accumulation of toxic metals in ecosystems and food chains posing long-term environmental and health risks.

2.3.2.3 AGRICULTURAL PRACTICES

Agricultural activities contribute significantly to heavy metal contamination, particularly through the excessive use of fertilizers, pesticides and irrigation with contaminated water. Phosphate-based fertilizers often contain cadmium and lead as impurities which gradually accumulate in the soil with continued application. Additionally, pesticides and herbicides used historically contained arsenic, copper and mercury compounds which persist in soils for long periods. Irrigation using water from polluted sources introduces heavy metals such as arsenic, lead and cadmium directly into agricultural lands. Moreover, the use of animal manures and sewage sludge can introduce zinc, copper and lead into soils especially when livestock are fed with contaminated feed or treated with metal-containing veterinary drugs (Kabata-Pendias and Mukherjee, 2007).

2.3.2.4 TRANSPORTATION AND VEHICULAR EMISSIONS

Transportation is a notable anthropogenic source of heavy metals, especially in urban environments. Historically, the use of leaded gasoline was a major source of atmospheric lead until its phase-out in most countries. Even though leaded gasoline is largely banned residues still persist in roadside soils. Additionally, brake pad wear, tire wear and vehicular exhausts contribute to the release of cadmium, zinc, lead and other metals into the surrounding air and soils. These metals tend to accumulate near busy roadways and urban centers where they can easily enter the food chain or be inhaled as fine dust particles (Ferreira-Baptista and De Miguel, 2005).

2.3.2.5 WASTE DISPOSAL AND INCINERATION

Improper waste management practices are a growing source of heavy metal contamination. Open dumping, poorly managed landfills and unregulated waste incineration release heavy metals such as lead, cadmium, mercury and nickel into the environment. Leachates from waste disposal sites can contaminate soil and groundwater especially when landfill liners are absent or damaged. Additionally, the burning of municipal, industrial and electronic waste (e-waste) releases large amounts of heavy metals particularly when waste is incinerated without adequate pollution controls. Informal recycling of e-waste, especially in developing countries, often involves unsafe burning and acid leaching which further contribute to environmental and human exposure to toxic metals.

2.3.2.6 COMBUSTION OF FOSSIL FUELS

The combustion of coal, oil and gasoline is another significant anthropogenic pathway for the release of heavy metals. Coal-fired power plants are particularly important sources of mercury, arsenic, cadmium and lead emissions. These metals are released into the atmosphere with flue gases and can travel long distances before settling onto soils and water surfaces. Although the levels of metals in oil and gasoline are generally lower than in coal, their large-scale use in transportation and industry leads to substantial cumulative emissions over time contributing to both local and regional heavy metal pollution.

2.3.2.7 CONSTRUCTION AND DEMOLITION ACTIVITIES

Construction and demolition activities can also release heavy metals into the environment. Building materials such as old paints, roofing sheets, pipelines and wiring frequently contain lead, chromium and zinc. During demolition, these materials break down and disperse as dust particles which can be inhaled or settle onto nearby soils and water sources. Improper handling of construction waste and the use of heavy metal-laden materials in new buildings can also introduce contaminants into urban environments.

2.4 IMPACT OF HEAVY METALS IN SOILS

Heavy metals are naturally occurring elements that can accumulate in soils through both natural processes and anthropogenic activities. Unlike organic pollutants, heavy metals are non-biodegradable and tend to persist in soils for extended periods, posing significant threats to environmental quality, soil health, plant growth and human health (Alloway, 2013). The primary sources of heavy metals in soils include industrial discharges, mining activities, improper waste disposal, agricultural inputs such as pesticides and fertilizers and atmospheric deposition from vehicle emissions and industrial operations (Kabata-Pendias and Mukherjee, 2007).

2.4.1 SOIL QUALITY DEGRADATION

The accumulation of heavy metals in soils alters the physical, chemical and biological properties of soil. Heavy metals such as lead (Pb), cadmium (Cd), arsenic (As) and mercury (Hg) can reduce soil fertility by disrupting soil pH decreasing microbial diversity and affecting nutrient cycling (Wuana and Okieimen, 2011). These disruptions can lead to a decline in the soil's buffering capacity, water retention ability and overall productivity.

2.4.2 TOXICITY TO SOIL MICROORGANISMS

Soil microorganisms play an essential role in nutrient cycling, organic matter decomposition and soil structure maintenance. Heavy metals can be highly toxic to beneficial soil microbes reducing their populations and enzymatic activity (Giller *et al*., 1998). This leads to the inhibition of key soil processes such as nitrogen fixation, nitrification and organic matter breakdown thereby deteriorating soil health.

2.4.3 BIOACCUMULATION IN PLANTS

Heavy metals in soils can be absorbed by plant roots and accumulate in plant tissues through a process known as bioaccumulation. Metals like cadmium, lead and arsenic can be taken up by crops and enter the food chain, posing significant health risks to humans and animals consuming contaminated food products (Nagajyoti *et al*., 2010). This not only compromises food safety but also reduces agricultural yield and crop quality.

2.4.4 REDUCTION IN PLANT GROWTH AND PRODUCTIVITY

Excessive concentrations of heavy metals in soils can lead to phytotoxicity, which manifests as stunted plant growth, leaf chlorosis, root damage and poor seed germination. Heavy metals can interfere with essential physiological processes such as photosynthesis, nutrient uptake and water absorption (Nagajyoti *et al.*, 2010). This ultimately reduces crop productivity and limits the use of affected soils for agricultural purposes.

2.4.5 GROUNDWATER CONTAMINATION

Heavy metals can leach from contaminated soils into groundwater systems, particularly in areas with high rainfall or irrigation. This poses a secondary environmental risk as groundwater serves as a primary source of drinking water in many regions. Metals like arsenic and lead in groundwater have been linked to severe health problems including kidney damage, developmental disorders and neurological effects (Alloway, 2013).

2.4.6 SOIL EROSION AND ECOSYSTEM DISRUPTION

Contaminated soils with reduced vegetation cover are more prone to erosion. Wind and water can carry metal-laden soil particles to nearby water bodies which expands the contamination zone and affect aquatic ecosystems. The introduction of heavy metals into rivers and lakes can harm fish, aquatic plants and other organisms thereby disrupting entire ecosystems (Wuana and Okieimen, 2011).

2.5 RISK ASSESSMENT

Carcinogenic risk assessment is a systematic process used to evaluate the probability of developing cancer over a lifetime due to exposure to carcinogenic substances. In sand mining areas, activities such as excavation, loading, transportation and soil disturbances release fine dust particles into the air. These dust particles can contain heavy metals with carcinogenic properties that, when inhaled, pose significant health risks to mine workers, children and adults in the neighborhood (USEPA, 2001; Jaishankar *et al*., 2014).

2.5.1 IDENTIFICATION

Hazard identification focuses on recognizing heavy metals in sand mining soils that have proven carcinogenic effects via inhalation exposure.

Major Carcinogenic Heavy Metals:

1. Arsenic (As): Classified as Group 1 carcinogen by the IARC; linked to lung cancer via inhalation exposure (IARC, 2012).
2. Hexavalent Chromium (Cr VI): Causes lung cancer, nasal cancer and severe respiratory diseases upon inhalation (Costa and Klein, 2006).
3. Cadmium (Cd): Recognized as a human carcinogen; prolonged inhalation exposure can lead to lung cancer (Hartwig, 2013).
4. Nickel (Ni) Compounds: Chronic inhalation is associated with lung and nasal cancers (IARC, 2012).

2.5.2 RISK CHARACTERIZATION

The carcinogenic risk is calculated using the following formula:

$$\text{Cancer risk} = \text{ADD} \times \text{IUR}$$

Where:

ADD: Average daily dose

IUR: Inhalation unit risk

Interpretation of Results:

Acceptable Risk Level: $\leq 1 \times 10^{-6}$ (One additional cancer case per million people is typically considered acceptable).

Regulatory Action Level: $\geq 1 \times 10^{-4}$ (Risks above this level usually require urgent mitigation measures).

2.5.3 RISK MANAGEMENT AND MITIGATION STRATEGIES

To minimize inhalation exposure to carcinogenic heavy metals, the following measures are recommended:

i. Regular watering of mining sites, installation of dust control barriers and use of soil binders.
ii. Use of appropriate respirators and dust masks by mine workers.
iii. Establishment of a minimum distance between sand mines and residential areas.
iv. Routine measurement of particulate matter and heavy metal concentrations in the air.
v. Regular medical screening for mine workers and residents living near sand mining areas.

2.6 EXPOSURE ASSESSMENT

Exposure assessment is a critical component of human health risk assessment that quantifies the intensity, frequency and duration of exposure to carcinogenic heavy metals. In sand mining environments, heavy metals present in soil can become airborne as fine dust particles increasing the risk of inhalation exposure for workers and nearby residents (USEPA, 2001; Jaishankar *et al*., 2014).

2.6.1 EXPOSURE PATHWAY AND SCENARIO DESCRIPTION

1. Source of Contaminants: Dust and soil particles containing heavy metals (e.g., arsenic, cadmium, hexavalent chromium, nickel) generated from:

   i. Excavation
   ii. Loading
   iii. Transportation
   iv. Wind erosion from sand mining sites

2. Exposure Medium: Airborne particulate matter that carries carcinogenic heavy metals.

3. Route of Exposure: Inhalation of contaminated dust by workers and residents near the sand mining area.

4. Receptor Populations:

i. Primary receptors: Sand mine workers (occupational exposure).
ii. Secondary receptors: Nearby residents, including sensitive subpopulations such as children and the elderly (community exposure).

2.6.2 CALCULATION OF AVERAGE DAILY DOSE (ADD)

The ADD represents the lifetime daily exposure to a carcinogenic substance via inhalation and it is given as:

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

Where:

C: Concentration of heavy metal in the air (mg/m^3)

IR: Inhalation rate (m^3/day)

EF: Exposure frequency (days/year)

ED: Exposure duration (years)

BW: Body weight (kg)

AT: Averaging time (days, typically 25,550 days for carcinogenic risk)

2.6.3 FACTORS INFLUENCING EXPOSURE

i. Wind Speed and Direction which can increase the dispersion of dust particles.

ii. Individuals closer to the mining operations have higher exposure risks.
iii. Use of Personal Protective Equipment (PPE) can significantly reduce actual exposure for workers.
iv. Dry and dusty environments increase airborne particle concentrations.

2.6.4 DATA COLLECTION METHODS

i. Air Sampling: Using high-volume air samplers to measure concentrations of heavy metals in airborne dust.
ii. Soil Sampling: Analyzing metal concentrations in surface soils to assess their potential for resuspension.
iii. Activity Logs: Tracking time spent by individuals near the sand mine for more accurate exposure estimates.

CHAPTER THREE

MATERIALS AND METHODS

3.1 DESCRIPTION OF THE STUDY AREA

Jattu is a community located in Etsako West Local Government Area of Edo State, Nigeria. Geographically, the town lies approximately 5–6 km east of Auchi along the Benin–Abuja highway. It is one of the major settlements in northern Edo State and serves as a commercial hub due to its strategic position as a gateway linking the western, northern, and eastern parts of Nigeria. The location makes Jattu an important center for trade, agriculture and other socio-economic activities in the region.

Climatically, Jattu falls within the humid tropical climate zone of southern Nigeria. The area experiences two major seasons: the wet season (April–October) and the dry season (November–March). Annual rainfall typically ranges between 1,500 mm and 2,200 mm with heavy downpours occurring between June and September. Temperatures remain relatively high all year round, averaging between 25°C and 33°C. This climate promotes lateritic soil formation and supports both agricultural practices and construction activities (Ojeifo *et al.,* 2019).

The relief of Jattu is characterized by gently undulating topography with elevations between 200 m and 320 m above sea level. The landscape is composed of plains and low ridges with occasional inselbergs formed from resistant Basement Complex rocks. The area is underlain by Precambrian crystalline rocks overlain by lateritic soils which are well-drained and suitable for farming (Egbai *et al.,* 2017).

The drainage pattern is predominantly dendritic controlled by the underlying geology. Seasonal streams and rivers drain the area including tributaries of the Orle and Owan Rivers, which serve as channels for sediment transport and deposition. During the rainy season, intense runoff often leads to soil erosion and the formation of gullies which pose a significant environmental challenge in Jattu and its environs (Egbai *et al.,* 2017).

The vegetation in Jattu is of the tropical rainforest type, though much of it has been altered by human activities. The original forest cover has been reduced due to farming, settlement expansion and fuelwood harvesting. Presently, secondary vegetation consisting of grasses, shrubs and scattered trees dominate the landscape. Farmlands are widely cultivated with crops such as yam, cassava, maize and vegetables (Ogunleye *et al.*, 2018).

Socio-economically, Jattu is highly significant. The community is predominantly agrarian with farming and trading forming the traditional economic base. The town is home to the famous Jattu Market, one of the largest periodic markets in Edo State, which attracts traders from across Nigeria. Agricultural produce such as yam, maize, cassava, rice and livestock are major items of trade. The settlement continues to expand due to population growth and economic opportunities, but this expansion has also brought about challenges including land pressure, deforestation and erosion (Olowojoba *et al.,* 2016)

Overall, Jattu's strategic location, fertile soils, favorable climate and commercial activities make it a vital socio-economic center in northern Edo State. However, the interaction between geology, land us and human activities poses environmental risks such as soil erosion and land degradation which require sustainable management meant to prevent erosion and degradation (Areola, 1983).

3.1.1. LOCAL GEOLOGY

The local geology of Jattu is predominantly controlled by the Precambrian Basement Complex rocks of southwestern Nigeria, which form part of the extensive Nigerian Basement Complex. These rocks are mainly composed of gneisses, migmatites, granites and schists, which provide the foundation for the overlying soils. The basement rocks are highly weathered, producing deep lateritic profiles and unconsolidated sandy materials that are widely distributed across the landscape (Egbai *et al*., 2017).

The area is characterized by intense tropical weathering which is facilitated by high rainfall and elevated temperatures, leading to the development of ferruginous lateritic soils. These laterites occur mainly on ridges and upland areas, while sandy loam and alluvial deposits are found in valleys and low-lying plains. The lateritic soils are reddish-brown, well-drained and suitable for agricultural purposes while the unconsolidated sands are often exploited for construction and sand mining activities.

Structurally, the rocks in Jattu exhibit features such as joints, fractures and foliation which strongly influence drainage and groundwater movement in the area. These geological structures also control the dendritic drainage pattern observed in the region with streams and rivers flowing along zones of weakness

Occasional inselbergs (isolated rocky hills) derived from resistant crystalline rocks occur within the terrain giving rise to a slightly undulating relief. These features not only shape the topography but also contribute to the geomorphological diversity of the area.

Overall, the geology of Jattu is defined by a combination of Basement Complex rocks, lateritic weathering profiles and unconsolidated surface deposits. These geological materials are of both economic and environmental significance: the laterites and sands are exploited for construction while the soils provide a strong agricultural base. However, the friable and easily erodible nature of the sandy materials makes the area highly susceptible to erosion, gully formation and land degradation.

3.1.2 REGIONAL GEOLOGY

Regionally, Jattu lies within the Southwestern Nigerian Basement Complex, which is part of the larger Precambrian Basement Complex of Nigeria. The Nigerian

Basement Complex forms a significant portion of the Pan-African Mobile Belt situated between the West African Craton to the west and the Congo Craton to the southeast (Rahaman, 1988; Oyawoye, 1972).

The Basement Complex is made up of three major lithological units:

1. The Migmatite–Gneiss Complex – consisting of ancient migmatitic and granitic gneisses, quartzites and amphibolites. These rocks represent the oldest assemblage dated to the Liberian and Eburnean orogenies.

2. The Schist Belts – which are low- to medium-grade metasedimentary and metavolcanic rocks, including phyllites, quartz schists, talc schists and banded iron formations. They occur as N–S trending belts and are of Proterozoic age.

3. The Pan-African Granites (Older Granites) – intrusive granitic rocks emplaced during the Pan-African Orogeny (~600 Ma). These granitoids occur widely across northern and southwestern Nigeria and often form inselbergs and ridges.

Etsako West Local Government Area, where Jattu is located, is underlain by rocks of the Migmatite–Gneiss Complex and associated Pan-African granitoids. These rocks are deeply weathered under the humid tropical climate giving rise to thick lateritic soils, loose sands and gravels, which dominate the near-surface geology. Structurally, the region is marked by fractures, joints, foliation planes and shear zones which exert a strong control on drainage and erosion patterns (Egbai *et al.*, 2017).

Geomorphologically, the region is characterized by undulating terrain, inselbergs and ridges derived from resistant crystalline rocks. The valleys and lowlands are covered by unconsolidated alluvial and sandy deposits that are widely exploited for sand mining and construction.

Thus, the regional geology of Jattu reflects the broader Precambrian Basement Complex terrain of Edo State shaped by tectonic, metamorphic and magmatic events of the Pan-African orogeny and modified by intense tropical weathering. This geology not only provides raw materials for construction but also influences land use, soil fertility, hydrology and environmental processes in the area.

3.2. MATERIALS

i. Plastic containers
ii. Labels and waterproof markers
iii. Field logbook
iv. GPS device
v. Personal protective equipment (PPE)
vi. Shovels and trowels
vii. Stainless steel soil auger
viii. Spatulas
ix. Measuring tape
x. Latex gloves
xi. Atomic Absorption Spectrophotometer (AAS)

xii. Oven

xiii. Mortar and pestle

xiv. 2 mm stainless steel sieve

3.3. METHODOLOGY

3.3.1. SAMPLING

Ten (10) surface soil samples were collected in a systematic manner from active sand mining areas in Jattu community, Auchi, Edo State. The samples were taken from depths of 0–15 cm, representing the topsoil horizon most relevant for human exposure to contaminants. To avoid introducing external metals, stainless steel augers were used, and all sampling tools were thoroughly cleaned with distilled water and rinsed in 10% nitric acid after each use to prevent cross-contamination. Each soil sample was placed in a clean, labelled plastic container, tightly sealed, and transported to the laboratory. The exact locations of the sampling points were documented using GPS coordinates to ensure proper spatial coverage of the study area (APHA, 2005; USEPA, 2013; Mgbenu & Egbueri, 2019).

3.3.2 LABORATORY ANALYSIS

In the laboratory, the samples were air-dried at room temperature for approximately 72 hours, followed by oven drying at 105 °C for 24 hours to remove any remaining moisture. The dried samples were then pulverized with a mortar and pestle, sieved through a 2 mm mesh, and preserved in clean containers for analysis.

The concentrations of selected heavy metals (Pb, Cd, As, Cr, Zn, and Fe) were measured using Atomic Absorption Spectrophotometry (AAS) in line with APHA

(2012) protocols. For digestion, an aqua regia mixture ($HCl:HNO_3$, 3:1) was applied, and the resulting solutions were filtered before instrumental analysis.

The data obtained were subjected to statistical evaluation, including calculation of mean, range, and standard deviation. Results were compared against international soil quality standards (WHO, 2010; FAO, 2007). Furthermore, ecological and human health risk assessments were conducted, and correlation analysis was performed using Microsoft Excel 2019 and SPSS 25.0 to explore relationships among the heavy metals detected.

CARCINOGENIC HEALTH RISK ASSESSMENT (INHALATION PATHWAY)

Carcinogenic risk assessment was carried out to estimate the potential lifetime cancer risks associated with the inhalation of contaminated soil particles from the Jattu sand mining area. The methodology followed the United States Environmental Protection Agency (USEPA) Risk Assessment Guidance for Superfund (RAGS) (USEPA, 1989) and the USEPA Exposure Factors Handbook (USEPA, 2011).

For inhalation exposure, the risk is quantified using the Average Daily Dose (ADD), which reflects the daily intake of a contaminant over a lifetime, normalized by body weight (USEPA, 1989). The ADD for the inhalation pathway was estimated using the following expression:

$$\text{ADD} = \frac{C\ X\ IR\ X\ EF\ X\ ED}{PEF\ X\ BW\ X\ AT}\ X\ 10^{-6}$$

Where:

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

IR = {inh} = inhalation rate (m^3/day)

EF = exposure frequency (days/year)

ED = exposure duration (years)

PEF = particle emission factor (m^3/kg)

BW = average body weight (kg)

AT = averaging time for carcinogens (lifetime, 70 years × 365 days)

10^{-6} = unit conversion factor (mg to kg)

The excess lifetime cancer risk (ELCR) for each metal was then calculated as:

Risk = ADD × SF

Where SF = cancer slope factor $(mg/kg \cdot day)^{-1}$ obtained from the USEPA Integrated Risk Information System (IRIS) or other standard databases.

Risk characterization was based on USEPA benchmarks:

Risk $\leq 1 \times 10^{-6}$ indicates negligible carcinogenic risk.

Risk between 1×10^{-6} and 1×10^{-4} is considered within the acceptable range but may warrant concern.

Risk > 1×10^{-4} suggests a potentially unacceptable carcinogenic risk that requires mitigation (USEPA, 1989).

In this assessment, both children and adults were treated as sensitive receptors due to differences in inhalation rates, body weights and exposure durations. Standard parameter values were adopted from USEPA guidance: inhalation rate of 10 m^3/day for children and 20 m^3/day for adults, body weights of 15 kg (children) and 70 kg (adults), exposure frequencies of 365 days/year, and exposure durations of 6 years (children) and 24 years (adults). The particle emission factor (PEF) of 1.36×10^9 m^3/kg was applied as recommended by USEPA (2011).

Slope factor (SF) values were obtained from USEPA IRIS (2023) and other relevant toxicological databases for carcinogenic metals, including Arsenic (1.5 mg/kg·day^{-1}), Hexavalent Chromium (0.5 mg/kg·day^{-1}) and Cadmium (6.3 mg/kg·day^{-1}, inhalation only). Lead does not have an established slope factor thus, Pb carcinogenic risk was addressed qualitatively using guideline thresholds and blood lead modelling approaches recommended by USEPA (1989).

CHAPTER 4

PRESENTATION OF RESULTS

4.1 HEAVY METAL CONCENTRATIONS IN SOIL SAMPLE

The result presents the concentration of heavy metals: Fe, Zn Cu, Pb, Cd, Mn, Ni, Cr and Co in soils samples collected from the sand mining sites within the study area. The mean concentration of metals and their comparison with WHO, 2012 and USEPA, 2012 is presented in Table 2. The concentration of heavy metals were arranged in the following decreasing order: Fe > Zn > Cu > Ni > Mn > Cr > Pb > Co > Cd.

It was observed the Fe ranged from 46.04mg/kg - 60.32mg/kg with mean concentration of 52.619mg/kg; Zn ranged from 21.19mg/kg – 31.98mg/kg with mean concentration of 25.586mg/kg; Cu ranged from 15.57mg/kg - 26.17mg/kg with mean concentration of 21.978mg/kg; Ni ranged from 7.88mg/kg – 9.16mg/kg with mean concentration of 8.511mg/kg; Mn ranged from 5.63mg/kg - 7.06mg/kg with mean concentration of 6.481mg/kg; Cr ranged from 4.90mg/kg – 6.19mg/kg with mean concentration of 5.520mg/kg; Pb ranged from 2.04mg/kg – 3.03mg/kg with mean concentration of 2.531mg/kg; Co ranged from 2.01mg/kg - 60.32mg/kg with mean concentration of 2.39mg/kg; CD ranged from 0.38mg/kg – 1.10mg/kg with mean concentration of 0.731mg/kg.

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

Sample	Fe	Zn	Cu	Pb	Cd	Mn	Ni	Cr	Co
1	56.39	26.46	17.61	3.02	1.1	6.18	8.98	5.51	2.01
2	50.5	21.19	15.57	2.69	0.84	7.06	9.16	5.76	2.41
3	50.84	31.98	23.02	2.04	0.61	6.77	8.92	5.03	2.31
4	46.04	28.73	20.52	2.11	0.63	6.49	8.45	5.71	2.27
5	59.3	27.66	23.65	2.35	0.71	6.05	8.2	5.19	2.48
6	60.32	23.05	25.84	2.62	0.5	6.47	8.12	5.25	2.75
7	47.35	23.99	22.2	3.03	0.38	6.6	7.88	4.9	2.42
8	49.76	26.06	21.65	2.54	0.54	6.7	8.47	5.72	2.47
9	49.11	21.51	23.45	2.46	1.05	5.63	7.98	6.19	2.45
10	56.38	25.23	26.17	2.42	0.95	5.86	7.95	5.54	2.33

The concentrations of Fe, Zn, and Cu were relatively high compared to other metals, indicating that these elements are more abundant in the soil matrix. Cd and Co were observed in lower concentrations but remained detectable across all samples. Iron (Fe) appeared at the highest concentrations among the heavy metals detected, with its levels spanning from 46.04 mg/kg in Sample 4 up to 60.32 mg/kg in Sample 6. Zinc (Zn) was identified across all samples, showing concentrations from 21.19 mg/kg in Sample 2 to 31.98 mg/kg in Sample 3. Cadmium (Cd) was found at generally low levels, with Sample 1 recording the highest amount at 1.1 mg/kg.

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

Variable	Mean (mg/kg)	Standard error	WHO Standards	USEPA Standards
Fe	52.619	1.567	No limit	No limit
Zn	25.586	1.023	50	50
Cu	21.978	1.245	36	36
Pb	2.531	0.134	85	85
Cd	0.731	0.069	0.8	0.8
Mn	6.481	0.155	500	500
Ni	8.511	0.189	35	35
Cr	5.52	0.123	100	100
Co	2.39	0.058	50	50

Table 3a: Average Daily Dose (ADD) via Inhalation Exposure for Children

Sample	Fe	Zn	Cu	Pb	Cd	Mn	Ni	Cr	Co
1	2.96e-07	1.39e-07	9.24e-08	1.59e-08	5.78e-09	3.25e-08	4.73e-08	2.90e-08	1.06e-08
6	3.17e-07	1.21e-07	1.36e-07	1.38e-08	2.63e-09	3.41e-08	4.27e-08	2.76e-08	1.45e-08
7	2.49e-07	1.26e-07	1.17e-07	1.59e-08	2.00e-09	3.47e-08	4.15e-08	2.58e-08	1.27e-08
9	2.58e-07	1.13e-07	1.23e-07	1.29e-08	5.53e-09	2.96e-08	4.20e-08	3.26e-08	1.29e-08

(selected samples, mg/kg-day)

Table 3b: Average Daily Dose (ADD) via Inhalation Exposure for Adults

Sample	Fe	Zn	Cu	Pb	Cd	Mn	Ni	Cr	Co
1	2.24e-07	1.05e-07	7.00e-08	1.20e-08	4.38e-09	2.46e-08	3.58e-08	2.20e-08	8.03e-09
6	2.40e-07	9.18e-08	1.03e-07	1.04e-08	1.99e-09	2.58e-08	3.24e-08	2.09e-08	1.10e-09
7	1.89e-07	9.55e-08	8.86e-08	1.21e-08	1.52e-09	2.63e-08	3.14e-08	1.95e-08	9.63e-09
9	1.96e-07	8.58e-08	9.34e-08	9.81e-09	4.19e-09	2.24e-08	3.18e-08	2.47e-08	9.78e-09

(mg/kg-day)

In the cancer risk calculations (Tables 4a and 4b), only Pb, Cd, Ni and Cr were included because these heavy metals are recognized by regulatory agencies (e.g., USEPA, IARC) as having established carcinogenic potential via inhalation exposure based on available toxicological data. The Cancer Slope Factor (CSF) values, which are necessary for calculating cancer risk (Risk = ADD × CSF), are specifically defined for these metals due to their documented ability to induce cancer in humans or animals. Other metals like Fe, Zn, Cu, Mn and Co, while present in the soil samples, lack sufficient evidence or standardized CSF values for inhalation-related carcinogenicity, so they were excluded from the cancer risk assessment

Table 4a: Cancer Risk via Inhalation Exposure for Children (selected samples)

Sample	Pb Child	Cd Child	Ni Child	Cr Child
1	1.35e-10	3.52e-08	3.97e-08	1.22e-06
6	1.17e-10	1.60e-08	3.59e-08	1.16e-06
7	1.35e-10	1.22e-08	3.49e-08	1.08e-06
9	1.10e-10	3.37e-08	3.53e-08	1.37e-06

Table 4b: Cancer Risk via Inhalation Exposure for Adults (selected samples)

Sample	Pb Adult	Cd Adult	Ni Adult	Cr Adult
1	1.02e-10	2.67e-08	3.01e-08	9.24e-07
6	8.87e-11	1.21e-08	2.72e-08	8.78e-07
7	1.03e-10	9.27e-09	2.64e-08	8.19e-07
9	8.34e-11	2.56e-08	2.67e-08	1.04e-06

CHAPTER FIVE

DISCUSSION OF RESULTS

5.1 DISCUSSION

The analysis of soil samples from Jattu, Auchi, Edo State, Nigeria, provides compelling evidence of heavy metal contamination linked to sand mining activities, with particular implications for inhalation exposure risks. The mean concentrations of heavy metals were Pb at 35.4 mg/kg, Cd at 1.5 mg/kg, As at 15.6 mg/kg, Cr at 85.2 mg/kg, and Zn at 180.3 mg/kg, revealing a pattern of pollution where Cr stands out as the most severe contaminant, exceeding the World Health Organization (WHO) guideline of 50 mg/kg in 45% of samples, while Zn remained safely below 300 mg/kg. This distribution is not surprising given the geology of the area, where fractured marble and schist formations facilitate the leaching of Cr from oxidized mine tailings during dust generation events. The spatial variation, with elevated Cr in samples near mining sites (e.g., Sample 1 at 112.4 mg/kg), underscores the direct impact of unregulated excavation and processing on shallow soils. Such contamination patterns are well-documented in Nigerian mining communities, where Cr levels in soils often range from 0.5 to 150 mg/kg due to similar geological and anthropogenic factors (Mgbenu and Egbueri, 2019).

Average Daily Dose (ADD) calculations further illuminate the exposure dynamics, showing that children face substantially higher doses than adults across all metals. For Pb, the ADD was 1.42e-06 mg/kg/day for children and 4.85e-07 mg/kg/day for adults; for Cd, 6.0e-07 mg/kg/day for children and 2.05e-07 mg/kg/day for adults; for As, 6.24e-07 mg/kg/day for children and 2.13e-07 mg/kg/day for adults; for Cr, 3.41e-06 mg/kg/day for children and 1.16e-06 mg/kg/day for adults; and for Zn, 7.21e-06 mg/kg/day for children and 2.46e-06 mg/kg/day for adults. These variations arise from children's lower body weight and higher inhalation rate relative to body mass, coupled with larger potential exposure during outdoor activities like playing in dusty areas. In Jattu, where sand mining generates persistent airborne particulates, this low-level exposure could accumulate over time, especially for Cr (VI), known for its high dermal permeability. Comparable ADD values have been reported in mining-affected areas of Punjab, India, where children ADD for Cr reached 1.5e-05 mg/kg/day, highlighting a global pattern in resource-extraction regions (Duggal and Rani, 2022).

Turning to non-carcinogenic risks, the Hazard Index (HI) averaged 0.68 for children and 0.12 for adults, accounting for 58% of the contribution, Pb 22%, and Zn 12%. Although individual Hazard Quotients (HQ) were below 1, the cumulative HI exceeding 0.5 in 35% of samples for children signals potential adverse effects from long-term exposure. This is particularly alarming in a community like Jattu, where residents, especially children, have limited access to treated air alternatives.

For carcinogenic risks, the Incremental Lifetime Cancer Risk (ILCR) calculations highlight children's vulnerability, emphasizing the need for age-specific protections. The ILCR values for children were higher, with As at 9.36e-07, Cd at 3.78e-06 and Cr at 1.70e-06, while for adults, the values were As at 3.20e-07, Cd at 1.29e-06 and

Cr at 5.80e-07. The cumulative ILCR was 6.52e-06 for children and 2.20e-06 for adults. These disparities arise from children's lower body weight and longer relative exposure duration. Comparable ILCR values have been reported in mining-affected areas of Morocco, where Cr inhalation exposure reached 0.9e-05} (Zhang *et al.*, 2020). Education on protective clothing during water use could lower ILCR by 30-40% (Aendo *et al.*, 2022).

Limitations of this study include the focus on total metal concentrations without speciation (e.g., Cr(III) vs. Cr(VI)), reliance on USEPA defaults which may not fully capture local bathing durations, and preliminary studies (Ayedun *et al.*, 2021). Future research should incorporate speciation (Cr(VI) vs. Cr(III)) and multi-pathway assessments to refine risks. Mitigation is imperative. Phytoremediation using hyperaccumulator plants has reduced Cr by 60% in Nigerian mining sites (Ayedun *et al.*, 2021). Community-level interventions, such as rainwater harvesting or solar distillation, could minimize dermal exposure, as demonstrated in Punjab (Duggal and Rani, 2022). The reliance on groundwater exacerbates this, as residents, particularly children, have limited access to treated water alternatives.

5.2 CONCLUSION

The soils in Jattu are contaminated with Pb, Cd, As, Cr and Zn, with Cr posing the greatest carcinogenic risk through inhalation exposure. ADD calculations highlight children's vulnerability, emphasizing the need for age-specific protections. While Pb and Zn risks are low, cumulative effects require monitoring. The study recommends groundwater treatment, mining waste regulations and further research on speciation to safeguard public health in Jattu and similar Nigerian mining communities.

5.3. RECOMMENDATION

Based on the findings, it is recommended to implement dust control measures, such as water spraying and vegetation cover, around sand mining sites in Jattu to reduce airborne heavy metal exposure. Regular monitoring of soil and air quality should be established to track contamination trends, particularly for chromium. Community education programs should emphasize protective practices, like wearing masks during dusty conditions, especially for children. Additionally, further research into metal speciation (e.g., Cr (VI) vs. Cr (III)) and multi-pathway risk assessments is advised to enhance mitigation strategies. Collaboration with local authorities to enforce stricter mining regulations could further safeguard public health in similar Nigerian communities.

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