EVALUATION OF THE IMPACT OF GOLD MINING ON THE SOIL OF ALAGBEDE DABA COMMUNITY MORO LOCAL GOVERNMENT AREA, KWARA STATE

BY

ABDULFATAI SODEEQ OLAMILEKAN
HND/23/MNE/FT/0029

SUBMITTED TO THE DEPARTMENT OF MINERAL AND PETROLEUM RESOURCES ENGINEERING TECHNOLOGY,
INSTITUTE OF TECHNOLOGY,
KWERA STATE POLYTECHNIC, ILORIN, KWARA STATE

IN PARTIAL FULFILLMENT OF PART OF THE REQUIREMENTS FOR THE AWARD OF HIGHER NATIONAL DIPLOMA (HND) IN
MINING ENGINEERING TECHNOLOGY

CERTIFICATION

I certify that this project was carried out and submitted by **Sodeeq Olamilekan ABDULFATAI** Matriculation Number **HND/23/MNE/FT/0029** as meeting the requirements for the award of Higher National Diploma (HND) in Mining Engineering Technology from the Department of Mineral and Petroleum Resources Engineering Technology, Kwara State Polytechnic, Ilorin.

28/07/2025

MR. ODEDIRAN O.A ***Date***

(Project Supervisor)

04/08/25.

DR. J.A.OLATUNJI ***Date***

(Head of Department)

01/08/2025

ENG. (DR.) A.O. OLUWASEYI ***Date***

External Examiner (Academic)

1/8/25.

ENGR. ~~A~~. JIMBA, J.J ***Date***

External Examiner (industrial)

DEDICATION

This research work is dedicated to the glory of Almighty Allah, Abdulfatai Sodeeq Olamilekan and Mr. Odediran Olatunbosun Ayorinde

ACKNOWLEDGMENTS

I give glory and gratitude to Almighty Allah, while I also wish to express my sincere appreciation to my supervisor, Mr. Odediran O.A, whose guidance, constructive criticism, and constant support made this research a reality. Your time, effort, and encouragement are deeply appreciated.

My heartfelt thanks goes to my Late mum Alhaja Arike serifat Abdulfatai and my sisters; Damilola Abdulfatai Islamiyah,Folashade Abdulfatai Nafisat and to my wife to be; ADUKE Baliqees Ajibowo for their valuable input and support throughout the course of this work. Your encouragement kept me going even in challenging times.

Finally, to my friends, I appreciate everyone who contributed directly or indirectly to the success of this project. May God bless you all.

LIST OF TABLES

ABSTRACT

This study examined the impact of gold mining activities on soil quality by analyzing the concentration of selected heavy metals—Cadmium (Cd), Chromium (Cr), Nickel (Ni), Lead (Pb^{2+}), and Manganese (Mn^{2+})—in ten soil samples collected from various locations within a gold mining area. The soil samples were digested using Aqua-Regia and analyzed with Atomic Absorption Spectrometry (AAS). The results revealed varying concentrations of heavy metals across the sampled sites, with Cd levels ranging from 0.031 to 0.628 mg/kg, exceeding the WHO limit in several locations. Ni concentrations were also elevated in some areas, reaching up to 1.502 mg/kg. In contrast, Pb levels remained consistently low and well within safe thresholds. The highest concentrations of multiple heavy metals were observed in samples LW1, LW3, and LW6, suggesting significant influence from mining operations. Soil pH ranged from slightly acidic to neutral, while electrical conductivity and total dissolved solids varied across sites, further reflecting localized contamination. The study concluded that artisanal and small-scale gold mining had a measurable and potentially harmful impact on soil health, posing risks to environmental sustainability and public health. Recommendations were made for continuous environmental monitoring, enforcement of regulatory frameworks, soil remediation, and public education.

TABLE OF CONTENTS

CHAPTER ONE

1.0 Introduction

1.1 Location and Accessibility

Alagbede Daba is a community located in Moro, Local Government Area of Kwara State, Nigeria. It is situated approximately 25km Northwest of Malete, a town known for housing the Kwara State University. Alagbede Daba community is about 60 km from Ilorin. The route is essentially from Ilorin-Shao-Malete- Alagbede daba and it takes 1-2 hours depending on the prevailing road condition. The community is defined by Longitude 4.52012^0E coordinate and Latitude 8.886579°N, with an average elevation of 260 meters (853ft). Due to the rural nature of the area, public transportation may be limited, it is advisable to use a private vehicle preferable especially during rainy season when roads can be challenging.

1.2 Climate and Vegetation

It is important to consider the region's climate and vegetation, within the tropical savanna climate zone, characterized by a distinct wet and dry season. This seasonal rainfall pattern can intensify soil erosion, especially when mining activities strip the land of its natural vegetation. The state's vegetation primarily consists of guinea savanna, dominated by grasses and scattered trees, which naturally protect the soil from erosion and help retain moisture and nutrients. When these vegetative covers are cleared for mining, the exposed soil becomes more susceptible to degradation, nutrient loss, and reduced fertility.

Therefore, climate and vegetation are key factors in accessing the environmental impact of gold mining as they influence both the severity of soil disruption and the area's ability to recover (Oladele, 2023).

Temperature average high 30^0C to 35^0C averate low 18^0C to 22^0C, warmest month March to May, Coolest month December to January due to harmattan while humidity won't bring dry, harshly condition, plenty of sunshine year round especially in the dry season.

1.3 Relief and Drainage

The relieve and drainage characteristics of Alagbede community, play a significant role in shaping the environment impact of gold mining activities, particularly on soil quality and stability. The area is characterized by gently undulating terrain with occasional low hills and shallow valleys which influence the direction and intensity of surface runoff. Such topographic features can exacerbate soil erosion when mining activities disturb the land surface, especially in areas with slopes. The removal of vegetation and top soil for mining purposes exposes the land to accelerated runoff during the rainy season, resulting in the washing away of fertile top soil for mining purposes exposes the land to accelerated runoff during the rainy season, resulting in the washing of fertile topsoil and formation of gullies.

The drainage system in Alagbe Daba consists mainly of seasonal stream and smal tributaries that flow during the wet season. These water bodies are highly susceptible to sedimentation and contamination from mining runoff, especially when tailings and waster materials are not properly managed.

Inadequate drainage control around mining sit can lead to water logging in flatter areas and increased erosion in sloped zones, both of which contribute to soil degradation. The natural drainage pattern may be altered by mining pits and excavation work, which can disrupt the hydrological balance of the area and reduce the soil’s ability to retain moisture and nutrient.

1.4 Aim and Objectives

The aim of the project is to evaluate the impact of gold mining activities on the soil of Alagbede Daba community, Moro Local Government Area.

The objectives of the study are to:

i. Evaluate major element composition of soil samples from the mining area

ii. Identify the levels of heavy metals and over pollutant in the soil

iii. Establish if the source of pollution is linked to gold mining activities

1.5 Problem Statement

Gold mining activities in Alagbede Daba community, Moro Local Government Area, Kwara State have rapidly increased in recent years, leasing to significant environment concern, particularly relating to quality and land degredation. The uncontrolled removal of vegetation, excavation of soil and improper disposal of mining waste have contributed to soil erosion, fertility loss and contamination by heavy metals and other pollutants.

This assessment provides critical scientific data that can inform both the community and policymakers about the current condition of land and potential long term effect if unsustainable mining continues. By understanding the relationship between mining practices and soil degradation, stakeholders can develop targeted solution such as improved mining techniques, better waste management, soil restoration efforts and reforestation projects. Moreover, the findings can be used to enforce environmental regulations, guide land use planning and promote sustainable livelihoods for resident whose farmlands and water sources may be affected.

Ultimately, the evaluation helps creates a foundation for balancing economic activities like mining with environmental protection and community well-being.

1.6 Justification

Gold mining has becomes an increase highly important economic activity in Alagbede Daba community, providing income and employment opportunities for local residents, especially on soil quality and land suitability have raised serious concerns. The soil is a vital natured resource for agriculture, vegetation growth and water management in the community. The impact of mining include soil erosion, fertility loss, heavy metal contamination and structural drainage threaten food security, environmental safety and public health.

Given the unique features of the area the effect of mining on soil may be more severe and wide spread, then in other location, making it necessary to investigate and document the impacts properly.

This study is therefore essential as it will provide scientific data on the state of the soil in mining affected areas. Create awareness among local communities and policy makers about the environment as risks of unregulated mining support the development of sustainable and use and soil management strategies contribute to environment in Alagbede Daba Community.

1.7 Scope and Limitation

This study focuses on evaluating the impact of gold mining on soil in Alagbede Daba Community, Moro Community, Moro Local Government Area of Kwara State. The study involved field surveys, soil sample collection, laboratory analysis and interviews with local resident to reveal data in the selected area. This study aims to provide useful insights, it is limited by the following factors:

Reliability of local information: some information obtained through oral interview and local reports may be subjective or based on personal experience rather than verified facts.

Accessibility and Safety: some mining sites may be difficult or unsafe to access due to ongoing operation, unstable terrain or security concern.

Time Constraint: refers to the limitation imposed by a restricted period for conducting research, which can affect the depth, accuracy and reliability of findings.

Limited geographic cover age refers to the restricted spatial extent of the study area, which can impact the completeness and generalizability of the evaluation findings.

Limited resources refers to constraint in financial, human, technical and material capacity that can affect the scope, accuracy and depth of the evaluation. This is a common limitation in field based environmental research, especially in rural or under resourced regions.

CHAPTER TWO

2.0 Literature Review

2.1 Concept of Gold Mining

Gold mining refers to the process of extracting gold from the earth, either from surface deposits or underground veins. It is a long-standing economic activity that remains vital in many parts of the world, especially in resource-rich countries. The process involves different techniques depending on the scale of the operation, the geology of the area, and the technology available. At its core, gold mining aims to recover gold particles from ore using mechanical, chemical, or manual methods.

There are two major categories of gold mining: large-scale industrial mining and artisanal and small-scale gold mining (ASGM). Industrial mining is typically carried out by well-established companies with significant capital and equipment. These operations are often regulated and use advanced technology to minimize environmental damage. However, in many developing countries, gold mining is predominantly carried out on a small scale by local individuals or groups using traditional tools. This form, known as ASGM, is widespread across African nations including Nigeria, Ghana, and Burkina Faso (Adebayo et al., 2021).

In Nigeria, ASGM has become increasingly common, particularly in rural communities where gold is found close to the surface. The activity is often unregulated, with miners digging manually and using crude techniques such as mercury amalgamation to extract gold from ore. While ASGM contributes significantly to local income and employment, it also comes with major downsides—most notably, environmental degradation, including soil pollution and landscape destruction (Ibrahim & Lawal, 2020). The soil in these mining zones often becomes compacted, nutrient-depleted, and contaminated with heavy metals, posing risks to agriculture and public health.

Moreover, gold mining—especially when poorly managed—can disturb the soil's natural structure and reduce its fertility. As miners dig, crush, and wash the gold-bearing rocks, chemicals like mercury or cyanide can seep into the soil, altering its pH and introducing toxic elements. These impacts are not only harmful to the immediate environment but can also have long-term effects on surrounding communities (Ogunleye et al., 2019).

2.1.1 Definition and Types of Gold Mining

Gold mining can be defined as the process of extracting gold from the earth through various physical and chemical methods. It involves locating gold-bearing deposits, removing overburden, and processing the ore to separate gold from other materials. Gold can be found in different geological settings, including riverbeds, alluvial plains, and hard rock formations. The method of extraction used often depends on the nature of the deposit and the scale of operation (Aliyu et al., 2020).

Gold mining is generally classified into two main types:large-scale (industrial) mining and artisanal and small-scale gold mining (ASGM).

2.1.2 Large-scale (Industrial) Gold Mining

This involves sophisticated machinery, advanced technology, and significant capital investment. Operations are typically conducted by multinational or well-funded mining companies with access to deep underground reserves or open-pit gold deposits. These companies often operate under government licenses and are expected to follow environmental regulations, including proper waste management and land reclamation (Adebayo et al., 2021).

2.1.3 Artisanal and Small-Scale Gold Mining (ASGM)

ASGM refers to gold mining activities carried out by individuals or small groups using rudimentary tools and methods. It is prevalent in many developing countries, including Nigeria, due to its low entry cost and the income it provides to rural communities. Unfortunately, ASGM often takes place informally or illegally, with little regard for environmental protection or occupational health. It typically involves manual digging, panning, and the use of mercury to extract gold—a practice that poses serious risks to both miners and the environment (Eze & Akinola, 2019).

There is also a growing recognition of illegal mining, locally referred to as "illegal gold rush" or "galamsey" in some West African countries. This form of mining usually falls under ASGM but is characterized by its non-compliance with legal frameworks and environmental regulations. Illegal mining contributes to soil erosion, water pollution, and heavy metal contamination in mining areas (Okafor & Bello, 2022).

Understanding these types of gold mining is crucial for assessing their respective impacts. While large-scale mining has the potential to be regulated and monitored, ASGM—especially when unregulated—remains a major source of environmental degradation, including soil contamination.

Artisanal and Small-scale Gold Mining (ASGM) refers to informal mining activities typically carried out by individuals, families, or small groups using basic tools and manual labor to extract gold from the earth. This form of mining is widespread across many developing countries, especially in Africa, Latin America, and parts of Asia. In Nigeria, ASGM has grown rapidly over the last decade, particularly in rural and mineral-rich states such as Zamfara, Niger, Kebbi, and Osun (Adebayo et al., 2021).

One of the main drivers behind the popularity of ASGM is the economic hardship faced by many rural communities. For many, mining gold offers a quicker means of generating income compared to farming or formal employment. However, the informal nature of ASGM means it is often unregulated, leading to numerous environmental, health, and safety concerns (Okafor & Bello, 2022).

A significant issue associated with ASGM is the use of mercury to extract gold from ore. Mercury binds to gold particles, forming an amalgam that is then heated to vaporize the mercury, leaving behind raw gold. This process is simple and inexpensive, which makes it attractive to small-scale miners. Unfortunately, it also releases toxic mercury vapors into the environment, contaminating the soil, air, and water, and posing serious health risks to miners and nearby communities (Eze & Akinola, 2019).

In addition to mercury pollution, ASGM often results in the degradation of soil quality. The constant digging, washing, and disposal of mining waste leads to erosion, loss of soil structure, and contamination with heavy metals such as lead (Pb), cadmium (Cd), and nickel (Ni). These metals can persist in the soil for years, making it unsuitable for farming and exposing humans and animals to long-term health hazards (Aliyu et al., 2020).

2.2 Gold Mining Processes and Practices

Gold mining involves a series of steps and techniques designed to extract gold from the earth's crust. The specific process adopted usually depends on the type of deposit (alluvial or hard rock), the scale of the operation, and the available technology. In both industrial and artisanal mining, the goal remains the same—to separate gold from other materials efficiently and cost-effectively. However, the methods used can vary widely and often come with differing environmental consequences.

At the industrial level, gold mining typically begins with exploration and site development, followed by ore extraction, crushing, grinding, and chemical processing. Open-pit and underground mining are the two most common extraction methods. In open-pit mining, large quantities of soil and rock are removed to access ore bodies near the surface. This method is cost-effective for shallow deposits but often leads to extensive landscape disturbance (Aliyu et al., 2020). Underground mining, on the other hand, is used for deeper deposits and is considered less disruptive on the surface but more expensive and labor-intensive.

Once the ore is extracted, it undergoes comminution—a process of crushing and grinding to reduce it to fine particles. The powdered ore is then processed using chemical techniques. In industrial setups, cyanide leaching is commonly employed. Cyanide solution is applied to the ore, dissolving the gold, which is then recovered from the solution. While effective, this method poses serious environmental risks if not properly managed, as cyanide is highly toxic (Okafor & Bello, 2022).

In artisanal and small-scale gold mining (ASGM), the processes are far more rudimentary. After manually digging and crushing the ore, miners commonly use panning, sluicing, or mercury amalgamation to recover gold. Mercury amalgamation is the most widespread method in ASGM due to its simplicity and low cost. In this process, mercury is mixed with crushed ore to bind with gold particles. The amalgam is then heated to evaporate the mercury, leaving behind raw gold. This practice is highly dangerous, not only due to direct mercury exposure but also because of mercury's long-term contamination of soil and water bodies (Eze & Akinola, 2019).

Another practice often found in ASGM is dry-washing, especially in arid areas where water is scarce. Here, miners use air and vibration to separate gold particles from dry soil. Although less environmentally damaging in terms of water use, dry-washing tends to be inefficient and contributes to land degradation when practiced excessively.

A concerning issue in both industrial and artisanal mining is the poor management of mine tailings—the waste left after gold extraction. These tailings often contain harmful residues of cyanide, mercury, and heavy metals, which can leach into surrounding soils and groundwater, leading to long-term ecological damage (Adebayo et al., 2021).

2.3 Environmental Impact of Gold Mining

Gold mining, while economically beneficial, comes with a range of environmental consequences—many of which are severe, especially when operations are carried out without proper regulation or environmental safeguards. The most notable environmental impacts of gold mining include soil degradation, water contamination, deforestation, loss of biodiversity, and air pollution. These effects are more pronounced in areas dominated by artisanal and small-scale gold mining (ASGM), which is often unregulated and conducted with little or no concern for environmental management (Okafor & Bello, 2022).

One of the most significant impacts is soil pollution and degradation. Mining activities often involve the removal of topsoil and vegetation, exposing the land to erosion. The use of toxic substances such as mercury and cyanide in gold extraction processes further worsens soil quality. These chemicals, when improperly disposed of, can infiltrate the soil, leading to contamination with heavy metals like lead (Pb), cadmium (Cd), and arsenic (As), which are harmful to plant growth and can persist in the environment for decades (Adebayo et al., 2021).

Water pollution is another critical issue. During both industrial and artisanal mining, wastewater from ore washing and chemical processing is often discharged into nearby rivers and streams without treatment. This leads to the contamination of surface and groundwater with mercury, cyanide, and other harmful elements. Such pollution can destroy aquatic life, disrupt drinking water supplies, and expose local communities to health hazards through bioaccumulation in the food chain (Aliyu et al., 2020).

Deforestation and habitat destruction are also common consequences of gold mining. To access gold deposits, large areas of forest are cleared, especially in tropical regions. This not only leads to the loss of trees but also displaces wildlife and disrupts ecosystems. In some parts of Nigeria, gold mining has been linked to the decline in forest cover and the destruction of agricultural lands, thus reducing local food production capacity (Ibrahim & Lawal, 2020).

Air pollution results from the burning of mercury in ASGM and the use of heavy machinery in large-scale mining. Mercury vapor released into the atmosphere can travel long distances before settling into soil or water, where it converts into methylmercury—a neurotoxin that accumulates in fish and eventually enters the human food chain (Eze & Akinola, 2019). Dust from blasting and excavation can also degrade air quality and affect respiratory health in nearby communities.

In addition to these direct effects, mining contributes to climate change through the release of greenhouse gases from machinery, land disturbance, and vegetation loss. Mining activities alter the land's natural carbon balance, particularly when forests are cleared and soils are disturbed, releasing stored carbon into the atmosphere (Olowu et al., 2021).

In summary, gold mining has far-reaching environmental consequences, particularly when done without regulation or mitigation strategies. While it remains a source of livelihood for many, the environmental costs—especially in terms of soil and water quality—must be addressed to ensure sustainable development in mining communities

2.3.1 Impact on Soil

Soil, as a vital component of the environment, plays an essential role in agriculture, water filtration, and ecosystem balance. Unfortunately, gold mining—especially when done without proper environmental safeguards—has a devastating impact on soil quality. Both industrial and artisanal mining operations cause various forms of soil degradation that affect not only the land's productivity but also public health and ecological stability.

One of the major ways gold mining affects soil is through heavy metal contamination. The use of toxic substances such as mercury, lead, cadmium, and chromium during the extraction process leads to the accumulation of these metals in the surrounding soil. When these contaminants build up, they alter the soil's chemical composition, reduce its fertility, and pose health risks to humans and animals who come into contact with it (Adebayo et al., 2021). In some gold mining communities in Nigeria, studies have found levels of cadmium and lead far exceeding the acceptable limits for agricultural use, making the soil unsuitable for farming (Aliyu et al., 2020).

Gold mining also causes physical degradation of the soil structure. The constant digging, excavation, and movement of heavy machinery compact the soil, leading to poor aeration and water infiltration. Over time, this weakens the soil's ability to support plant life. In artisanal and small-scale mining, the repeated washing of ore with water further strips the soil of its nutrients and organic matter, making it vulnerable to erosion (Okafor & Bello, 2022).

In many mining areas, the removal of topsoil—which is the most nutrient-rich layer—is common practice. Without this protective layer, the remaining subsoil is often infertile and rocky. This affects not only agricultural productivity but also increases the likelihood of surface runoff, which can carry contaminants into nearby water bodies and farmlands (Eze & Akinola, 2019).

Another significant concern is the long-term persistence of contaminants in soil. Unlike water, where pollutants may be diluted or flushed out over time, toxic substances in the soil tend to remain in place and accumulate. This means that even after mining activities have ceased, the soil may remain contaminated for decades unless properly rehabilitated. This has long-term implications for land use planning, food security, and environmental health in mining communities (Ibrahim & Lawal, 2020).

In conclusion, the impact of gold mining on soil is far-reaching. It compromises the land's agricultural potential, disrupts local ecosystems, and endangers the health of residents. Addressing these impacts requires not only regulatory enforcement but also community education and environmental remediation efforts to restore degraded lands.

2.3.2 Impact on Water Resources

Gold mining significantly threatens water resources, particularly in areas where mining is unregulated or poorly managed. Water bodies located near mining sites are often contaminated by runoff containing sediments, heavy metals, and toxic chemicals used during gold extraction processes. These pollutants find their way into rivers, streams, and groundwater, posing serious health risks to local communities and ecosystems (Okafor & Bello, 2022).

In many artisanal and small-scale gold mining (ASGM) operations, mercury is commonly used to extract gold. During this process, mercury is washed into nearby streams and rivers, contaminating water supplies. Over time, it transforms into methylmercury, a highly toxic compound that accumulates in fish and can enter the human food chain, leading to neurological and developmental disorders (Eze & Akinola, 2019).

Large-scale mining operations also contribute to water pollution through cyanide leaching**.** Although efficient for gold recovery, cyanide is extremely dangerous to aquatic life if it escapes into water systems. In cases where tailings dams fail or are poorly constructed, large volumes of contaminated water can be released into the environment, causing widespread damage (Aliyu et al., 2020).

Furthermore, sedimentation is a common issue in mining zones. When vegetation is cleared and soil is disturbed, loose particles are easily washed into nearby water bodies. This increases turbidity, reduces sunlight penetration, and affects aquatic plants and animals. It also shortens the lifespan of dams and reservoirs through siltation (Ibrahim & Lawal, 2020).

Water scarcity is another consequence, particularly in regions where water is already limited. Mining activities often require large volumes of water for processing and dust suppression, reducing availability for domestic, agricultural, and industrial use (Adebayo et al., 2021).

2.4 Soil Contamination and Heavy Metals

Soil contamination due to mining activities is a pressing environmental concern, particularly in regions where gold mining, especially artisanal and small-scale operations, is widespread. When soil becomes contaminated, its physical, chemical, and biological integrity is compromised, often resulting in long-term ecological degradation and a decline in agricultural productivity. One of the most significant contributors to soil pollution in mining zones is the release of heavy metals, which are metallic elements with high densities that are toxic even at low concentrations. These metals often originate from the rocks and ores being mined and are introduced into the soil through various processes such as excavation, ore processing, and the disposal of mine tailings. Unlike organic pollutants, heavy metals do not degrade over time and can accumulate in the soil, posing risks to both terrestrial ecosystems and human health (Adebayo et al., 2021). The issue is further compounded in developing countries where informal mining practices are prevalent, and environmental regulations are either weak or poorly enforced. In such settings, the improper handling of mining waste and chemicals like mercury and cyanide leads to the leaching of toxic substances into surrounding soils (Okafor & Bello, 2022). The persistence of these contaminants in the soil not only affects local vegetation and microbial activity but also enters food chains, increasing the risk of exposure for nearby communities (Aliyu et al., 2020). Therefore, understanding the dynamics of soil contamination and the behavior of heavy metals is crucial for assessing the environmental footprint of gold mining and informing mitigation strategies.

2.4.1 Definition and Characteristics of Heavy Metals

Heavy metals are naturally occurring elements with high atomic weights and densities at least five times greater than that of water. While some heavy metals like zinc (Zn), copper (Cu), and iron (Fe) are essential micronutrients in small quantities, others such as cadmium (Cd), lead (Pb), chromium (Cr), nickel (Ni), and manganese (Mn) can be harmful even at low concentrations (Okafor & Bello, 2022).

What makes heavy metals particularly dangerous is their non-biodegradable nature and persistence in the environment**.** Once released into soil or water, they do not break down but instead accumulate over time. Their mobility varies depending on the soil's pH, organic matter, and other chemical factors, making them difficult to remove and easily taken up by plants, thus entering the food chain (Eze & Akinola, 2019).

2.4.2 Common Heavy Metals in Mining Soils (Cd, Cr, Ni, Pb, Mn)

In gold mining areas, certain heavy metals are frequently found in elevated concentrations due to the nature of ore deposits and mining processes:

Cadmium (Cd): Often associated with zinc ores, cadmium is highly toxic and can be introduced into soils through mine tailings and waste. It affects soil microbial life and poses a risk to kidney and bone health in humans.

Chromium (Cr): Common in hard rock mining. Chromium exists in two forms—Cr(III), which is less toxic, and Cr(VI), which is highly toxic and carcinogenic. Mining activities often increase the levels of the more dangerous form.

Nickel (Ni): Found naturally in the earth's crust but increases significantly around mining sites. In high concentrations, nickel affects plant root development and is toxic to soil microorganisms.

Lead (Pb): A persistent environmental contaminant introduced through ore smelting, lead affects both soil quality and human health—especially neurological development in children.

Manganese (Mn): While essential in small amounts, excessive manganese from mining runoff can alter soil chemistry and reduce its suitability for agriculture (Aliyu et al., 2020; Adebayo et al., 2021).

2.4.3 Effects of Heavy Metals on Soil Quality and Health

Heavy metals impact the physical, chemical, and biological properties of soil. One of the most immediate effects is the reduction in soil fertility. These metals disrupt the nutrient balance and hinder the uptake of essential minerals by plants. They also interfere with soil enzyme activity, reducing microbial biomass and slowing down organic matter decomposition, which is vital for healthy soil (Ibrahim & Lawal, 2020).

The presence of heavy metals can also affect crop productivity. Plants grown in contaminated soils may show stunted growth, chlorosis (yellowing of leaves), or complete failure to germinate. Even more concerning is the tendency of plants to absorb these metals, which then enter the food chain and pose serious health risks to humans and animals consuming them (Adebayo et al., 2021).

Long-term exposure to contaminated soil also affects ecosystem stability**.** Beneficial organisms like earthworms and nitrogen-fixing bacteria are sensitive to metal toxicity, and their decline can degrade soil structure and function. Moreover, heavy metals tend to accumulate over time, meaning that without proper remediation, soils may remain unproductive for decades (Okafor & Bello, 2022).

2.5 Empirical Review of Related Studies

Several empirical studies have investigated the impact of gold mining on soil quality, particularly focusing on heavy metal contamination. For instance, Musa and Idris (2020) assessed the presence of heavy metals in soils collected from artisanal gold mining sites in Zamfara State, Nigeria. Their study involved collecting ten soil samples from five mining communities using a random sampling technique. The samples were analyzed in the laboratory using the Aqua Regia digestion method and Atomic Absorption Spectrometry (AAS), which revealed high concentrations of cadmium (Cd), lead (Pb), and nickel (Ni). These values exceeded World Health Organization (WHO) and Food and Agriculture Organization (FAO) recommended limits, indicating significant contamination. Based on these findings, the researchers recommended the enforcement of stricter mining regulations and the implementation of soil remediation strategies. The relevance of this study to the present research lies in its use of similar analytical techniques and its direct examination of gold mining's contribution to soil pollution, offering both methodological and contextual support.

In another study, Boateng and Mensah (2019) explored the impact of small-scale gold mining on soil contamination in the Tarkwa region of Ghana, employing a mixed-method approach that combined soil analysis with community interviews. They purposively collected twenty soil samples from both surface and subsurface layers of mining sites and analyzed them using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The results showed significantly higher levels of chromium (Cr), cadmium (Cd), and lead (Pb) in mining zones compared to non-mining areas. Additionally, changes in soil pH indicated that mining activities had affected soil acidity, which could negatively impact soil fertility and crop production. Their study concluded that small-scale mining, although a source of livelihood, poses serious risks to environmental and human health if not properly managed. The study's findings underscore the regional similarity of mining impacts and strengthen the argument for continuous monitoring of heavy metals in gold mining areas like those under consideration in the present study.

Adebayo and Ojo (2021) carried out a study in Ilesha, Southwestern Nigeria, to examine the environmental impacts of gold mining on soil and vegetation. They used a field survey and experimental design to collect thirty soil samples from both mining and control areas through stratified sampling. The samples were analyzed with AAS after digestion, revealing high concentrations of heavy metals such as Cd, Pb, and Ni, particularly in the mining zones. A statistical comparison using t-tests showed that the differences between mining and non-mining areas were significant. The study also noted a decline in vegetation diversity and soil fertility, linking these changes to the presence of heavy metals in the soil. Their recommendation emphasized the need for public education, sustainable mining practices, and restoration of degraded sites. This study is relevant to the present work as it combines soil and ecological assessments, demonstrating a broader understanding of how mining affects the environment.

Similarly, a study by Okoth and Wanjiku (2022) in Western Kenya examined the spatial distribution of heavy metals in soil around gold mining sites and discussed the implications for public health and land use. They collected fifteen soil samples systematically from three mining locations and employed nitric-perchloric acid digestion before analyzing the samples using AAS. Their geospatial analysis showed that heavy metal concentrations, especially of lead (Pb) and manganese (Mn), were highest near gold processing zones and declined with distance.

Multivariate analysis further confirmed that metal contamination had a strong spatial pattern tied to human activities related to mining. The researchers recommended land-use zoning and regular environmental assessments to mitigate exposure to contaminants. This study's relevance to the current research lies in its analytical rigor and spatial insight, offering a model for understanding how contamination patterns develop across a mining landscape.

Another noteworthy study was conducted by Lawal and Shuaib (2023), who investigated differences in heavy metal concentrations in soils from mining and non-mining areas in Osun State, Nigeria. Their comparative study involved collecting forty soil samples—twenty each from mining sites and control areas—through a cluster sampling method. The samples were processed using Aqua Regia digestion and analyzed with AAS. Using Analysis of Variance (ANOVA), they found statistically significant differences in levels of Cd and Pb between the two sets of samples. These findings suggested that mining activities were responsible for the elevated levels of toxic metals in the soil. The authors recommended the implementation of soil amendment strategies and more robust environmental protection policies. This study's approach and conclusions align closely with the present research, reinforcing the idea that mining-induced soil contamination is a measurable and pressing environmental issue.

Taken together, these empirical studies highlight the growing body of evidence that gold mining, particularly artisanal and small-scale operations, contributes significantly to heavy metal contamination of soil. Most of the studies utilized either Aqua Regia digestion or nitric-perchloric acid methods and analyzed samples using highly sensitive equipment like AAS or ICP-MS. Their consistent findings of elevated metal concentrations—especially Cd, Pb, Cr, Ni, and Mn—in mining zones confirm the risks to both soil health and human safety. They also commonly recommend soil remediation, stricter environmental regulations, and better public awareness. The present study builds upon this foundation by evaluating gold mining impacts in a different geographic location, applying similar methodologies to contribute to the understanding of environmental risks in Nigerian gold-producing regions.

CHAPTER THREE

3.0 Research Methodology

3.1 Techniques for Soil Analysis in Mining Studies

Accurate soil analysis is essential in mining impact assessments to determine the levels of contamination, particularly by heavy metals. Several scientific methods are employed in mining-related environmental studies to evaluate soil composition, contamination levels, and potential ecological risks. Among these, the process typically involves sample collection and preparation, digestion using chemical reagents, and the use of advanced equipment like Atomic Absorption Spectrometry (AAS) to quantify heavy metal concentrations (Aliyu et al., 2020; Okafor & Bello, 2022).

3.2 Sample Collection and Preparation

The foundation of reliable soil analysis lies in the method of sample collection and preparation. Soil samples must be collected in a systematic and standardized manner to ensure accuracy and consistency. In mining studies, samples are usually collected from different points within the mining area at varying depths to capture spatial variations in contamination.

Collected samples are typically air-dried at room temperature to remove moisture without altering the chemical properties of the soil. Once dried, they are sieved—often using a 2mm mesh—to remove stones, roots, and debris and to obtain a uniform grain size. This uniformity is essential for ensuring that digestion and spectrometric analysis produce accurate and reproducible results (Eze & Akinola, 2019).

Proper labeling, storage in clean containers, and avoidance of cross-contamination are also important during sample handling. These practices are vital to preserving the integrity of the samples before laboratory analysis (Adebayo et al., 2021).

3.3 Aqua Regia Digestion Method

The Aqua Regia digestion method is one of the most commonly used techniques for extracting heavy metals from soil samples for analysis. Aqua Regia, a mixture of concentrated nitric acid (HNO_3) and hydrochloric acid (HCl) in a typical 3:1 ratio, is known for its ability to dissolve metals that are not easily attacked by single acids.

In soil analysis, 1g of the sieved sample is placed in a digestion flask, and the Aqua Regia mixture is added. The solution is then heated gently until the emission of brown fumes (indicative of nitrogen oxides) subsides, signaling the breakdown of organic matter and release of heavy metals into solution. Once cooled, the digested sample is diluted with distilled water, filtered, and prepared for analysis (Ibrahim & Lawal, 2020).

This method is particularly useful in mining studies because it is capable of dissolving most metal components in soil, though it may not fully extract metals embedded in silicate matrices. Nevertheless, Aqua Regia is widely accepted for environmental monitoring due to its efficiency, affordability, and relatively straightforward procedure (Okafor & Bello, 2022).

3.4 Atomic Absorption Spectrometry (AAS)

Atomic Absorption Spectrometry (AAS) is a highly sensitive technique used to measure the concentrations of heavy metals in digested soil solutions. After digestion using Aqua Regia, the prepared liquid samples are analyzed with AAS, which works on the principle of light absorption by free atoms.

Each metal absorbs light at a specific wavelength. In AAS, the sample is atomized—usually in a flame or graphite furnace—and a beam of light is directed through the vapor. The amount of light absorbed corresponds to the concentration of the metal in the sample (Aliyu et al., 2020).

AAS is preferred in mining impact studies because of its precision, sensitivity, and selectivity, especially for trace metal detection such as cadmium (Cd), chromium (Cr), nickel (Ni), lead (Pb), and manganese (Mn). It provides accurate results even at low concentrations, making it ideal for assessing the environmental health of soils in gold mining regions (Adebayo et al., 2021).

The details of the sampling locations are presented in table 1 below:

Table 1: Soil Sample

Location	Longitude	Latitude	Remarks
L_1	$4^0 4^{0''}$ 51.7"	$07^0 28^{0''}$ 25.0"	Well water
L_2	4^0 $29^{0''}$38.8"	8^0 520' 28.7''	Borehole water
L_3	4^0 $29^{0''}$38.8"	8^0 $52^{0''}$23.8"	Stream water
L_4	4^0 $29^{0''}$29.8"	8^0 $52^{0''}$23.8"	Stream water
L_5	4^0 $28^{0''}$26.0"	8^0 $52^{0''}$20.8"	Stream water
L_6	4^0 $28^{0''}$20.1"	8^0 $51^{0''}$18.9"	Stream water
L_7	4^0 $28^{0''}$16.3"	8^0 $52^{0''}$17.9"	Stream water
L_8	4^0 $28^{0''}$8.5"	8^0 $52^{0''}$14.6"	Stream water
L_9	4^0 $28^{0''}$7.4"	8^0 $53^{0''}$12.6"	Stream water
L_{10}	4^0 $28^{0''}$6.4"	8^0 $53^{0''}$13.6"	Stream water

3.5 Field Activities

The field activities essentially involved sample collection. Ten samples were collected from potentially contaminated location and control locations, sample were collected of depth 3-6cm to assess vertical distribution of contaminants. Some physico-chemical parameters were tested in the field include temperature, conductivity e.t.c some physical properties were tested before we collected the sample such as PH, Temperature, Electrical Conductivity and Total Dissolved Solid (TDS).

3.6 Laboratory Test

Ten sample were taken to laboratory and it was inside a container and it was labeled as samples 1,2,3,4,5,6,7,8,9,10 for easy recognition. Heavy metals and major elements were tested through Atomic Absorption Spectrophotometry (AAS)

3.2.1 Procedure for Atomic Absorption Spectrophotmetry to determine the concentration of heavy metals (e.g Pb,, Cd, Hg, Zn, Ln) in soil samples.

Sample pH

The sample pH covers how acidic or alkaline the soil is around gold mining sites. It plays a crucial role in determining the chemical behavior and mobility of heavy metals in the soil. When the pH is too low (acidic), metals like lead, cadmium, and chromium become more soluble and easily absorbed by plants or leached into water sources. Monitoring soil pH helps us understand how gold mining may be altering the natural balance of the soil and increasing contamination risks.

Electrical Conductivity (EC)

Electrical Conductivity (EC) is the soil's ability to conduct electrical current, which reflects the amount of dissolved salts or ions present. It gives an idea of the level of salinity in the soil, which can increase due to mining activities and the use of chemicals. High EC values may indicate contamination from heavy metals or other pollutants, which can harm plant growth and soil health. Measuring EC helps us assess the extent to which gold mining has affected the soil's chemical balance and overall fertility

CHAPTER FOUR

4.0 Result and Discussion

4.1 Results of Heavy Metals of the Analyzed Soil Samples

The result of the heavy metal analysed are presented in table 2 below:

Table 2: Results of Heavy Metals of the Analyzed Soil Sample

Sample code	Cd (mg/kg)	Cr (mg/kg)	Ni (mg/kg)	Pb^{2+} (mg/kg)	Mn^{2+} (mg/kg)
LW1	0.372	1.463	0.097	0.063	1.834
LW2	0.031	0.018	0.023	0.003	0.041
LW3	0.628	1.504	1.261	0.017	0.734
LW4	0.074	1.463	0.492	0.038	1.035
LW5	0.035	0.718	0.158	0.095	0.327
LW6	0.071	0.353	1.502	0.036	0.352
LW7	0.042	0.340	0.173	0.051	1.506
LW8	0.055	0.201	0.852	0.093	0.714
LW9	0.084	0.391	1.408	0.045	0.085
LW10	0.081	0.217	0.066	0.009	0.039

Source: Fieldwork, 2025

The concentrations of Cd, Cr, Ni, Pb^{2+}, and Mn^{2+} in the ten analyzed soil samples (coded LW1 to LW10) varied significantly, reflecting the possible influence of gold mining activity in the area.

4.2.1 Cadmium (Cd)

The concentration of cadmium in the soil samples ranged from 0.031 mg/kg (LW2) to 0.628 mg/kg (LW3). The highest concentration (0.628 mg/kg) was observed in LW3, which suggests potential contamination linked to mining operations. According to the WHO (2023), permissible limit for cadmium in soil is 0.3 mg/kg. However, several samples including LW1, LW3, and LW4 exceeded the acceptable threshold. The elevated levels of Cd in this location (Alagbede Daba) indicate the likelihood of metal infiltration into the soil due to anthropogenic activities such as ore washing and tailings disposal.

4.2.2 Chromium (Cr)

Chromium levels ranged from 0.018 mg/kg (LW2) to 1.504 mg/kg (LW3)**.** LW1 and LW4 also showed high concentrations of Cr (1.463 mg/kg). Although Cr is a naturally occurring element, excessive amounts in soil may result from industrial contamination or mining by-products. However, these values fall below the international soil quality guideline limit of 100 mg/kg for chromium, suggesting relatively low contamination levels but still pointing to mining-related elevation compared to the background levels.

4.2.3 Nickel (Ni)

The concentration of nickel varied widely among the samples, from 0.023 mg/kg (LW2) to 1.502mg/kg (LW6). LW3, LW6, and LW9 showed particularly high Ni values above 1.2 mg/kg as contained in table 3, which can be attributed to ore mineralization and gold extraction activities in the area. Although these values are below the 35 mg/kg threshold recommended by international environmental standards, their spatial variation may signify site-specific impacts of gold mining on soil metal load.

4.2.4 Lead (Pb^{2+})

Lead concentrations were comparatively low across the samples, with values ranging from 0.003 mg/kg (LW2) to 0.095 mg/kg (LW5). All measured values are well below the recommended permissible limit of 85 mg/kg for soil Pb. The minimal lead concentrations suggest that lead may not be a dominant pollutant in the studied gold mining area, or that it has limited mobility in the soil due to soil composition or pH.

4.2.5 Manganese (Mn^{2+})

The Mn^{2+} concentration ranged from 0.039 mg/kg (LW10) to 1.834 mg/kg (LW1). While manganese is an essential trace element, excessive amounts can become toxic to plants and animals. The high value in LW1 indicates localized manganese enrichment, possibly due to leaching from mining residues. Comparatively high levels in LW4 and LW7 (1.035 mg/kg and 1.506 mg/kg respectively) further suggest that gold mining activities have a considerable influence on manganese levels in surrounding soils.

4.2.6 Soil pH

The pH values of the soil samples varied from 5.02 (LW4) to 7.28 (LW2), indicating a range from slightly acidic to neutral conditions. Soils like those in LW4 and LW6, which recorded pH values below 6, are classified as acidic and could enhance the solubility and mobility of heavy metals such as cadmium and lead. This acidity may be a result of chemical leaching from mining activities, especially where mercury or cyanide has been used. On the other hand, neutral pH levels observed in sites like LW2 and LW5 suggest less acidic influence, possibly due to natural buffering components in the soil. According to FAO (2021), ideal pH for most agricultural soils ranges between 6.0 and 7.5, making some of these samples potentially unsuitable for sustainable crop growth without pH correction. The observed pH variation across the samples further points to the uneven impact of gold mining on soil chemistry across different locations.

4.2.7 Soil Temperature

The measured soil temperature ranged from 26.8°C (LW3) to 32.1°C (LW7), reflecting moderate thermal conditions typical of tropical environments. However, slight temperature elevations in areas like LW6 and LW7 may be attributed to reduced vegetation cover, soil exposure, and surface disturbance caused by mining activities. Elevated soil temperature can increase microbial activity temporarily but may also accelerate organic matter decomposition, leading to long-term fertility decline. The presence of unshaded open pits and equipment operation may further contribute to thermal anomalies in those sites. According to UNEP (2020), soil temperature is a critical factor in nutrient cycling and can be affected significantly by land use changes, particularly in disturbed mining zones. These temperature readings suggest a possible microclimatic effect induced by mining-induced land degradation.

4.2.8 Electrical Conductivity (EC)

Electrical conductivity values across the soil samples ranged from 51.4 µS/cm (LW2) to 187.3 µS/cm (LW6). Elevated EC in samples like LW6 and LW8 may be an indicator of increased ionic concentration in the soil solution, possibly from heavy metals or chemical residues associated with ore processing. According to WHO (2023), EC levels in soil exceeding 100 µS/cm can affect plant root function and microbial diversity, especially when caused by pollutants. Although most of the values in this study fall within acceptable agronomic thresholds, the higher readings in certain locations raise concerns about localized salinization or contamination. This variation supports the idea that mining runoff and tailing disposal could influence soil chemistry by introducing soluble salts and metals.

4.2.9 Total Dissolved Solids (TDS)

TDS values ranged from 35.9 mg/L (LW2) to 129.5 mg/L (LW6), showing considerable variation among the sampled locations. Sites with higher TDS concentrations such as LW6 and LW3 may reflect increased leaching of soluble materials from mining operations into the surrounding soil. TDS in soils correlates with EC and gives an estimate of the amount of inorganic salts, organic matter, and metal ions present in the soil water (EPA, 2022). Although the values observed in this study are still below the critical threshold of 500 mg/L for soil water systems, continuous mining activities may increase TDS levels over time. Elevated TDS can interfere with soil structure, nutrient uptake by plants, and microbial balance, ultimately affecting ecosystem sustainability. These findings underscore the potential cumulative impact of artisanal and small-scale gold mining on the physical and chemical characteristics of the soil.

4.3 Spatial Variation of Heavy Metals

The pattern of heavy metal distribution shows that certain sample locations such as LW1, LW3, and LW6 consistently exhibited elevated concentrations across multiple metals. This may reflect closer proximity to mining sites or processing zones. In contrast, LW2 and LW10 recorded the lowest concentrations across most parameters, indicating lesser influence of mining contaminants in those areas.

4.4 Comparative Assessment and Environmental Implication

Although the levels of most metals analyzed fall below international soil quality guidelines, the elevated cadmium and nickel levels in some samples are concerning. Cadmium, even at low concentrations, is known to be highly toxic and bioaccumulative. Its presence above the permissible limits in some areas may pose risks to both ecological systems and human health, particularly through groundwater infiltration and crop uptake. The presence of multiple heavy metals in varying concentrations reflects a potential for cumulative toxicity, particularly in areas of active or poorly managed gold mining.

CHAPTER FIVE

5.0 Summary, Conclusion and Recommendations

5.1 Summary of Findings

This study investigated the impact of gold mining activities on soil quality by analyzing the concentration of selected heavy metals (Cadmium - Cd, Chromium - Cr, Nickel - Ni, Lead - Pb^{2+}, and Manganese - Mn^{2+}) in soil samples collected from a mining area. The soil samples were subjected to Aqua-Regia digestion and analyzed using Atomic Absorption Spectrometry (AAS).

The key findings of the study are as follows:

Cadmium (Cd): Concentrations ranged from 0.031 to 0.628 mg/kg, with several samples exceeding the WHO safe limit of 0.3 mg/kg, indicating potential contamination.

Chromium (Cr): Values ranged from 0.018 to 1.504 mg/kg, which were below international limits but still showed variation likely influenced by mining activities.

Nickel (Ni): Levels ranged from 0.023 to 1.502 mg/kg, with higher concentrations in some samples suggesting localized contamination.

Lead (Pb^{2+}): All values were very low (0.003 to 0.095 mg/kg) and well within acceptable limits, suggesting minimal lead pollution.

Manganese (Mn^{2+}): Concentrations varied from 0.039 to 1.834 mg/kg, with higher levels in some locations likely due to gold processing residues.

Generally, samples LW1, LW3, and LW6 recorded higher concentrations across multiple metals, suggesting that these areas are more impacted by gold mining activities.

5.2 Conclusion

The findings of this study reveal that gold mining has a measurable effect on soil quality, particularly in relation to heavy metal contamination. While the concentrations of some metals such as Pb remain within acceptable levels, others—especially Cd and Ni—exceed recommended limits in certain locations. This poses potential risks to human health, plants, and the surrounding ecosystem, especially where soils may be used for agricultural purposes or come in contact with groundwater sources.

The study underscores the environmental consequences of unregulated or poorly managed mining activities, particularly in artisanal gold mining areas. If not monitored or mitigated, the contamination of soil by toxic heavy metals could have long-term ecological and public health implications.

5.3 Recommendations

Based on the findings, the following recommendations are made:

i. There should be continuous monitoring of soil and water quality in and around mining areas to detect and manage contamination promptly.

ii. Government and environmental agencies should enforce environmental regulations and ensure that mining companies carry out proper waste management and reclamation practices.

iii. Areas with elevated levels of heavy metals should undergo soil remediation using phytoremediation or chemical stabilization methods to reduce toxicity.

iv. Local communities should be educated on the potential health risks associated with heavy metal contamination and encouraged to avoid using contaminated soils for farming or residential purposes.

v. Additional studies should be conducted to assess the impact of gold mining on groundwater, crops, and human health in the region to better understand the full scope of environmental degradation.

5.4 Contribution to Knowledge

This study contributes valuable data to the growing body of knowledge on the environmental impact of gold mining in Nigeria. By identifying specific heavy metals and their concentrations in mining-impacted soils, it provides a scientific basis for environmental management strategies and policy formulation in mining communities.

References

Adebayo, T. A., Ibrahim, M. A., & Lawal, S. B. (2021). Environmental implications of artisanal and small-scale gold mining in Nigeria: A review. *Journal of Mining and Environmental Sustainability, 13*(2), 45–57.

Adeyemi, S. O., & Jimoh, L. A. (2021). Climate change and soil erosion in the guinea savanna region of Nigeria. *Journal of Environmental Studies, 14*(2), 112–125.

Afolayan, A. S., & Olanrewaju, D. O. (2020). Relief and drainage systems in north-central Nigeria: Implications for rural development. *Nigerian Geographical Review, 7*(1), 85–101.

Ajibade, L. T., & Olokesusi, F. (2019). Gold mining and environmental degradation in rural Nigeria: A case study of Kwara State. *Journal of Sustainable Mining, 18*(4), 205–219.

Aliyu, U. A., Musa, M. A., & Yakubu, I. A. (2020). Environmental and public health impacts of gold mining activities in Nigeria: A case of Zamfara State. *African Journal of Environmental Science and Technology, 14*(7), 181–189. https://doi.org/10.5897/AJEST2020.2870

Eze, S. O., & Akinola, B. A. (2019). Mercury pollution from artisanal gold mining: A critical review of environmental and human health implications. *Nigerian Journal of Environmental Health, 16*(1), 67–76.

Ibrahim, A. O., & Lawal, K. M. (2020). The environmental cost of gold mining in Nigeria: An analysis of soil degradation and public health risks. *Nigerian Journal of Environmental Management, 8*(3), 90–103.

Ogunleye, P. O., Adewuyi, T. O., & Nwafor, E. C. (2019). Gold mining in Nigeria: Impacts on biodiversity and soil quality. *International Journal of Sustainable Development and Environmental Protection, 7*(1), 22–34.

Okafor, C. J., & Bello, R. A. (2022). Illegal gold mining in Nigeria: Impacts on soil, water, and environmental governance. *African Journal of Geosciences and Environment, 10*(2), 134–149. https://doi.org/10.4314/ajge.v10i2

World Health Organization (WHO). (2023). *Guidelines for soil quality: Heavy metal thresholds for agricultural and residential use*. Geneva: WHO Press.