

**Mercury Contamination Risk Assessment in Artisanal Small-Scale Gold Mining Sites in
Uke and Environs, Nasarawa State**

**Henry Olapade DAVIES
LCUPG/001668**

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Natural and Applied Sciences, Lead City University,
Ibadan, Oyo State, Nigeria**

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Certification

This is to certify that **Davies, Henry Olapade** with Matriculation number **LCU/PG/001668** carried out this research work titled “**Mercury Contamination Risk Assessment in Artisanal Small-Scale Gold Mining Sites in Uke and Environs, Nasarawa State**” in the Department of Biological Sciences, Faculty of Natural and Applied Sciences, Lead City University, Ibadan, Oyo State, for the award of Doctor of Philosophy (Ph.D.) Degree in Environmental Management and Toxicology and that this has not been previously submitted.

Dr. Omotayo Sindiku
(Supervisor)

Date

Dr. Felicia Adesina
(Head of Department)

Date

Dedication

This research work is done to glorify the Almighty God and dedicated to my family.

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Acknowledgement

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Even though the above -mentioned institutions and persons have assisted in the process of this research work, I alone stand responsible for the errors, if any found in the work.

Abstract

The main focus of this research was to investigate the environmental effects of the use of mercury, a potent neurotoxicant, by artisanal miners processing gold at Uke mining sites in Nassarawa State. The research adopted multidisciplinary research approach involving analytical, quantitative and geospatial methods. The samples analyzed for both seasons includes, 10 fish samples, 39 water samples, 24 plants samples, 20 soil (wastes) tailing samples, 20 agricultural soil samples and 3 river sediments. The mercury concentration was measured using Direct Mercury Analyser (DMA80) and USEPA 7473 standard method. Moreover, remote sensing technique was adopted to process satellite imageries to extract NDVI values and Land use cover for the area. Results showed concentrations of mercury in fish within WHO allowable human consumption limit of 0.5 mg/kg, with bioaccumulation order within the organs as follows; gills>liver>intestine >muscle>bone. The values in soil ranges from 0.0162 to 0.387 mg/kg in wet season while the dry season ranges from 0.025 to 4.125 mg/kg which is above the crustal average of 0.003 mg/kg. The tailings have 0.003 to 0.142 mg/kg in dry season while 0.011 to 0.314 mg/kg in the wet season which is above expected limit. Plants mercury concentration confirmed that Rice, Pepper and Sweet Potato are above the allowable range of 0.03-0.1mg/kg and should be a concern for food safety in the area. The mercury in river Uke is above WHO threshold of 0.002 mg/kg. The result indicates positive correlation with low NDVI values and stressed vegetation. The Geoaccumulation Index and Contamination Factor Values, confirmed low contamination with the soil tailings as a point sou. This work developed a GIS-based model using the weighted method in ARCGIS to help predict mercury migration and produce pollution vulnerability map for risk management.

Keywords: Gold, Mercury, Remote Sensing, Tailings, Fish

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List of Acronyms

Abbreviation	Meaning
AAS	Atomic Absorption Spectroscopy
ANOVA	Analysis of Variance
GIS	Geographic Information System
DMA	Direct Mercury Analyser
WHO	World Health Organisation
UNIDO	United Nations Industrial Development Organisation
UNEP	United Nations Environment Programme
USEPA	United States Environmental Protection Agency
RfD	Reference Dose
ASM	Artisanal Small Scale Mining
ASMG	Artisanal Small Scale Mining of Gold
NDVI	Normalised Differential Vegetation Index
NIR	Visible near Infrared
EMR	Electromagnetic Radiation
UV	Ultraviolet Region
LAI	Leaf Area Index
SDVI	Standard Deviation Vegetation Index
MMSD	Federal Ministry of Mines and Steel Development
FMENV	Federal Ministry of Environment
NESREA	National Environmental Standards and Regulation Enforcement Agency.
MCO	Mining Cadastral Office

EIA	Environmental Impact Assessment
VEB	Vertical Engineered barriers
CF	Contamination Factor
Igeo	Geoaccumulation index
LOAHL	Lowest observed Adverse Effect Level
PTWF	Provisional Tolerable Weekly intakes
STEL	Short Term Exposure Level
TLV	Threshold Limits Value
PHE	Potential Harmful Elements
ALT	Alanine Transaminase
AST	Aspartate Transaminase
ALP	Alkaline Phosphatase
PbA	Lead Acetate
CNS	Central Nervous System
ERA	Ecological Risk assessment
HRA	Health Risk Assessment
SPSS	Statistical Package for the Social Sciences
DEM	Digital Elevation Models

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Chapter One

Introduction

1.1 Background to the Study

Mineral resources have been one of the pillars of economic sustainability of many nations. It has provided primary raw materials for the industrial development in most countries, resulting in the ceaseless demand for it, towards economic growth and development^{1,2,23,26}. In spite of its positive benefits, the improper management and control of mining activities have resulted in wanton damage to the environmentⁱ. In most advanced countries mining has played a pivotal role in the sustainable development of the economy but a carefully planned environmental management plan in most cases have reduced the emerging hazards from mining^{4,5,10,23,25}. This is not the case in most developing countries where unregulated mining activities is mostly carried out by artisanal miners who are driven by poverty and practice artisanal small-scale mining (ASM) as an alternative to live hood^{3,6,7}.

The gold ore processing involves the addition of elemental mercury crushed to primary ore to constitute an amalgam^{11,12,15}. This mixture is subjected to heat via a stove or local made fire which subsequently results into the extraction of mercury from the gold. At this point, exposure to mercury is detrimental to both the miner and the immediate community. This is because elemental mercury is highly volatile and its inhalation by the humans results into severe health issues such as impairment to nervous, and other sensitive body systems. Moreover, the discharge of mercury into the environmental media through the anthropogenic activities of the artisanal

miners eventually results into disruption into the food web via mercury contamination of mercury^{13,14,19}.

In Nigeria, Gold occurrences spread across over twelve states along a metallogenic province, called the Schist belt³⁰. It covers majorly the South western and North-western parts of the country; it spreads from Ilesha in Osun state to Gausau in Zamfara state³¹. The gold production in these states are predominantly done by artisanal miners. In trying to diversify the economy of the nation from oil, previous administrations have laid emphasis on the mining sector as one of the focal sectors for national development, for this reason the demand for gold has reached unprecedented levels. Thus, igniting the quest for its exploration all over the country²⁵.

Consequent upon the above, ASGM activities has increased tremendously prompting the use of large amount elemental mercury for gold processing^{18,19}. The unregulated discharge of mercury to the environment often results into wanton damage to the ecosystem^{4,24}. This is because the biogeochemical cycle of mercury enables it to occur in different forms, elemental mercury in particular is volatile and can easily be dispersed into the various environmental media but become more toxic under an anaerobic environment, where it is converted via microbial activities and methylated into organic mercury. e.g., methyl-mercury (MeHg)^{15,20}. The health effect of exposure to methyl mercury is catastrophic since it causes harm to the central nervous system. The chemical characteristics of this potent neurotoxin enables it to dissolve easily in lipids enabling easy access to biological membranes. Moreover, bioaccumulation and biomagnification in food chains are accelerated by the protein binding quality of MeHg^{7, 24}. The global attention was drawn to the lethal effect of MeHg during the Minamata Bay and Agano River mercury poisoning episode, where several lives were loss, as a results of contamination of

fish by methyl mercury, during the 1950s and 1960s^{15,16}. Several other studies have narrated the menacing health effects of mercury contamination such as neurological damage, kidney, memory loss, heart and even death. To this end, this study focused on the gathering of baseline data to assess the various risk associated with the discharge of mercury to the ecosystem during gold processing by artisanal miners in Uke, Nassarawa state, Nigeria. This research became very important to provide baseline data for managing such risk all over Nigeria^{3,12}.

1.2 Statement of the Research Problem

The application of mercury in gold processing, majorly by artisanal miners, has been a source of concern globally^{6,15}. Uncontrolled use of mercury have resulted in severe health implications due to exposure to miners and mining communities in many parts of the world. It has therefore become imperative that extensive study on safe best practices by artisanal and small-scale during their gold processing operations be carried out.

Mercury is commonly used as an essential part of the amalgam in the extraction of gold by miners. The anthropogenic release of this harmful metal into the environment often results into contamination of the ecosystem and poses great danger to human existence. The sustainable management of this hazard requires the acquisition of veritable baseline data to ensure monitoring and development of mitigation measures by researcher and policy managers²³. There is paucity of data on this project site which necessitated the need for this project.

Accordingly, it has become pertinent that a critical understanding of the various complex scenarios such as socio-cultural, technological, topographical factors are considered, to be able to provide mitigation measures to mercury pollution menace. It is believed that the data generated

from this project would form part of the national repository database on mercury which can form the basis for better decision making in risk management of the hazard¹⁹.

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1.3 Justification of the Study

The Lead poisoning incidence in Zamfara State Nigeria in 2010, where children were lost due to negative mining practices, led to a clarion call for safe mining practices amongst artisanal miners, especially the use of mercury during ASGM mining activities³. In order not to witness such unprecedented national disaster again, there is an awakening campaign to address the growing application of mercury in gold processing²². This has become pertinent since gold mineralization is very prominent in states such as Osun, Oyo, Zamfara, Kebbi, Sokoto, Kaduna, Nassarawa, Kogi etc., the gold resources of these states are in most cases being extracted by artisanal miners.

According to a World Health Organisation report, about 850,000 Nigerians are vulnerable to mercury poisoning due to activities of artisanal miners using mercury to process gold³⁰. The use of mercury to process gold has made close to a million Nigerians vulnerable to mercury contamination. This pose a great danger to public health of these communities and countrywide. In a related research on mercury on the burden of Disease (BoD), Nigeria ranks among the countries in Africa with the highest number of artisanal miners and highest Disability weight^{1,26}. The outcome of this work is expected to outline strategies expected to curb the possible health impact from mercury contamination.

The deliverables from this study includes production of risk maps and GIS based mercury vulnerability map for monitoring mercury contamination.

1.4 Aim and Objectives of the Study

The aim of this work was to evaluate the levels of mercury concentration in the environmental media such as fish, stream sediment, agricultural soils, edible plants surfacewater (river water)

and underground-water systems in the project area and to carry out the human health risk assessment of the community. Remediation measures are also to be suggested.

The specific objectives were;

- i) Evaluate the mercury content in soils, plant, surface, groundwater systems and fish from the Uke River;
- ii) Determine risk and human health assessment of the area of study;
- iii) Produce Risk Maps of mercury and develop GIS decision support system.

1.5 Research Questions

The research was geared to resolve the following questions:

1. Does the mercury values within the ecosystem such as soil, water, plants and fish within the safe WHO, EPA threshold limits?
2. Does the mercury from the gold processing activities of ASMG have direct impact on the mercury contamination of the environmental media?
3. Does the mercury usage by miners pose a risk to human health and environment in the community?

1.6 Significance of the Study

The availability of relevant basic data is essential to management of pollution and other hazards to human existence. Consequently, this study is necessary to collate vital geochemical dataset required to manage possible threat to the ecosystem through the activities of artisanal miners in Uke. This will culminate into the design of remediation measures to manage the hazard.

1.7 Scope of the Study

The research covered the assessment of the mercury concentrations in soil, ground water, tailings, plants, stream water as well as characterization of associated risks. The work entailed the use of analytical, geospatial and quantitative methods to investigate mercury contamination affecting the artisanal miners and community.

The details of this work included:

- The use of Landsat imagery processing of study area for land use and NDVI studies
- Reconnaissance survey: carried out seasonal field mapping of study site for collection samples and interview of correspondents.
- Carried out sample collection and preparation during wet and dry seasons (sample media includes, stream, plants, sediments, soils, and surface and groundwater.
- Execution of geochemical analysis of samples from the study site. The interpretation of the analytical data.
- Produce and design depicting mercury concentration maps within the ASGM system.
- Integration of various thematic dataset such as slope, flow accumulation, elevation, NDVI to develop a GIS based mercury vulnerability model.

1.8 Limitation of the Study

This paucity of analytical infrastructure for mercury was a limiting factor in this work. This was later resolve with the identification of an appropriate laboratory. Consequently, the high cost of analyzing samples also restrained the numbers of samples analysed in this work since it was not sponsored. Nevertheless, conformity with conventional sampling standard was never jeopardized. Secondly, the uncooperative attitude of artisanal miners in the release of their urine for analysis also constitute a major constraint in this research work.

Lastly, the correspondents used in the questionnaire survey were restricted to the immediate environment of the gold processing center.

1.9 Operational Definition of Terms

Environment: The natural world in which people, animals and plants live, as a whole or in a particular geographical area especially as affected by human activity.

Pollution: The presence or introduction into the environment of a substance which have harmful or poisonous effects.

Artisanal Mining: informal mining activities carried out by using low technology or rudimentary tools. Most times employing the use of hands.

Toxicity: The toxicity of a substance is the degree to which it is poisonous.

Risk Assessment: is the possible occurrence of an undesired outcome.

Mercury Methylation: is the process of forming methylmercury (MeHg). The methylation of mercury can occur abiotically or biotically. Biotically, the primary methylators of mercury are sulfate-reducing and iron-reducing bacteria.

Mercury Amalgamation: a process of extracting metals (as native gold and silver) from their ores by the addition of small quantities of mercury to the stamping or grinding unit so that the resulting amalgam is caught on mercury-coated copper plates from which it is then scraped, the precious metals in it being recovered by distilling off.

Phytoremediation: is a plant-based approach, which involves the use of plants to extract and remove elemental pollutants or lower their bioavailability in soil. Plants have the abilities to absorb ionic compounds in the soil even at low concentrations through their root system.

Normalized Difference Vegetation Index (NDVI): is a widely-used metric for quantifying the health and density of vegetation using sensor data. It is calculated from spectrometric data at two specific bands: red and near-infrared. The spectrometric data is usually sourced from remote sensors, such as satellites.

Google Earth Engine: Google Earth Engine combines a multi-petabyte catalog of satellite imagery and geospatial datasets with planetary-scale analysis capabilities. Scientists, researchers, and developers use Earth Engine to detect changes, map trends, and quantify differences on the Earth's surface. Earth Engine is now available for commercial use, and remains free for academic and research use.

Land Use and Cover Change (LUCC): is the study of land surface change. Land use (such as agriculture, pasture, or plantation) describes human use of land, while land cover (such as forest or desert) describes the biophysical characteristics of the land surface.

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Chapter Two

Literature Review

2.1 Conceptual Framework

Great economies are maintained on a long-term basis for nations of the world possessing and developing significant mineral resources sectors. Excellent business senses are also achieved from these developments when strict sense of stewardship on environmental management practices is adopted at such mine sites. Extraction of minerals from earth's crust thus constitutes mining activities and is second only to agriculture as the world's oldest and important activity which spans from the Stone Age. Africa is well endowed with mineral resources. It harbors the world's largest mineral reserves of platinum, gold, diamonds, chromite, manganese, and vanadium^{1,10}. However, some of these unpattern able mining activities on surface and subsurface has tremendous impact on the environment, with the end product of reduction of forest cover, erosion of soil, pollution of air, water and land and affect ecosystems in general. Gold mining and smelting activities and the long-term excessive application of fertilizers and agrochemicals over time have been identified as main anthropogenic releases. These are possible activities that exacerbate contamination magnitude, and ecological risk level of trace metals in riverine surface sediments in mining areas². Mercury contamination has pervaded many artisanal gold mining communities in the world, especially in developing countries. In Africa, the prevalence has become disturbing as these poses a threat to the biodiversity and inherent ecosystems. In Ghana, an evaluation of the potential risk of mercury pollution in soils and other eco-media of an artisanal gold mining community was carried out⁸. Enrichment Factors classified the soils of the study area as being moderately to extremely severely contaminated with mercury. The spatial distribution shows the contamination of mercury is highest at residential facilities and decreases through the community to the outskirts covered by vegetation³.

2.2 Review of Previous Work

Significance of contamination risk posed by artisanal gold mining is also highlighted by various researchers highlighting the hazardous nature of mercury and other heavy metals in Peru, China, Ghana, Indonesia and Nigeria where the release of mercury into the environment has caused catastrophic effects on the ecosystem^{2,4,7,8,6,11,14}. Particularly in Nigeria, in year 2010, the unregulated artisanal mining of gold in Zamfara State, North-Western Nigeria resulted in a Lead poisoning epidemic, which led to the death of not less than 400 children under the age of five¹². Consequently, irrespective of the local and international interventions in the affected communities, the death toll rose even higher in year 2013 and is considered to be the worst case of lead poisoning in modern history⁹.

Other related works carried out mercury contamination through artisanal mining in gold bearing areas of Ilesha, Anka, and Zamfara^{10,12,33}. In most of these studies emphasis was on determination of health and ecological risks especially the carcinogenic effect due the exposure to mercury. Moreover, the studies focused assessing the impact of mercury on water, soil, sediments, fish and plants. The samples were subjected to different analytical techniques using AAS and ICPMS to determine concentration of mercury in the environment. The pollution indices commonly used in assessing the contamination impact includes Hazard index, Hazard Quotient, Geoaccumulation, Contamination, Carcinogenic indices. Threshold limits were determined using the W.H.O permissible limits and the USEPA models. In most cases, polluted media pose very high ecological risks resulting in health risk on humans.

In South America, increase of mining activities has negatively impacted on ecosystems^{91,96}. A review conducted in Columbia, analyses national information levels on coal and Hg in island/coastal/marine as well as freshwater ecosystems and human groups using fishery resources as a framework^{38,198}. While considering a choice of fish is because fish are the main source of animal protein in marine coastal-island and mainland communities.

Out of 32 Colombian departments 15 have records of total mercury (THg) in water, sediments, fish, and human communities. Around 205 ton/year of mercury was discharged into the ecosystem. In human hair for example (15.3 to 50.15 $\mu\text{g/g}$), mercury exceeds the international maximum levels allowed (ILA) and the national standard (5.0 $\mu\text{g/g}$). Mercury levels in freshwater fish show 3.3 $\mu\text{g/g}$ of THg and levels in marine and coastal-island fish are 1.2 $\mu\text{g/g}$ THg exceeding the ILA (0.5 $\mu\text{g/g}$) standard for fish that will be consumed. Carnivorous species have a THg between 0.04 and 2.55 $\mu\text{g/g}$ suggesting bioaccumulation and magnification of heavy metals¹⁰. Prolong anthropogenic activity (particularly Mining) would have negative effects on the soil chemistry that may need total land appraisals.

A similar systematic investigation performed to assess the pollution and risk level of trace metals in river sediments located in the greatest gold production base in China¹⁴. The geo-accumulation index was used to assess the contamination degree. The sediment quality guidelines and potential ecological risk index were employed to complete an ecological risk assessment. Correlations and principal component analyses were applied to check relationships among trace metals and ascertain potential pollution sources. The results suggested that the sediments in the river were most polluted by As, Cd, and Hg followed by Cu, Pb, and Zn. There could be effects of suspended sediment and metal pollution on riverine ecosystem and fish

population can be responsible for genetic changes and population extinction as the risks from mining activities and fish population decline¹⁵. On a long-term basis, the accumulation of mercury contaminants in aquatic habitats not only is a treat to aqua culture but has a potential of total diminishing of aquatic heritage. The geochemistry of sediments in receiving environments indicates the potential for Hg-methylation to form highly bioavailable Hg species. An assessment on the contamination threat from consumption of local seafood, samples of fish, molluscs and crustaceans were collected from the Namlea fish market and analyzed for THg concentrations. Result showed that river, estuary and marine ecosystems downstream of ASGM operations on Buru Island (Indonesia) are exposed to dangerously high Hg concentrations, which are impacting aquatic food chains, and fisheries resources⁹⁸. Health wise, it is widely acknowledged that there is a myriad of health risk associated with Artisanal and small-scale mining (ASM) obviously from Mercury (Hg) contamination is an issue of concern^{6,12}. A scoping review of peer-reviewed publications, harnessed available electronic databases ranging from PubMed, Scopus, Academia and Web of Science from inception to March 2022. Relevant information with emphasis on human and environmental exposures and health effects in a context of ASM, Mercury and ASGM were put together^{19,24,27,36}.

2.3 Local Geology

The basement rocks represented in the area are mainly rocks of the migmatites gneiss complex, metasediments and meta-igneous rocks and Pan African granitoids⁷². There is also the presence of intrusive veins of quartz and pegmatites, which host some gem-stones like black tourmaline associated with most of the major rocks.

The rocks of migmatite gneiss complex comprises of various types of gneisses ranging from thinly laminated gneisses to the banded gneisses. There are also the biotite rich gneisses and biotite garnet gneisses. The Pan African granitoids are represented by variants of granites from porphyritic biotite granite with large phenocrysts of K-feldspars to the medium – fine grained biotite, observed some parts of the area^{74,75,76}.

Structural trends in the crystalline basement complex rocks are dominantly NNE/SSW with significant associated NNW/SSE and minor E-W and N/S trends dipping 60°NW³. These structural lineaments in the basement complex rocks are believed to be ancient structural trends. Intermittently active since at least late Precambrian times. These ancient lines also serve as possible zones of emplacement of gold, base metal, and other mineral occurrences like garnet, k-feldspar⁷³.

The study area Uke is generally underlain by basement rocks represented mainly by rocks of the migmatites gneiss complex, metasediments and meta-igneous rocks and Pan African granitoids. There is also the presence of Intrusive of vein quartz and pegmatites.

Three distinct lithologies were identified within the project area and described as follows; medium to coarse grained Biotite Granites and Pegmatites/quartz, as minor intrusions.



Plate 2.1: Biotite Granites rock in the Area with Gold Bearing Quartz Veins

Source: Author's Field Work, 2023

The medium - coarse grained Biotite Granites occupied about 70% of the area, underlying the entire western flank and stretches to southeast and northwest of the quadrant. They are generally light to dark grey in colour (Plate 2.1).

The Pegmatite intruded the medium to coarse grained biotite granite. On the scale of 1: 1000, the pegmatite was mapped in details. The largest intrusion is about 120m x 65m trending NW – SE direction. Boulders of pegmatites abound around Tudun Tafa with clear contacts with the granites. Also, contact between medium to coarse grained granite and pegmatite intrusion was exposed at Daban Nemu. The Pegmatites occupies just about 10% of the area. Pegmatites and quartz occur as vein and vein filling respectively and traverses the granites in the northeastern quadrant of the project area. The pegmatite shows a variety of composition; from the quartz to quartz-mica veins. The latter appear to be the gold hosting rock as evident from existing work (Plate 2.2).

Do Not Copy, Lead City University, Nigeria



Plate2.2 : The Medium - Coarse Grained Biotite Granites

Source: Author's Field work, 2023

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2.4 Environmental Impact of Mining

Human activities such as industrial production, mining, agriculture and transportation, release high amounts of Potentially Harmful Elements (PHE) into surface and groundwater, soils and ultimately to the biosphere^{11, 70}. Their toxicity depends on several factors including the dose, route of exposure, and chemical species, as well as the age, gender, genetics, and nutritional status of exposed individuals. Because of their high degree of toxicity, even in traceable levels in living organisms, As, Cd, Cr, Pb, and Hg rank among the priority metals that are of public health significance. These metallic elements are considered systemic toxicants that are known to induce multiple organ damage, even at lower levels of exposure¹³. They are also classified as human carcinogens (known or probable) according to the U.S. Environmental Protection Agency, and the International Agency for Research on Cancer.

The presence of PHE (also referred to as potential Harmful Elements) in the water may have a profound effect on the microalgae which constitute the main food source for bivalve mollusks in all their growth stages, zooplankton rotifers, copepods, and brine shrimps and for larval stages of some crustacean and fish species. Moreover, bio-concentration and magnification could lead to high toxicity of these metals in organisms, even when the exposure level is low^{12, 7, 8}. Human exposure to PHE is inevitable, and studies have reported toxicity can result in brain damage or the reduction of mental processes and central nervous function, lower energy levels, damage to DNA, and alterations on the gene expression, skin and liver, muscle, blood composition, lungs, kidneys, heart, and other vital organs for humans and other living organisms^{9,10,11,16}

Long-term exposure to PHE may result in slowly progressing physical, muscular and neurological degenerative processes that mimic Alzheimer's disease, Parkinson's disease,

muscular dystrophy, multiple sclerosis, gangrene, diabetes mellitus, hypertension and ischemic heart disease²⁶. High-dose heavy metals exposure, particularly mercury and lead, may induce severe complications such as abdominal colic pain, bloody diarrhea, and kidney failure. On the other hand, low-dose exposure is a subtle and hidden threat, unless repeated regularly, which may then be diagnosed by its complications, e.g., neuropsychiatric disorders including fatigue, anxiety, and detrimental impacts on intelligence quotient (IQ) and intellectual function in children.

These Heavy metals have been excessively released into the environment due to rapid industrialization, manufacture of fertilizers and to the high production of industrial waste originated from metal plating, mining activities, smelting, battery manufacture, tanneries, petroleum refining, paint manufacture, pesticides, pigment manufacture, printing or photographic industries^{12,27}. This has created a major global concern because they are non-biodegradable and can be accumulated in living tissues, causing various diseases and disorders within the food chain. During gold mining operations other elements are often present and also dissolved include Cu, Pb, Zn, Fe, Co, Hg, with geologically enriched environments containing high concentrations¹⁷.

Analyses of human biomarkers have been used to demonstrate occupational or environmental exposure to toxic elements. Urine, blood, hair and nails reflect metal mean level in human body. This section confirms that globally the activities of artisanal miners has remained a major anthropogenic source of mercury which is often associated with lead, both heavy metals causes environmental contamination resulting into hazardous effects on the health of the vulnerable population.

2.5 Artisanal and Small-Scale Mining (ASM) in Africa

Mining has been one of the key primary industries since the development and civilization of mankind. Mining is done in large scale, medium and artisanal and small-scale mining. The large scale and medium scale mining is dominated by corporations from developed countries and economy. Artisanal Small-Scale mining (ASM) is typically undertaken by the developing and under developing countries mostly in Africa.

In definition **Artisanal Mining** is that which is characterized by manual labour, or *zero* to minimal mechanization; *zero* to minimal geological knowledge; zero or very low start-up capital; is usually unfavorable due to lack of adequate specific policy and regulatory frameworks; is sometimes formal (with precarious mining passes/cards) but mostly informal while **Small Scale Mining** is usually formal (with mining title); semi-mechanized; has limited geological knowledge; low to medium start-up capital; regulated by the Mining Code; required to produce an environmental impact assessment study.

There are about 30 million people involved in ASM in 80 countries worldwide, 30 – 40% of whom are in Africa⁴⁰. More than 35 different minerals which make a significant contribution to the world's production of critical mineral products are those in ASM mine and process. For instance, in 2005, 15% of the gold production (400 – 600 t/a) valued at approximately 20 billion USD was undertaken by ASM. The ASM activity generates and supports secondary activities/economies of close to 100 million people with the sector supporting direct and indirect livelihoods of 120 – 150 million people. Several studies report that there are at least 9 million women and 2 million children involved in Artisanal Small-Scale mining ASM activities worldwide^{1,37,64}. The main commodities mined by artisanal and small-scale miners in terms of value are gold and diamonds which are produced by 15 million ASM (for gold only). ASM

produces about 10 - 15% of the world's mined gold; between 15-20% of mined diamonds and approximately 20-25% of tin and tantalum; and about 80% of precious and semiprecious stones (coloured gemstones)⁸².

Africa hosts more than one third of the world's mineral resources, and has potential for exploitation of more resources as a great part of the continent has not been properly explored. This potential is not yet harnessed for the benefit of the Africans. Although the continent has natural/mineral resources, it lacks adequate human capital; financial resources; industrial linkages which would promote competitive markets for the mineral resources; infrastructure; and to some extent the political systems, fiscal and mining regimes that would address the key issues in this regard.

It is estimated that about 12 million people are involved in ASM and produce a variety of mineral commodities with prominence in terms of value to gold, diamonds, coltan and coloured gemstones. ASM contributes significantly to the economic development of the countries where it is practiced⁷. In some countries it constitutes the only mining activity and produce 100% of the metallic mineral commodities. However, in Africa the mining sector is faced with numerous challenges related to the informality of its economic streams; illegal mining conduct; environmental disruptions; poverty; vulnerability to trade in conflict minerals; slavery and forced labour; child labour and human rights abuses in the mining camps¹⁶¹.

2.6 Artisanal and Small-Scale Mining in Nigeria

Nigeria is enriched with over forty (40) types of minerals including marble, gypsum, lithium, silver, granite, gold, gemstones, bentonite, iron ore and talc. The mining and solid mineral sector of the extractive industry in Nigeria has always been a viable green-field particularly since the descent of gold mining after it peaked from 1935 – 1941⁷². Due to poverty, overbearing government regulations and lack of adequate financial support, gold mining is majorly conducted by artisanal miners in Nigeria.

According to recent findings, the mining of solid minerals in Nigeria is performed in over 90% by ASM while the remaining 10% represent mining of infrastructure minerals such as limestone, aggregates, shale and laterite⁷⁹. Other operators include the Small-Scale Miners and the Large-Scale Miners. The Small-Scale Miners are registered enterprises/limited liability companies that carry out mining operations using Artisanal, Alluvial and other forms of mining operations involving the use of low-level technology or application of methods not requiring substantial expenditure and operating within Small-Scale Mining Lease Areas. The country reports having 179 ASM sites where at least 400,000 miners exploit a variety of minerals. Nigeria has also 1.5 million people indirectly involved in mining, of whom 300,000 are service providers to the ASM mining sector¹⁹⁷.

2.7 Gold Occurrences in Nigeria

The reliance on the economic benefits of gold has placed high priority in the exploration for gold deposits and possible occurrences. Geochemical pathfinders are minerals that often formed in close association with gold. Therefore, their presence even in seemingly gold-barren rock opens up the possibility of locating a nearby gold deposit. Examples of minerals that are geochemical pathfinders for gold include silver, copper, lead, zinc, cobalt, nickel, arsenic, antimony, tellurium, selenium and mercury. These minerals are an important tool in gold exploration. Their identification can help explorers determine the

\ possibility of gold occurrence in a particular environment⁷³. Structurally, primary gold mineralization is associated with veins, stringers, lenses, reefs and similar bodies of quartz, quartz-feldspar and quartz-tourmaline rocks in both the supracrustal rocks and basement. The veins usually range in thickness from several centimeters to few meters, and often displaying lenticular or pinch and swell (boudinage) structure and invariably steeply inclined occurring as isolated body or as parallel or echelon veins system.

In Nigeria, several researchers have stated the association of Nigerian gold with the schist belts. A study reported that gold mineralization is found mainly in the Archean to Lower Paleozoic Basement rocks of the schist belts and gneisses which are confined to the western part of northwest zone and are commonly found in quartz veins and reefs within several lithologies with their morphological types including bed concordant veins or discordant vein system^{1,37,64}. Also, another study observed there is a spatial relationship with some schist belts although gold quartz veins also occur in gneisses (e.g. Malele, Diko and Iperindo), and some gold bearing quartz veins carry some sulphides, galena and pyrite being the most common and the veins are very often conformable with the general N–S to NNE–SSW structural grain of the basement and occur in a

variety of geologic settings which suggests that there was more than one period of mineralization⁷². Moreover another author noted that gold occurs both as placers (alluvial and eluvia) and primary vein deposits within the schist belts of northwest and southwestern Nigeria⁷³. About 90% of Nigeria's total gold production has been from alluvia deposits derived from primary gold mineralization in the basement. Some of the most important occurrences are at Maru, Anka, Kwaga, Gurmana, Birnin-yauri, Okolum, Dogon-Daji and Iperindo areas, and are all associated with the schist belts, and several new artisanal workings within the Kushaka schist belt at places like Gusoro, Zumba, Maitumbi-Minna, Pago and Maiwayo village which is almost at the contact between the basement and the Nupe sandstone.

The different types of host rocks of Nigerian gold showing different petrographic characteristics as earlier researcher stated that correlate to several period of mineralization was controlled by deep seated curvilinear transcrustal fracture system. These deep-seated fracture systems, Anka-Yauri-Iseyin (AYI) and Kalangai-Zuru-Ifewara (KZI) as shown in Figure 2.1 are believed to serve as conduits to the subsidiary fractures which are linked to these major fractures and form sites of gold deposition. The major commercial gold deposits and some smaller occurrences are shown in Figure 2.2 and Table 2.1 respectively. According to most of the authors gold is associated with the schist belts of northwest and southwest Nigeria.

Table 2.1 State and Some Locations of Gold Occurrence in Nigeria

S/n	State	Location
1.	Zamfara	Anka, Maru, Malele
2.	Kebbi	Bin Yauri, Mararaba, Waya, Rafin Bakin Dutsi, Laka and Gerin Hawal
3.	Kaduna	Tsohon Birnin Gwari and Kwaga
4.	Niger	Gurmana
5.	Kogi	Okolom-Dogondaji, and Egbe-Isanlu Area
6.	Kwara	Bishewa, Ologomo, Agboro, Korobiri, Degeji, Ndanaku, Mari, Oputa, Lokomosi, Tunga Bichi, Gbajubo, Giloadi and Birnin Ruwa
7.	Osun	Iperindo (Ilesha)
8.	Ogun	Ajegunle-Awa
9.	Oyo	Shaki and Irawo areas
10	Ekiti	Ijero
11	Cross River	Oban Massif area
12	FCT, Kano, Kastina, Kwara	

Source⁷⁷

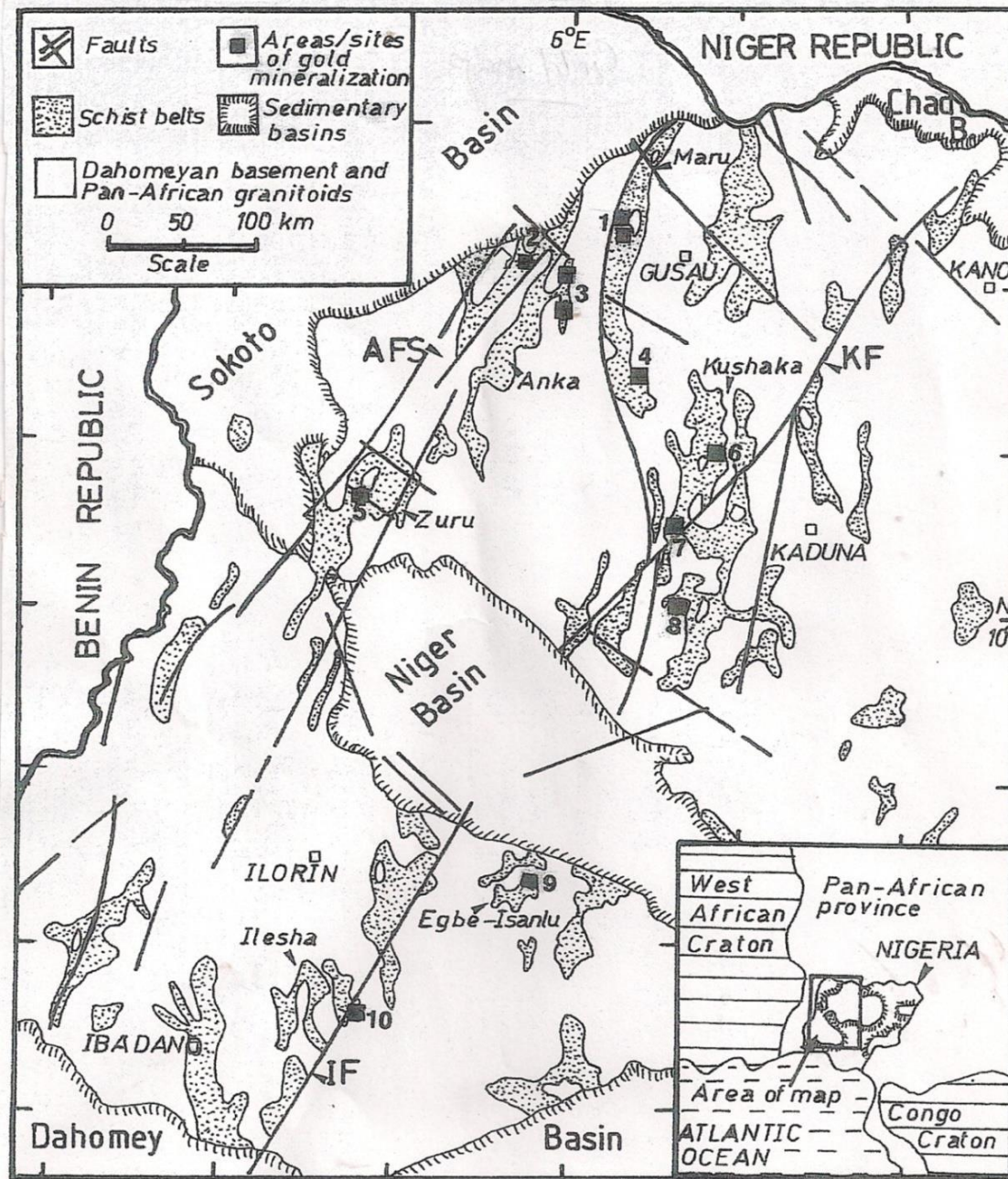


Figure 2.1: Map of Transcrustal Fracture System

Source⁷⁷

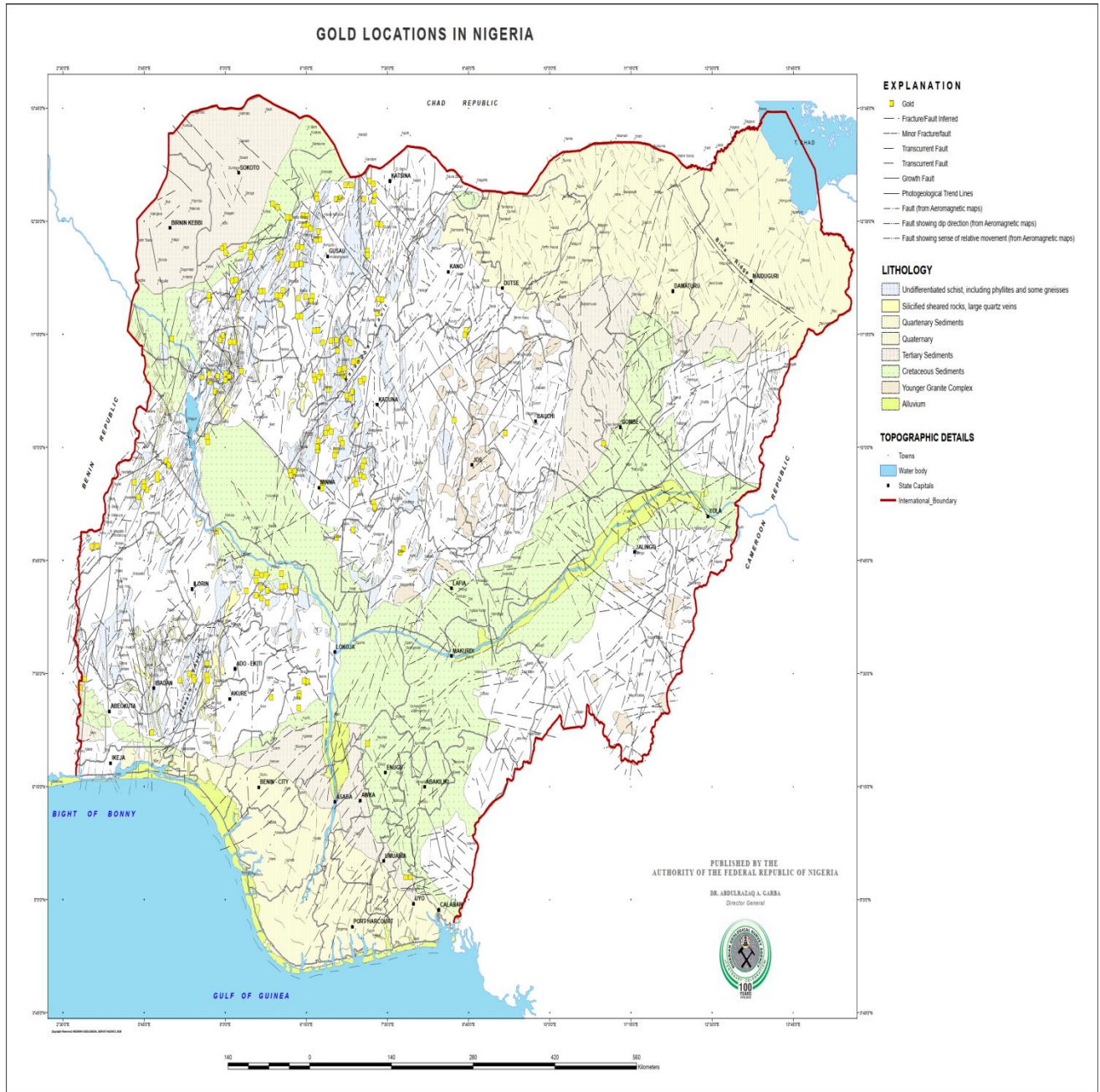


Figure 2.2: Map of Gold Occurrences in Nigeria

Source⁷⁷

2.8 Gold Processing Methods

The mining method employed by artisanal gold miners depends on the types of deposit being exploited and its location. Alluvial gold mineral is mixed with the sand and gravel of rivers, streams and lakes. Running water washes it from upstream and deposits as sand. The mineral is usually in the form of fine grains or small nuggets. Gold mineral can also be found in quartz and can be extracted after crushing the rock¹³⁰.

Over the years, miners have adopted many methods for mining. As a result of the poor financial base of small-scale miners, the majority relies solely on the traditional method of mining, which are largely artisanal, featuring simple equipment like shovels, pickaxes, pans, chisels and hammers as in the case of Zamfara¹³¹. The methods that are mostly employed by small-scale mining can be categorized into the following groups:

2.8.1 Shallow Alluvial Mining (Sluicing and Washing) Method

This method is also known as “dig and wash” techniques¹³². It is used to mine shallow alluvial deposits usually found in valleys or low-lying areas in depths not exceeding three meters. Vegetation is initially cleared and the soil excavated until the mineral-rich layer is reached. Mineralized material is removed and transported for processing. As a result of the relative ease of reaching these deposits and treating such ores, a significant proportion of the industry’s operations are of this type. For similar reasons, illegal workings are predominant in this area.

2.8.2 Deep Alluvial Mining Method

It is used to mine deep alluvial deposits found along the banks of major rivers. It involves excavating a pit and digging until the minerals bearing gravel horizon, which is typically located at depths of 7 to 12 meters is reached. Terraces or benches are constructed along the sides of pits

to prevent collapse and then the mineral bearing units are removed and processed to recover the minerals.

2.8.3 Hard Rock (Lode) Mining Method

It is used to mine bearing reefs which can be located close to the surface or deep-seated minerals. Holes are sunk to intercept the mineral reefs and when accomplished, the reefs are worked along the strikes⁸. Where such reefs are weathered, small-scale miners use chisels and hammers to break the ore. In case the ore is hard, explosives are commonly used.

2.9 Methods of Processing/Recovery of Gold

2.9.1 Panning

Panning is one of the simplest methods for recovering alluvial gold. The prospector fills the pan with gold sand from the river or stream and then washing the gold mineral by swing it around the stream. Since gold mineral is heavier than sand, so it settles to the bottom of the pan. By plunge a pan of dirt around the water, the lighter sand materials are washed away, leaving required gold minerals. Panning is a fairly slow process as an experienced panner can process only about 10 pans an hour¹⁷⁰.

2.9.2 Sluicing

This includes the use of a sluice box. A sluice box is a long, narrow trough made out of wood, metal or plastic. It is placed in running water with a slight downhill tilt, so that water flows through the box. The prospector shovels gravels into the top of the box where the water enters. As the water runs through the box, it washes away the lighter gravels and sediment,

leaving concentrated minerals behind. A sluice box allows a prospector's process five to 10 times the amount of materials he can pan in a day¹⁷⁰.

2.10 Gold Amalgamation

The use of mercury to recover gold, a process known as amalgamation, is a common and simple method of gold recovery that had been in existence for centuries. It was first used in Spain as early as 200 B.C and subsequently used extensively by the Romans and Egyptians around 50 B.C⁷⁹. According to UNEP, amalgamation method is now the most commonly used method in more than 80 countries to recover gold in more than 100 million ASGM sectors, resulting to the release of hundreds of grams of mercury into the air, soil and water⁶⁴.

A study described amalgamation as a process of mixing free gold particles with mercury to form a compound known as amalgam (an alloy of mercury and gold). The amalgam is then heated with a blow torch or over an open flame to vaporize mercury leaving the gold behind⁸². World Health Organisation advised miners to avoid whole-ore amalgamation, where mercury is mixed with all of the ore mined¹⁹⁶. This is because almost 90% of the mercury used is lost to the environment, thereby causing severe health exposure problems to the miners and their environs. UNIDO suggested an alternative to whole-ore amalgamation as pre-concentrating the ores, using gravity separation (sluice and centrifuge) before adding mercury, which allows the miners to mix mercury with a much smaller amounts of ore that contains a higher concentration of gold and reduces the mercury losses to about 10%⁸³.

A study investigation shows that over 90% of mercury vapor was escaping into the atmosphere which accounts for 300 metric tons per year worldwide when amalgam burns in an open air without using retort, but when retort is properly used, over 95% of mercury used was recovered

and only very little as low as 0.5% was lost to the environment thereby reducing human health risks to the miners and their families⁸².

Do Not Copy, Lead City University, Nigeria

2.11 Mercury in the Environment

Mercury is a naturally occurring metal found throughout the environment, concentrations have been enriched due to mobilization by humans for thousands of years into the atmosphere, as well as aquatic and terrestrial ecosystems¹⁸. According to the U.N Environment Report: Mercury occurs naturally in the environment and exists in several forms which can be organized under three headings: *metallic mercury* (also known as elemental mercury), *inorganic mercury*, and *organic mercury*³⁷. Metallic mercury is liquid at room temperature, is a shiny, silver-white metal. Metallic mercury is the elemental or pure form of mercury (i.e., it is not combined with other elements). Metallic mercury metal is the most common liquid metal used in thermometers and some electrical switches. At room temperature, some of the metallic mercury will vaporize and form mercury vapors. Mercury vapors are colorless and odorless. The more temperature intensity, the more vapors will be released from liquid metallic mercury.

Individuals who have breathed mercury vapors reported a metallic taste in their mouths. Metallic mercury has been discovered at 714 hazardous waste-sites nationwide. Inorganic mercury compounds occur when mercury combines with elements such as chlorine, sulfur, or oxygen. These mercury compounds are also called mercury salts. Most inorganic mercury compounds are white powders or crystals, except for mercuric sulfide (also known as cinnabar) which is red and turns black after exposure to light. The combinations of mercury with carbon forms the compounds called "organic" mercury compounds or organomercurials. There is a potentially large amount of organic mercury compounds; however, the most common encountered organic mercury compound in the environment is methylmercury (also known as monomethylmercury). Dimethylmercury, at the same time, is a colorless liquid. Various forms of mercury occur naturally in the environment. The most common natural forms of mercury found

in the environment are metallic mercury, mercuric sulfide (cinnabar ore), mercuric chloride, and methylmercury. Some microorganisms (bacteria and fungi) and natural processes can change the mercury in the environment from one form to another²³. The most common organic mercury compound usually generated by microorganisms and natural processes from other forms is the methylmercury.

Methylmercury is of particular concern because it can accumulate in certain freshwater and saltwater fish and marine mammals to higher levels greater than levels in the surrounding water²⁴. Mercury mined as cinnabar ore, which contains mercuric sulfide. The metallic form is refined from mercuric sulfide ore by heating the ore to temperatures above 537.8 degrees Celsius. This evaporates the mercury in the ore, and the vapors are then captured and condense to form the liquid metal mercury³⁷. There are several uses for liquid metallic mercury. It is used in the production of chlorine gas and caustic soda, and in the extraction of gold from ore or articles that contain gold. It is also used in thermometers, barometers, batteries, and electrical switches. Silver-coloured dental fillings typically contain about 50% metallic mercury³⁷.

Metallic mercury is still used in some herbal or religious remedies in Latin America and Asia, and in rituals or spiritual practices in some Latin American and Caribbean religions such as Voodoo, Santeria, and Espiritismo. These uses pose a health risk from exposure to mercury both for the user and for others who may be exposed to mercury vapors in contaminated air. Certain inorganic mercury compounds are used as fungicides. Inorganic salts of mercury, including ammoniated mercuric chloride and mercuric iodide, have been used as ingredient in skin-lightening creams. Mercuric chloride is a topical antiseptic or disinfectant agent. In earlier times, mercurous chloride was widely used in medicinal products including laxatives, worming

medications, and teething powders. Has recently been replaced by safer and more effective agents. Other chemicals containing mercury are still used as antibacterials. These products include mercurochrome (contains a small amount of mercury, 2%), and thimerosal and phenylmercuric nitrate, which are used in small quantity as preservatives in some prescription and over-the-counter medication. Mercuric sulfide and mercuric oxide may be used to color paints, and mercuric sulfide is one of the red coloring agents used in tattoo dyes.

Methylmercury is produced primarily by microorganisms (bacteria and fungi) in the environment, rather than by human activity²⁵. Until the 1970s before the adverse health effects of methylmercury were known, methylmercury and ethylmercury compounds were used to protect seed grains from fungal infection and the usage of methylmercury and ethylmercury as fungicides was banned. The use of phenylmercuric compounds as antifungal agents in both interior and exterior paints, was also banned in 1991 because mercury vapors were released from these paints.

2.12 Global Impact of Mercury in Gold Mining and Minamata Convention

The use of mercury in small-scale mining is a global issue that has devastating effects on life in general. Since February 2009, when 92 countries reached an agreement and signed the Minamata Convention on Mercury (Treaty). In the 2020 Convention on mercury the Treaty had registered 127 signatory countries¹⁶⁷. The Treaty is named after the city of Minamata, Japan, which is the location of the first, well documented and widespread case of mercury related poisonings.

In Minamata, local villagers began to notice that large numbers of dead fish and birds were appearing in the bay near the town. Also, other strange occurrences were taking place, such as birds losing their ability to fly and cats dying due to uncontrolled convulsions. Soon after

these strange events started taking place, a large number of babies, being the most vulnerable to methylmercury poisoning, being born were showing similar unexplained symptoms such as ataxia, numbness in the hands and feet, general muscle weakness, narrowing of the field of vision, and damage to hearing and speech. In extreme cases, insanity, paralysis, coma, and death follow within weeks of the onset of symptoms⁴².

The Treaty aims to ensure that adverse effects are prevented and has the purpose of protecting others from suffering the same fate as those in Minamata through reducing the release of methylmercury into the environment by enacting procedures intended to reduce global mercury use, supply, and trade. The Treaty, recognized the problems associated with illegal and informal industry, and have recommended measures that are meant to lead to global formalization of small-scale mining operations by ensuring that the miners have access to training, credit, and cleaner technologies.

The Treaty stressed the importance of financial, technical, technological, and capacity-building support, particularly for developing countries, and countries with economies in transition, in order to strengthen national capabilities for the management of mercury and to promote the effective implementation of the Convention. Article 7 of the Treaty specifically applies to small-scale gold mining and processing in which mercury amalgamation is used. The Treaty ensure that where such activities occur steps to reduce and possibly eliminate the use of mercury and also requires the mining party should develop strategies to prevent the diversion of mercury or mercury compounds used; educate, promote research sustainable non-mercury alternatives, provision of technical and financial assistance, and partnership to assist the implementation of this Article.

2.13 Mercury Sources and Environmental Exposures

Mercury is naturally occurring element of about 80 $\mu\text{g}/\text{kg}$ in the Earth's crust. Over geological time, it has been distributed all over the environment by natural processes, such as volcanic activity, fires, movement of rivers, lakes, and streams; oceanic upwelling, and biological processes. Since the development of humans, and particularly since the industrial revolution of the late 18th and 19th centuries, anthropogenic sources have become a major contributor to the environmental distribution of mercury and its compounds^{10,37}. Estimates of the total annual mercury releases that result from human activities range from one-third to two-thirds of the total mercury releases and its ranked third among the most toxic substances in the world by United States Government Agency for Toxic Substances and Disease Registry^{10,41}. As with other components of the lithosphere, natural global cycling has also been primary contributor to the presence of chemical elements in water, air, soils, and sediments³⁸. This process involves off-gassing of mercury from the lithosphere and hydrosphere to the atmosphere, where it is transported and deposited onto land, surface water, and soil, depending on varying factors that includes the chemical form of mercury present, stack height, characteristics of the area surrounding the emitting site, topography, and meteorology⁵⁴.

Categorically, the primary sources release Hg from the lithosphere to atmosphere while secondary reservoirs re-emit the deposited mercury from the surface into the atmosphere in other words, human activities that involving mercury such as; mining operations ASM, industrial processes, combustion of fossil fuels (especially charcoal), production of cement, and incineration of municipal chemical and medical wastes, gold production, steel and iron production⁴³.

Fossil fuel combustion, mining, and smelting, and from solid waste incineration is the source of approximately 80% of the elemental mercury released to the air. About 15% of the total is released to the soil from fertilizers, fungicides, and municipal solid waste (e.g., waste that contains discarded batteries, electrical switches, or thermometers). An additional 5% is released from industrial wastewater to waters in the environment. ASGM⁴⁴ has the largest share of 32% of Hg into the air, and Mercury share estimated from metallurgy sector was 13.2% and from cement industry was 10.8%⁵⁸.

2.14 Mercury Mobilization and Transportation

Mercury through anthropogenic activities or natural processes, can be mobilized from natural deposits into the biosphere. It can travel long distances within air masses and water currents, undergo methylation into Methylmercury (MeHg: CH_3Hg^+), and bio-magnify and bio-accumulate in food chains to levels that can be dangerous. The major sources of Methyl Mercury in the aquatic environments are terrestrial and runoff, particularly from wetlands and atmospheric deposition. Also, continual global industrialization has been increasing Hg deposition which will have environmental consequences. Forest soil are considered among the main sources of CH_3Hg^+ in aquatic environments⁴⁵.

Atmospheric Hg is dumped onto the cryosphere and emitted back to the atmosphere. This deposition of Hg due to its high mobility in the cryosphere is linked with the process of atmospheric Hg depletion events during the polar spring. Snowmelt is also strongly considered to be a main source of Hg release into lakes and water sources. Ice and melted water containing Hg are indicative of its net deposition onto snow packs. However, long-rang transport of CH_3Hg^+ is reported in polar regions, Arctic, Antarctic, Tibetan plateau and the Himalayas, more investigation are required to estimate the net Hg deposition during specific periods⁴⁶. In addition,

meteorological changes also contribute largely to the Hg reservoirs. Stable Hg in soil outflows after becoming labile into fluvial systems. Alterations of hydrological and meteorological conditions induce the entrance of Hg into rivers which is then introduced into the marine environment. The CH_3Hg^+ can be biomagnified and bio-accumulated through the aquatic food web⁷ and fishes⁸ and enters into the human body⁴⁷.

2.15.1 Sources of Mercury

According to the 2018 Global Mercury Assessment by UNEP, mercury sources are grouped as follows:

- i) Natural sources released due to the natural mobilization of naturally occurring mercury from the Earth's crust through, for example, volcanic activity, geothermal activity or rock weathering (mercury deposited in plants can also be re-emitted and remobilized during forest fires);
- ii) Current anthropogenic (human activity-related) releases from the mobilization of mercury impurities in raw materials (including fossil fuels – especially coal but also gas and oil);
- iii) remobilization of historic anthropogenic releases previously deposited in soils, sediments, waters, landfills or waste piles⁶⁴.

According to WHO anthropogenic sources of mercury are;

2.15.2 Artisanal and Small-Scale Gold Mining (ASGM): Mercury is an essential material used in the amalgamation process during gold processing by Artisanal Small Miners. The Mercury is mixed with whole ore and processed to free gold. The Mercury is subsequently discharged with tailings into the environment.

2.15.3 Biomass Burning (domestic, industrial and power-plant energy production : Emissions from biomass are important source of mercury to the atmosphere. Biomass

is the oldest and most widely used renewable energy source. Biomass burning involves agricultural residues and fuelwood. Also forest fires, grassland fires and crop residues are important sources of biomass.

2.15.4 Cement Production (raw materials and fuel, excluding coal): The production of cement is a source of anthropogenic emission of mercury. This is because mercury is present in the raw materials e.g., limestone and in the fuel (coal) used in cement manufacturing process. The major pathway for mercury releases from cement industry is via emissions to the atmosphere.

2.15.5 Cremation Emissions: Mercury is emitted into the atmosphere when individuals with dental amalgam fillings are cremated.

2.15.6 Chlor-Alkali Production (Mercury Process): The mercury-cell process is one of the three manufacturing processes used by the chloralkali sector to produce chlorine and caustic soda. This process remains a significant use of mercury globally and can be an important source of mercury releases to the environment.

2.15.7 Oil Refining: Low mercury emissions is released during refining process of petroleum products and natural gas prior to combustion.

2.15.8 Pig Iron and Steel Production (Primary): Iron and steel production is one of the main anthropogenic sources of mercury (Hg) emission and release. Oxidized and particulate Hg discharged from iron and steel enterprises deposit into surrounding soil, which accumulate and introduce environmental risks.

2.16.1 Mercury Life Cycle

Understanding the relationship between local condition and mercury levels in the environment is key to predicting changes in the concentration of mercury and its ability to be absorbed by living things. Mercury emitted to the atmosphere from natural cycling (e.g., forest fire), geogenic (e.g., volcanoes, rock weathering) and anthropogenic activities. Mercury deposited on earth's surface can be transformed through microbial processes and fishes^{39,71}. The mercury life cycle is an

illustration relating the transformation processes of mercury from the sources, atmosphere and methylation in aquatic environment⁵⁷.

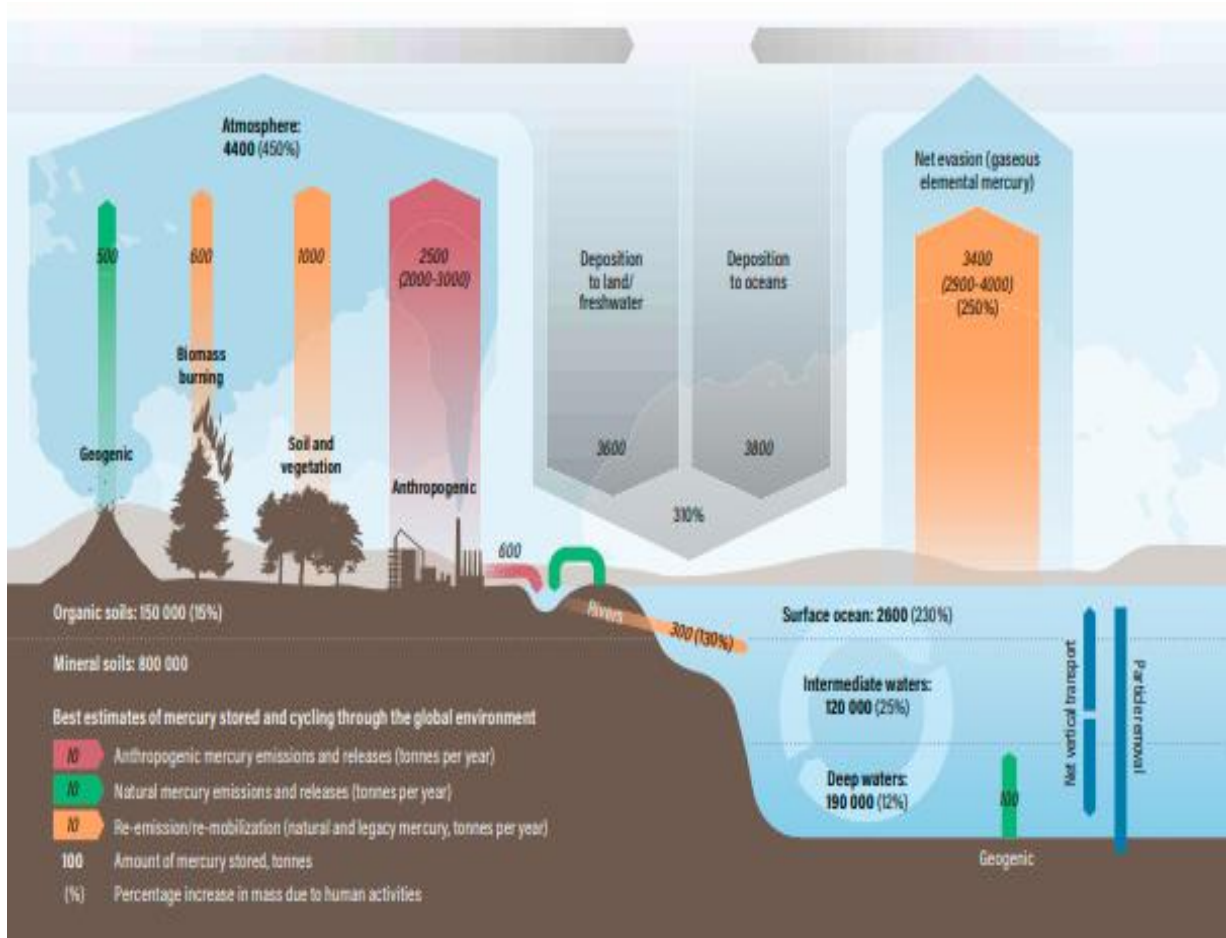


Figure 2.3: Mercury life Cycle

Source⁵⁷

2.16.2 Human Exposure to Mercury

Point sources of anthropogenic mercury release, transformation and re-volatilization from environmental media, sorption to soil and sediment particles, and bioaccumulation in the food webs contribute to further distribution and subsequent human exposure^{49,50,51}. The degree of mercury in the atmosphere (i.e., the air you breathe in the general environment) has been increasing and this continuous release of mercury has resulted in levels that are currently three to six times higher than the estimated levels before the industrial era atmosphere. About 10 to 20 nano-grams of mercury per cubic meter (ng/m^3) of air have been measured in urban outdoor atmosphere⁵². These levels are hundreds of times lower than levels still considered to be “safe” to breathe. Background levels in non-urban settings are even lower, generally about $6 \text{ ng}/\text{m}^3$ or less. Mercury levels in surface water are generally less than 5 parts of mercury per trillion parts of water (5 ppt, or 5 ng per liter of water), about a thousand times lower than “safe” drinking water standards. Normal soil levels range from 20 to 625 parts of mercury per billion parts of soil (20–625 ppb; or 20,000–625,000 ng per kilogram of soil). There are three primary categories of mercury and its compounds: Elemental mercury, which may occur in both liquid and gaseous states; Inorganic mercury compounds, including mercurous chloride, mercuric chloride, mercuric acetate, and mercuric sulfide; and organic mercury compounds. Organic mercury compounds are formed when mercury combines with carbon which occurs when microscopic organisms in water and soil convert elemental and inorganic mercury into an organic mercury compound, methylmercury, which accumulates in the food chain⁵⁸. Thimerosal and phenylmercuric acetate are other types of organic mercury compounds made in small amounts for use as preservatives.

Elemental mercury is the main form of mercury released into the air as a vapor through natural processes. Direct exposure occurs in occupational use of mercury, majorly in mining and gold extraction, chlor-alkali industries, dentistry, pharmaceutical industries, pesticide production and seed treatment^{37,55,56,65}.

Exposure by the general population and in occupational settings is primarily through inhaling mercury vapours/fumes, food-chain, and consumer products⁶⁰. The average level of atmospheric mercury is now approximately 3– 6 times higher than the level estimated for preindustrial ambient air. Dental amalgam constitutes a potentially significant source of human exposure to elemental mercury, with estimates of daily intake from amalgam restorations ranging from 1 to 27 µg/day, the majority of dental amalgam holders being exposed to less than 5 µg mercury/day⁶⁶.

2.17 Mercury Effect on Human Health

2.17.1 Health Effects

Several adverse health effects have been reported by many researchers^{136,138}. Studies have shown elemental and methylmercury are toxic to the central and peripheral nervous systems^{157,159,173}. The inhalation of mercury vapor can produce harmful effects on the nervous, digestive and immune systems, lungs and kidneys, and may be fatal. The inorganic salts of mercury are corrosive to the skin, eyes and gastrointestinal tract, and may induce kidney toxicity if ingested. Other symptoms metallic taste, nausea, abdominal pain, vomiting, diarrhea, tremor, irritability, headache, weakness, chest pains, dyspnea (shortness of breath), cough, sore throat, fever,

pneumonitis (inflammation of the lungs), palpitations, albuminuria (kidney dis-function), skin irritation, death^{46,68,91}.

2.17.2 Mercury Symptoms

Neurological and behavioral disorders may be observed after inhalation, ingestion or dermal exposure of different mercury compounds. Symptoms include tremors, insomnia, memory loss, neuromuscular effects, headaches and cognitive and motor dysfunction. Mild, subclinical signs of central nervous system toxicity can be seen in workers exposed to an elemental mercury level in the air of 20 $\mu\text{g}/\text{m}^3$ or more for several years. Numerous research on the neurological impact assessment of mercury on adults have been reported, findings show general deficits such as numbness, imbalance, memory, impairment, motor disturbance, hearing impairments, paraesthesia, static and dynamic imbalance, poor motor coordination and reduction in visual field, cognitive and motor deficits, color vision and visual deficits, insomnia and memory loss has also been reported in occupational exposures^{47,48} research on neurological effects on children due to parental exposures revealed deficits motor and language development, decreased mental development and psychomotor development index and visual-motor integration deficits, working memory deficits, verbal comprehension deficits, auditory processing and reasoning impairment^{23,88,96}. Kidney effects have been reported, ranging from increased protein in the urine to kidney failure. Several studies examining children in ASGM communities have also found associations between mercury levels and increased deep tendon reflexes, poor leg coordination, decreased performance on visuospatial organization tests, and reduction in motor function, attention, visual contrast sensitivity and manual dexterity^{22,23,31}.

2.17.3 Human Biomarker

Mercury exposures in humans can be estimated by measuring contamination levels in various body tissues⁸⁵. These measurements of pollutants and/or their metabolites, also known as biological markers (or biomarkers), are useful as tools for human exposure assessment, and as surveillance tools for monitoring mercury exposure in individuals and populations. Several researchers have shown that hair, blood, urine are biomarker for determining the level of mercury exposures in the human body^{26,28,29,30}. Further details are explained in the immediate sections.

2.17.4 Hair Scalp

Hair scalp is generally the preferred choice to document methylmercury exposure as it provides a simple, integrative and, non- invasive sample. Growing hair incorporates methylmercury during its formation and the levels contained show a relatively direct relationship with blood mercury level. Because once mercury is incorporated in hair it cannot return to the blood, thus it provides a good long-term marker for exposure MeHg.

2.17.5 Blood

Mercury in blood reflect exposure through ingestion of contaminated fish or drinking water, inhalation of elemental vapor in ambient air, and exposure through dental amalgam and medical treatment. The presence of mercury in the blood indicates recent or current exposures to mercury.

2.17.6 Urine

Mercury in Urine are usually considered the best measure of recent exposures to inorganic or elemental mercury vapor, as urinary mercury is thought to most likely indicate the present

mercury level in the kidney and because it accumulates in the kidney and is slowly excreted through the urine it also the best measure for past exposure^{59,64}.

2.18 Mercury Reference Level

Based on risk assessments and other considerations, several countries and international organizations have established levels of daily or weekly methylmercury or mercury intakes estimated to be safe (or without appreciable risk to health)^{83,84}. The World Health Organization report on Guidance for Identifying Populations at Risk from Mercury Exposure compiled the tolerable intake for total mercury which does not pose appreciable risk to the human health^{37,66,67}.

The Joint FAO/WHO Expert Committee on Food Additives (JECFA), which also evaluates chemical contaminants in the food supply, has established provisional tolerable weekly intakes (PTWIs) for total mercury at 5 µg/kg body weight and for methylmercury at 1.6 µg/kg body weight¹⁷¹. To assess possible risks due to inhalation exposures, the USEPA established an RfC for elemental mercury of 0.3 µg/m³, based on a lowest-observed-adverse-effect-level (LOAEL) (adjusted for intermittent exposure) of 9.0 µg/m³ and an uncertainty factor of 30 (to account for sensitive human subpopulations and database deficiencies) and Reference Doses (RfDs) for mercuric chloride of 0.3 µg/kg/day and methylmercury 0.1 µg/kg/day. The JECFA also established a PTWI of 1.6 µg/kg body weight/week for methylmercury³⁴.

The provisional tolerable weekly intakes (PTWI) is the amount of a substance that can be consumed weekly over an entire lifetime without appreciable risk to health and is an end-point used for food contaminants, (such as heavy metals with cumulative properties). Its value represents permissible human weekly exposure, protecting the most susceptible part of the population, to those contaminants unavoidably associated with the consumption of otherwise

wholesome and nutritious foods^{61,62,63}. **Reference Dose (RfD)** or (Reference Concentration RfC) is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious noncancer effects during a lifetime. It is not a direct estimator of risk but rather a reference point to gauge the potential effects. Table 2.2 shows a number of Governments and other organizations that have estimated the tolerable weekly intake/reference levels for methylmercury exposure that are intended to be protective against adverse effects.

Table 2.2: Reference Levels for Methylmercury

Country/Organization	Reference (mg MeHg/kg bw/ week)	Level	Year Adopted
Canada	0.0014		1997
Japan	0.002		2005
Netherlands	0.0007		2000
United States	0.0007		2001
JECFA	0.0016		2003

Source¹⁹⁶

The World Health Organization collected data on background exposure in the occupational from national biomonitoring studies and from cross-sectional studies¹⁹⁶. According to the report, the European Union limit set by the Scientific committee on Occupational Exposures limits (SCOEL) are:

- TLV: 0.025 mg/m³ as TWA (not classifiable as a human carcinogen)
- EU Occupational Exposure Limit: 0.02 mg/m³ as TWA
- MAK (inhalable fraction): 0.02 mg/m³.

And according to American Conference of Governmental Industrial Hygienists (ACGIH):

- Elemental and inorganic forms: TWA: 0.025 mg/m³
- Alkyl compounds: TWA: 0.01 mg/m³;
- Short-term exposure limit: 0.03 mg/m³
- Aryl compounds: TWA: 0.1 mg/m³

According to International Labour Organization:

- TLV: 0.025 mg/m³, as TWA; (skin),
- MAK: (inhalable fraction): 0.02 mg/m³

The time-weighted average (TWA) is the average exposure within the workplace to any hazardous contaminant or agent using the baseline of an eight-hours-per-day or 40-hours-per-week work schedule. The TWA reflects the maximum average exposure to the hazardous contaminants to which workers may be exposed without experiencing significant adverse health effects over the standardized work period.

The short-term exposure level (STEL) is the acceptable average exposure over a short period of time, usually 15 minutes as long as the TWA is not exceeded. The threshold limit value (TLV) is a level to which it is believed a worker can be exposed day after day for their working lifetime without adverse effects.

Biomonitoring program has shown mercury concentrations in adult is higher than in children, reported that blood mercury levels in adults were approximately 2.1-fold higher than in children, and this varied across age groups¹⁹⁶. For example, in the second cycle (2009–2011) of the Canadian Health Measures Survey, median blood mercury levels in Canadians increased with age as follows: 0.21 µg/L for children aged 6–11; 0.19 µg/L for young people aged 12–19; 0.5 µg/L for adults aged 20–39; 1.0 µg/L for adults aged 40–59; and 1.2 µg/L for adults aged 60–79. Even though many reports are available on the adverse effect of mercury on human health there is no exact established limit or threshold.

2.19 Mercury Effect on Exposed Animals

In an animal model of acute toxicity, exposure to Hg vapor (550 µg/m³) resulted in mercury deposits in different parts of the brain and also in the spinal cord⁶⁶. In mice Mercury vapor

exposure can cause a 70% increase in brain metallothionein (a metal binding protein)¹⁹⁵. Mercury accumulation in the brain was also observed in treated rats. Renal injury can also occur from chronic mercury vapor exposure. Investigation of kidney tissues of Wistar rats exposed to 1 mg/m³ Hg vapor per day revealed histological alteration of the kidneys after 45 days². However, the renal mercury deposition might be slow by the inhibition of γ -glutamyltranspeptidase, resulting in increased urinary Hg concentration. The basis for such reduction refers to the role of γ -glutamyltranspeptidase in the reuptake of mercury-glutathione conjugate in glomerulus. Following renal injury related to HgCl₂, the antioxidative system of the rat kidney is compromised. Decreasing glutathione peroxidase activity and increased contents of oxidative lipids and proteins occurred as well as morphological changes in renal tissue 72 hours after intoxication. After four days of oral exposure to mercury compounds (HgCl₂ and Me-HgCl) in rats caused intestinal fluid accumulation, mucosal injuries, and diarrhea. Administration of Hg (5 mg/kg) reduced mRNA and downregulated aquaporin in the rat gastrointestinal tract. Impaired aquaporin expression seems to be involved in the GI tract harmful effects related to mercury consumption. Mercury induced hepatotoxicity was shown in an HgCl₂ treatment animal model. The hepatotoxicity of mercury was determined by histopathological analysis and investigating elevated liver enzymes level including alanine transaminase (ALT), aspartate transaminase (AST), and alkaline phosphatase (ALP). An Hg-induced hepatotoxicity study showed gender differences in Wistar rats and female rats had higher levels of Hg accumulation in the liver. It was suggested that sex-dependent effects of liver damage via Hg exposure be related to the organic anion transporter 3 (Oat3). Male rats showed decreased expression of Oat3²⁷. The decrease in the Oat3 abundance will limit Hg intake into the liver, leading to lower hepatotoxicity in males. It seems that the organic anion transport is regulated by sex

hormones. The expression of Oat3 protein is strongly elevated by testosterone. The expression of these transporters may be regulated by sex hormones.

Do Not Copy, Lead City University, Nigeria

2.20 Exposure and Contamination of Lead and Mercury in Gold Mining

Lead is a harmful environmental pollutant which has high toxic effects to many body organs^{104,107}. Even though Pb can be absorbed from the skin, it is mostly absorbed from respiratory and digestive systems. Pb exposure can induce neurological, respiratory, urinary, and cardiovascular disorders due to immune-modulation, oxidative, and inflammatory mechanisms¹¹⁷. Furthermore, Pb could disturb the balance of the oxidant–antioxidant system and induce inflammatory responses in various organs. Exposure to Pb can produce alteration in physiological functions of the body and is associated with many diseases. Pb is highly toxic which has adverse effects on the neurological, biological, and cognitive functions in the bodies^{33,34}. The international level-of-concern for Pb poisoning is 10 µg/dl in the blood^{141,142}. Adulteration of opium with Pb has been considered as a threat to human health in recent years.

2.21 Lead Effects on Exposed Animals

Daily administration of lead acetate (PbA) (15 mg/kg, ip) for 2 weeks in pregnant Wistar female rats induced pro-inflammatory cytokines including IL-1 β and TNF- α in the hippocampus and IL-6 in the forebrain of immature rat brain²⁸. These results suggested that chronic lead exposure causes inflammation in the central nervous system (CNS) of immature rat brain which might be through activation of glial cells. Lead exposure (0.1–0.4 MPb) increased serum endothelin-1 (ET-1), serum nitric oxide (NO), and eosinophil peroxidase (EPO) accompanied with lung pathological changes in ovalbumin (OA) sensitized and non-sensitized guinea pigs³. Exposure to PbA (0.1–0.4 MPb) increased serum total protein, histamine, and total and differential white blood cells (WBC) counts of guinea pigs. Hemological effects of chronic toxicity of the PbA (0.4%) in drinking water for 12 weeks in adult male rats showed significantly decreased red blood cells (RBC) count, while increasing total and differential WBC counts. Sub chronic

exposure to Pb at 10 and 100 times the normal concentrations via drinking water in rats increased activities of AST, ALP, and levels of urea nitrogen and creatinine. Besides, exposure to Pb induced necrotic changes in brain, liver, and kidneys⁷. Intraperitoneal administration of PbA (10 mg/kg, bw) to induce hepatotoxicity in rats enhanced hepatocyte abnormalities and increased acid phosphatases (APs), ALP, AST, ALT, and lactate dehydrogenase (LDH) levels. Exposure of rats to PbA significantly reduced antioxidant parameters such as glutathione peroxidase (GPx), catalase (CAT), superoxide dismutase (SOD), and glutathione S-transferase (GST) and decreased glutathione (GSH) content in hepatocytes and erythrocytes. In addition, Pb significantly increased oxidative parameters including malondialdehyde (MDA) and H₂O₂ concentrations as well as expression of cyclooxygenase-2 (COX-2). Adult male rats exposed to PbA (500 mg/L) showed significant elevation in the levels of serum ALT, AST, urea, uric acid, and creatinine. PbA also increased lipid peroxide and reduced GSH, SOD, CAT, and GPx levels in liver and kidney tissues of induced animals. Administration of Pb (1 mg/kg, bw, ip.) in rats for a period of 4 weeks significantly increased lipid peroxide level in the liver, but antioxidant parameters such as SOD and CAT activities did not change statistically. Subcutaneous administration of PbA (100 mg/kg, bw) in rats increased the levels of lipid peroxidation (LPO) including MDA and 4-hydroxyalkenals (4-HDA) levels in the liver and kidneys compared to the control animals. Moreover, PbA decreased SOD and total GSH in the liver and kidneys of rats¹⁹¹. It has been reported that PbA (500 mgPb/L) in drinking water promoted apoptosis by activation of mitochondria cytochrome C release and inhibited Bcl-2 proteins and activation of caspase-3 in kidneys of the exposed rats⁴. In a study, administration of PbA (25 mg/kg, bw, ip.) for 5 days in rats increased urea and creatinine levels while it decreased total protein and albumin in the serum. The reduction of antioxidant parameters including GPx, CAT, and SOD and induction of

hyperlipidemia resulted from lead induced toxicity³². Furthermore, hemorrhage in the renal tubules, degeneration in epithelial cells, disruption of Bowman's capsule, and necrosis area in kidney tissue were observed³⁵. Orally administered PbA (30 and 60 mg/kg, bw) 3 days in a week for 3 months in rats reduced testicular weight, sperm count, and testicular ALP activity. PbA also induced abnormal sperm count, seminiferous tubules necrosis, and disappearance of seminiferous tubular epithelium in a dose-dependent manner.

2.22 Environmental Impact of ASGM

2.22.1 Environmental Impact

The environmental costs of ASGM are in general higher than those of other types of mining⁷⁰. This means that ASGM is dirtier unit of out than any other medium-sized or large and modern mining operations¹⁹³. Another problem of ASGM is the great individual number of polluters, normally concentrated in a specific area, which causes significant local impacts. It is very difficult to control or monitor environmental violations or enforce regulations because of the lack of resources and the inaccessible nature of most operations. ASGM harms the physical and social environment during the stages of mining (exploration, exploitation, processing and closure). Some major environmental impacts of ASGM are discussed hereunder^{80,194}.

2.22.2 Forest Degradation

ASGM involves clearing of land for mineral detection and settlement of the miners⁸¹. This involves the cutting down of valuable trees and massive destruction of the trees with fire instituted by the miners. In most cases settlements of Artisanal and Small Scale Gold Miners in the newly discovered rich vein gold often lead to rampant deforestation, but also the import of social evil associated with urbanization which include alcohol abuse, prostitution, child labor, land use conflicts among local communities as well as water pollution, land contamination, lead

poisoning and other diseases. The extensive deforestation in the area also causes a reduction in bioiversity¹⁶³.

2.22.3 Land Degradation

Artsanal small scale gold mining in most cases degrades lands and forests and destroys the vegetation, including economic trees and the ability of natural forest to regenerate¹⁶⁸. Land degradation threatens the economic and physical survival of the environment which leads to household and national food insecurity¹⁵⁴. Artisanal small-scale gold mining in the area involves the removal of top soil and movement of huge volumes of rock materials¹⁶⁹. This disfigures the topography and surface drainage that causes deforestation and soil erosion, dust generation, long-time compaction, subsidence and reduced agricultural productivity. The accumulation of environmental impacts of numerous ASGM operations in the area has left uncovered and unprotected open pits¹⁷⁹.

2.22.4 Water Pollution

Medecins Sans Frontieres noted that the activities of ASGM in Zamfara state have the potential to promote water pollution and depletion of both surface and natural underground sources as they are highly dependent on water¹¹⁵. The miners carry out their sieving and amalgamation process on the river bed which leads to siltation, colouration and chemical pollution of stream and rivers that provide drinking water for mining communities and animals^{100,189,192}. The operation of ASGM generates a lot of waste stockpile that dumped on top soil or water body. These wastes contain significant amounts of contaminants that dissolve and leach out by precipitation into local streams and community water sources¹⁵⁶. The impact of water pollution of ASGM on the ecosystem and people could be so severe resulting to contamination of available surface and underground water. ASGM inmost cases is associated with the mushrooming of unplanned

squatter camps located close to water courses with poor or no sanitary facilities. This development has high chances for considerable amount of water pollution from human waste¹⁶¹.

2.23 Socio-economic Impact of ASGM

There are a lot of socio – economic factors that are negatively affects the operations of artisanal gold mining across the world. These includes:

2.23.1 Unregulated Migration in Mining Areas

Most miners in the communities where they mined are migrants, who do not have a legitimate claim in the areas where they operate. The mass migration of miners in a newly discovered rich area has often resulted in the displacement of the original inhabitants and the disturbance of local customs and long-established economic activities in the host community⁹⁹.

2.23.2 Land Tenure and Resource Use Conflicts

The tendency of miners to swarm around a deposit area often results in conflicts in mining rights and resource uses which often lead to violent confrontations between and among them as well as with the local residents. The opening up of mining for large-scale mining companies has also resulted in increasing confrontations between these companies and small-scale miners⁹⁸.

2.23.3 Limited Access to Health and Basic Amenities

Most mining communities also have either no or little access to clean water or basic health care services. Break out of diseases like malaria and diarrhea have been documented in several mining areas. Other diseases frequently experienced by miners include tuberculosis, skin diseases, pneumonia, cough and upper respiratory tract infections^{97,101}. There are also reported cases of venereal diseases like gonorrhoea. Transportation to these areas and other infrastructures

like hospitals, electricity, housing, educational institutions (above primary level) are either non-existence or in a sorry state.

2.23.4 Exposure of Miners to Occupational and Safety Hazards

Basic safety equipment like helmets, safety boots, gloves and dust masks appear to be of low priority among miners; hence their exposure to health risks ranging from the effects of poor ventilation of exposure to dust and toxic chemicals¹⁰⁵.

2.23.5 Exploitation of Workers

Lack of capital and formal sources of credit has forced mine workers to deal with local financiers under terms dictated by the latter. This has often put the workers at the losing end of the bargain. Miners, including minors, also work under hazardous environments and receive compensations which are often not commensurate with the strenuous work rendered¹⁰².

2.23.6 Absence of Social Security Benefits for Miners

Notwithstanding the risks encountered by the mine laborer and the meager income they receive from exposing their life and limbs to the dangers of the trade, they do not have any health or life insurance or any social security benefits where contractors are required by the partner corporation to provide labor-mandated benefits to their workers. Absence of these security benefits, miners merely cling on the verbal assurance of financiers and customary practice that in case something onward happens to them, the latter will be financially responsible⁹⁸.

2.24 Risk Assessment

Risk is the possible occurrence of an undesired outcome. It is defined as “the likelihood that a harmful consequence will occur as the result of an action or condition. It involves the combined evaluation of hazards and exposure”. There are many types of risk assessment (RA): Health RA, Environmental RA, Ecological RA, Disaster RA, etc.

Environmental Risk Assessment (ERA) is defined as- “an estimate of the likelihood or probability of an adverse impact on the environment resulting from human activities”. In other words, it is a formal procedure for identifying and estimating the risk of environmental damage. This has become an integral part of the planning phase of various projects, particularly those involving manufacturing. It provides insights on the environmental concerns encountered by various organizations. Proper assessment leads to an understanding of the likely adverse impacts and the risks imposed on the environment caused by various operations of an organization. Health Risk Assessment (HRA) is the process of estimating the nature and probability of adverse health effects in humans who may be exposed to environmental contaminant¹¹¹. It is also a process used to estimate health effects that might result from exposure to carcinogenic and non-carcinogenic contaminants¹¹³.

Human health risk assessment is a process used to estimate the health effects that might result from exposure to carcinogenic and non-carcinogenic chemicals. Health risk assessment has been used to establish the probably of adverse health effects in humans exposed to hazardous chemicals in contaminated environments both national and international level^{161,162}. According to the WHO guidelines, health risk assessment uses on health hazard characterization and health impact assessment¹⁹⁶. The health characterization process involves the identification and assessment of the hazard in the environment and its effects on the human health based on the

evidence from epidemiology studies while health impact assessment involves the quantification of contaminant (hazards) concentration and releases, the identification of exposed populations, the identification of potential exposure pathways and the estimation of contaminants intakes for each pathways for a range of scenarios and land uses^{166,172}. Four basic steps involved in the risk assessment process are: hazard identification, exposure assessment, toxicity (dose-response) assessment, and risk characterization. Risk is defined as the probability of suffering harm while hazard is the source of risk⁹⁷.

Hazard Identification basically aims to investigate what contaminants are present at a site, their concentrations, and their spatial distribution¹¹⁰. The purpose of **exposure assessment** is to measure or estimate the intensity, frequency, and duration of human exposures to an environmental contaminant.

Dose-Response Assessment estimates the toxicity, considering adverse effects and exposure levels of carcinogenic and noncarcinogenic contaminants¹²⁰. The carcinogen slope factor (CSF) and the reference dose (RfD), are two principal toxicity indices used. RfD values are derived from animal studies using the “No observable effect level” principle. For humans, RfD values are multiplied 10-fold to account for uncertainties¹¹⁷.

Risk Characterization predicts the potential cancerous and noncancerous health risk of the population by integrating all the information gathered from hazard identification, exposure assessment, and toxicity assessment to arrive at quantitative estimates of cancer risk and hazard indices^{174,175}.

Generally, Risk assessment techniques are systematic design and checklist for identifying potential hazard concerns and at the same providing information to decision-makers about the

possible consequences of actions, source treatment, disposal and remediation options, as well as clean-up standards of contaminated sites¹²¹.

2.25 GIS and Remote Sensing Applications in Natural Resources

In identifying landscape characterization to disturbance, GIS and Remote Sensing has proved to be powerful tools in landscape ecology by means of mapping disturbance zones in ecosystem, quantifying its impact on the biodiversity and detecting land cover changes over a period of time¹⁴⁶. To understand the cause effect of disturbance on flora, a time series on land cover change is needed. Recent studies have shown that biodiversity of terrestrial ecosystem is expected to be mainly affected by land use changes within the next 100 years¹⁶⁴. Land cover changes are local and site specific yet their collective impact is one of the most important facets of global environmental change¹⁵⁰. Since the local ecosystems are linked to prevailing climatic conditions, any change in climate is expected to effect changes in the ecosystems. On the other hand, a change in the local or regional ecosystems can cause variations in the climatic condition, particularly with their role as carbon dioxide sink or their effect on greenhouse gasses¹²⁵.

Information about a given ecosystem might be collected both by ground-based and remote sensing methods. Ground-based methods of data acquisition include field observations and gathering in-situ data, while data collection using remote sensing is based on the use of image data acquired by sensors of different types. Remote sensing technology is used to collect data on inaccessible or dangerous sites, which are not easily accessible using ground methods. This is because remote sensing enables to collect data about the area at a distance without direct contact with the object under investigation. Information is acquired by measuring the interaction of electromagnetic radiation with the earth's surface and data are stored as images, and interpretation is possible using GIS software¹³⁹.

Information obtained from features and processes on the land, water, and atmosphere make use of characteristic absorption and reflection of various wavelengths of light within the EMR spectrum. Environmental remote sensing typically refers to detailed field-based measurements (e.g., field spectrometry); airborne imagery; and satellite imagery. Specifically, the type of data acquired in remote sensing makes use of the visible, near infrared (NIR), and shortwave infrared (SWIR) parts of the electromagnetic radiation (EMR) spectrum^{143,144}. Environmental monitoring using remote sensing depends on selecting the variation index extraction technique, remote sensing platform, remote sensing satellite that provides high spatial resolution images and long-time data series of consistent and comparable data. Remote sensing of vegetation is mainly performed by obtaining the electromagnetic wave reflectance information from canopies using passive sensors. It is well known that the reflectance of light spectra from plants changes with plant type, water content within tissues, and other intrinsic factors¹⁴⁵. The reflectance from vegetation to the electromagnetic spectrum (spectral reflectance or emission characteristics of vegetation) is determined by chemical and morphological characteristics of the surface of organs or leaves¹⁴⁷. The main applications for remote sensing of vegetation are based on the following light spectra: (i) the ultraviolet region (UV), which goes from 10 to 380 nm; (ii) the visible spectra, which are composed of the blue (450–495 nm), green (495–570 nm), and red (620–750 nm) wavelength regions; and (iii) the near and mid infrared band (850–1700 nm)¹³⁹. The emissivity rate of the surface of leaves (equivalent to the absorptivity in the thermal waveband) of a fully grown green plant without any biotic or abiotic stress is generally in the range of 0.96–0.99 and is more often between 0.97 and 0.98. On the contrary, for dry plants, the emissivity rate generally has a larger range going from 0.88 to 0.94. Vegetation emissivity in the near and mid infrared regions has been widely studied within plant canopies. Indices extracted from this light

spectrum range can attributed to a range of characteristics beyond growth and vigor quantification of plants related to water content, pigments, sugar and carbohydrate content, protein content, and aromatics, among others. Different applications are dependent on the reflectivity peaks or overtones for specific compounds within the visible and near/mid infrared regions of light spectra. Plant reflectivity in the thermal infrared spectral range (8–14 μm) follows the blackbody radiation law, which allows interpreting plant emission as directly related to plant temperature. Hence, indices obtained from this spectra range can be used as a proxy to assess stomata dynamics that regulates transpiration rate of plants. Therefore, the later indices can be used as indicator of plant water status and abiotic/biotic stress levels¹⁴⁹.

One of the most used and implemented indices calculated from multispectral information as normalized ratio between the red and near infrared bands is the Normalized Difference Vegetation Index (NDVI)¹⁴⁰. A direct use of NDVI is to characterize canopy growth or vigor; hence, many studies have compared it with the Leaf Area Index (LAI), where LAI is defined as the area of single sided leaves per area of soil¹⁴⁸. Vegetation information from remote sensed images is mainly interpreted by differences and changes of the green leaves from plants and canopy spectral characteristics known as allometric measurement. The most common validation process is through direct or indirect correlations between VIs obtained and the vegetation characteristics of interest measured in situ, such as vegetation cover, LAI, biomass, growth, and vigor assessment. More established methods are used to assess VIs using direct and georeferenced methods by monitoring sentinel plants to be compared with VIs obtained from the same plants for calibration purposes.

Normalized difference vegetation index (NDVI) have been used to monitor vegetation growth changes at different times, and analyzed the potential factors related to vegetation growth. Landsat series data were implored to explored the changes in NDVI in coal mine in Dongsheng District, Inner Mongolia, China, to monitor their vegetation coverage and growth, and analyze ecological changes in various condition used the NDVI time series from the satellite data to evaluate the vegetation status and analyze the impact of mining on soil characteristics¹⁴⁹. They also applied the standard deviation vegetation index (SDVI) to reduce the impact of climate factors on mining on time series. The use of vegetation coverage to explore, vegetation is another commonly used method. A study took the Malanzhuang Iron Mine of Tangshan Shougang as their research region in China, and utilized Landsat TM/ETM+ data and the difference analysis method to explore the ecological restoration effects of the mining region based on vegetation coverage¹⁹⁹. Eventually, they obtained the ecological restoration effect. Some researchers studied the relevant types of mine vegetation, and the relationship between the growth of the mine vegetation and the surrounding soil and heavy metals, and monitored the ecological restoration of the mine. In this study and many others, NDVI have been employed to monitor environmental contamination of mercury from gold mining activities and vegetation changes over a time series of five years^{151,153,155}.

2.26 The Legal, Policy and Institutional Framework Governing ASGM in Nigeria

In considering how to address mercury use and lead poisoning linked to artisanal mining, an overview of the roles of various government institutions at the federal and state level, as well as their respective legal and regulatory authorities. In Nigeria, solid mineral extraction falls exclusively under the purview of the Ministry of Mines and Steel Development, other agencies have a role in regulating corollary aspects of mining activities, including the use of mercury itself. For instance, issues associated with the environmental impact of mining activities falls under the jurisdiction of the Federal Ministry of Environment and various state environmental authorities. State and local authorities (including Emirates and Local Government Areas) can also exert some authority over mining-related activities.

2.26.1 Overview of Key Regulatory Institutions

The legal framework governing mining activities and their environmental impacts is implemented primarily by two federal agencies – the Federal Ministry of Mines and Steel Development (MMSD), and the Federal Ministry of Environment (FMENV). MMSD according to the 2007 Minerals and Mining Act administers Nigeria’s mining laws and regulations, while FMENV according to the National Environmental Standards and Regulation Enforcement Agency (NESREA) Act, administers the country’s general environmental protection law. The Ministry of Mines and Steel Development was established in 1985 to spur development of the country’s solid mineral resources. It is the principal actor with respect to information, policy, and regulatory oversight of the country’s solid minerals sector. Its roles include formulating policy; providing information and knowledge to enhance investment in the sector; regulating operations; and generating appropriate revenue for the government.

The Ministry administers the 2007 Minerals and Mining Act and the 2011 Minerals and Mining Regulations. It contains four primary technical departments:

1. **The Mining Cadastral Office (MCO)** - established for the purposes of administering mineral titles and maintaining cadastral registers. Other functions of the MCO include but are not limited to: considering applications for mineral titles and permits; issuing, suspending and revoking mineral titles; receiving and disposing of applications for renewal, extension of areas of, transfer and relinquishment of mineral titles; maintaining a chronological record of all applications in respect of mineral titles; and maintaining a priority book and general registry book.
2. **The Mines Inspectorate Department (MID)** - has the sole duty of supervising all reconnaissance, exploration and mining operations for the purposes of ensuring that they comply with the provisions of the Act. Other functions of the MID include: supervising and enforcing compliance by mining title holders with all mining regulations relating to health and safety, conducting investigations and inspections necessary to ensure that all conditions relating to grant of mineral titles as well as the requirements of the Act are complied with, and review programs for controlling mining operations for recommendation to the Minister.
3. **The Mines Environmental Compliance Department (MECD)** - has various responsibilities which include monitoring and enforcing compliance with all environmental requirements imposed by the Act and the Regulations, periodical audit of all environmental requirements provided by the Act, the Regulations and any other law for the purposes of making recommendations on same to the Minister, and review of all

plans, studies and reports on the mining environment prepared by holders of mineral titles;
and

4. **The Artisanal and Small-Scale Mining Department (ASSMD)** - The ASSMD has the responsibility of assisting, and supporting small scale and artisanal mining operations in the country. Other functions of the ASSMD include provision of extension services for mining cooperatives and small-scale miners, including organizing, support, and assisting ASM miners on exploration, exploitation, mineral processing, and entrepreneurial training, and assisting artisanal and small-scale miners to access the Solid Mineral Development Fund established by the Act.

The ASM Department aims to facilitate healthy relationships between miners and the community as well as between miners and large-scale corporations. In addition, the Department is tasked with coordinating involvement with international governments and multi-lateral organizations (including UNEP, the World Bank, and the Department for International Development).

The Federal Ministry of Environment was established in 1999 to ensure effective coordination of all environmental matters. Its mandates include, among other things:

- i. monitoring and enforcing all environmental protection related matters;
- ii. prescribing standards and enacting regulations on water quality, effluent limitations, air quality, atmospheric protection, ozone protection, noise control, and the removal and control of hazardous substances;
- iii. Cooperating with Federal and State Ministries, Local Government, statutory bodies, and research agencies on matters relating to the protection of the environment and the conservation of natural resources.

2.26.2 Mining Law, Policy and Regulations

The primary legal framework administered by MMSD consists of the 2007 Minerals and Mining Act and the 2011 Minerals and Mining Regulations. Three policy documents²⁰⁰– the 2008 National Minerals and Metals Policy, the 2009 Vision 2020 National Technical Working Group on Minerals and Metals Development Report, and the 2012 Road Map for the Development of [the] Solid Minerals and Metals Sector – provide further guidance. These legal and policy tools address artisanal and small-scale mining to varying degrees. While they cumulatively give MMSD a wide range of authority to support artisanal and small-scale miners, in reality the Ministry's assistance to small-scale and artisanal miners has been predicated on the lawful existence of mining cooperatives, which are far fewer than the number of unregistered miners currently engaged in mining activities.

Minerals and Mining Act of 2007 and 2011 Minerals and Mining Regulations Seeking to strengthen practices in the mining sector, Nigeria passed the Minerals and Mining Act of 2007, to be administered by the MMSD through its five departments. The Act, which repealed the Minerals and Mining Decree of 1999, vested title in all mineral resources to the federal government and prioritized mining over other land uses. The Act established a Mining Cadastral Office to administer mineral titles and maintain registers of mining leases. It also created an Inspectorate Department and an Environmental Compliance Department, established a mine permitting system, and sets forth requirements relating to environmental protection and community benefits. The Act empowers MMSD to issue six types of permits, licenses, and leases, as described below. Permits generally convey non-exclusive use rights, while licenses

provide exclusive rights for a limited purpose and leases provide exclusive ownership rights for a broader purpose.

- (1) Reconnaissance Permits—right to access land to search for mineral resources on a nonexclusive basis
- (2) Exploration Licenses—right to explore mineral resources on an exclusive basis, including right to erect machinery and plants, along with the right to conduct bulk sampling and sell samples
- (3) Mining Leases—right to exclusively use, occupy, and carry out mineral exploitation in the area covered by the lease, not to exceed 50 km
- (4) Small-Scale Mining Leases—right to exploit minerals in area between 5 acres and 3 square km using low level technology or application of methods not requiring substantial expenditure
- (5) Water Use Permits—right to use water for exploration, mining, or quarrying
- (6) Quarry Leases—right to remove and dispose of any quarriable minerals, including necessary excavation and construction, in area not exceeding 5 square km

Under the Act, purchasers of gold are also required to apply for a license to purchase minerals. The Act specifically requires that gold obtained under a Small-Scale Mining Lease (which includes artisanal-mined gold) be sold to a licensed Mineral Buying Center. Although most of the Act is directed at large-scale, commercial mining activities, it does include a short chapter on Small-Scale Mining, following the example of its predecessor, the 1999 Decree.

The Act defines artisanal mining as a subset of small-scale mining; as such, artisanal mining is included in the requirements governing small-scale mining. Both artisanal and small-scale

miners can apply for a small-scale mining lease (with artisanal miners first required to form a cooperative), but there is no lease available under the Act specifically for artisanal mining activities. The specific requirements for a small-scale mining lease are discussed further below.

In May 2011, MMSD finalized the Minerals and Mining Regulations under the 2007 Act. The regulations include a brief section on —Artisanal and Small-Scale Mining Operation, which allows miners to register as artisanal and small-scale mining cooperatives and obtain extension services from the Ministry, including assistance in securing financial support from the Solid Minerals Development Fund. As noted above, artisanal mining cooperatives are also eligible to apply for mineral titles in the form of a small-scale mining lease. Small-Scale Mining Leases Under the 2007 Act, the Mining Cadastre Office grants small-scale mining leases for operations between three acres and five square kilometers. As noted above, the small-scale mining lease covers both artisanal and small-scale mining activity. Each small-scale lease application must be accompanied by a showing of technical competence (at minimum, a certificate in mining or a related field) and financial capability (evidence of sufficient working capital through a bank statement or reference letter). In addition, applicants must provide a land survey and a prefeasibility study.

A small-scale mining leaseholder cannot engage in extensive and continued use of toxic chemicals, cannot dig more than seven meters, and cannot continually use explosives. In practice, the Mining Cadastre Office encourages small-scale (and artisanal) miners to form cooperatives in order to decrease transaction costs and formalize mining practices. Small-scale mining leases last five years, after which the lease must be renewed. All leaseholders must apply in order to export minerals for commercial purposes. An annual surface rent is payable to the owner or occupier of

the land subject to the lease. The holder of the small-scale mining lease (and any other mineral title holders) must also pay compensation to the occupier or owner of the land for any disturbance to the surface of the land. In addition, a small-scale mining leaseholder may apply to transfer the ownership of the mineral title, subject to the fee below. Fees for small-scale mining leases are as follows (all in Naira):

- Application Processing Fee: 10,000
- Annual Service Fee: 10,000
- Renewal Processing: 30,000
- Tailing Deposit Application: 10,000
- Application to Abandon Work: 20,000
- Application for Transfer: 50,000
- Permit to Export Minerals: 10,000

Mine operators are also required to ensure that all tailings are properly treated before disposal, although in practice, many tailings are sold for further processing. In addition, all mineral processors must ensure that toxic materials are stored and used in a safe and secure manner. Mine health and safety are monitored through periodic inspections (conducted by the Mines Inspectorate) that analyze whether each mine is in compliance with technical requirements. During extraction, a small-scale leaseholder must keep detailed records and must pay royalties based on production. The royalty is three percent for gold mining. All leaseholders must submit an approved EIA to the Mines Environmental Compliance Department prior to mining, along with rehabilitation and environmental protection plans. The EIA is submitted to the Federal Ministry of the Environment with participation from the Mines Environmental Compliance Department. In addition, every leaseholder must contribute to an Environmental Protection and Rehabilitation Fund, in proportion to potential adverse impacts from that particular operation. All

small-scale miners must also submit a Community Development agreement, outlining the rights and arrangement between the miner and the community representatives.

2.26.3 2008 Minerals and Metals Policy

The 2007 Act served as a springboard for development of the 2008 Minerals and Metals Policy, which reflects a stated desire by the Ministry of Mines to expand the solid minerals sector and capitalize on increasing global minerals prices. The 2008 Policy calls for a comprehensive approach to mineral resources development that supports artisanal and small-scale miners. Related objectives include the promotion of small-scale mining activities and the formalization of informal mining activities, as well as the development of a legal and regulatory framework reflecting international best practices. The Policy also identifies social equity and benefit-sharing for mining communities, in addition to the contribution of ASGM to sustainable livelihoods, among its bases for action. Notably, it directs the Artisanal and Small Scale Mines Department to support artisanal and small-scale miners by organizing, supporting, and assisting small-scale mining operations; providing extension services to ASM operators, improving sustainable livelihoods in ASM communities; facilitating strong relationships between miners and communities; registering ASM operators and mineral buying centers; and maintaining ASM records and reports. The Policy also identifies seven specific objectives for government action, including access to funding, needs-driven research, training opportunities, information sharing, promoting small-scale mining activities, facilitating co-existence of large and small mining operations, and establishing the Solid Minerals Development Fund. Road Map for the Development of Solid Minerals and Metals Sector Released by MMSD in April 2012, the Road Map sets forth the goal of establishing a vibrant minerals and metals industry and outlines a set of policy priorities for the solid minerals subsector (including a shift from low-level technology

mining to modernized mining and processing; forming linkages between ASGM miners and expected medium and large-scale mining investors; promoting a participatory policy process; and ensuring community benefits, among other things). It also identifies challenges to development of the solid minerals sub-sector, which include a number of ASM-related factors such as the high proportion of ASM operations leading to environmental degradation and health hazards; the occurrence of illegal mining activities; mineral smuggling; and a lack of appropriate technology. In addition, the Road Map presents a set of nine performance targets. While the performance targets do not directly address ASGM issues, one target entails —protecting the rights of host communities and ensuring that mining activities lead to greater economic empowerment of the people. Although not an official policy, the Vision 2020 National Technical Working Group on Minerals and Metals Development Report, released in July 2009, presents a blueprint for improving Nigeria’s minerals and metals sector. The report includes an assessment of Nigeria’s minerals and metals sector, a 2020 vision and strategic plan, and an implementation roadmap and monitoring framework. It also addresses the ASM sector in part, emphasizing the need to minimize the adverse environmental impacts of artisanal mining and the importance of helping the miners form cooperatives and participate more formally in the mining sector. Its recommendations include a provision calling for MMSD to —control and strengthen artisanal and small-scale mining operations by;

- i. encouraging the formation of mining cooperatives with a view to empowering them towards sustainable growth in the industry;
- ii. establishing license buying centers to serve as an interface between mining cooperatives/licensed miners, local users and export markets;

- iii. providing extension services to artisanal and small-scale miners in the form of technical assistance and support services; and
- iv. providing micro-credit to artisanal and small-scale miners.

2.27 Federal Environmental Laws, Policies and Regulations

In 1999, Nigeria replaced the Federal Environmental Protection Agency with the Federal Ministry of the Environment. Then, in 2007, under the authority of Section 20 of the Constitution, Nigeria passed the National Environmental Standards and Regulation Enforcement Agency (NESREA) Act, which supplanted FEPA as the primary law governing environmental protection. NESREA is a parastatal organization of the Federal Ministry of the Environment (FMENV) that conducts environmental impact assessments and has a mandate to enforce international environmental agreements such as the Minamata and Basel Conventions¹⁶⁷. Environmental Impact Assessment Under the Environmental Impact Assessment Decree No. 86 of 1992, the Ministry of the Environment must complete pre-construction review of activities raising environmental concerns. No activity falling under the mandatory list provided in the Decree, including mining activities in new areas exceeding 250 hectares, in addition to ore processing (including concentrating for gold), can be executed without an EIA.¹⁰⁰ The Minerals and Mining Act and its regulations supplement the Decree by mandating a pre-construction EIA for all mining leases. All completed EIAs are reviewed by the Ministry of the Environment and the Mines Environmental Compliance Department within the MMSD. Under the Decree, EIAs must include a description of the activity, the potential affected environment, and the practical

alternatives, along with an assessment of likely or potential environmental impacts, identification and description of mitigation measures, and an indication of gaps in knowledge⁸³. Mining-specific requirements include a surface infrastructure plan (including water pollution management), and surface water, groundwater, and air pollution analysis.

In addition to complying with requirements from the Minerals and Mining Act and the EIA decree, mining operations must comply with background environmental law carried out by the Ministry of the Environment through NESREA. The NESREA Act tasks the Ministry of Environment with passing regulations with the purpose of protecting public health or welfare.¹⁰⁴ With respect to mining, the FMENV passed regulations in 2009 governing Pollution Abatement in Mining and Processing of Coal, Ores and Industrial Minerals.¹⁰⁵ The regulations seek to minimize pollution from the mining and processing of coal, ores, and industrial minerals and contain emissions limits for specific pollutants, among other things¹⁹⁶. However, the regulations do not address mercury use in ASGM activities and Nigeria does not currently have any laws or regulations that restrict mercury use in ASGM. Refer to National Environmental Standards and Regulation Enforcement Agency platform further information; Artisanal and Small-Scale Gold Mining in Nigeria Recommendations to Address Mercury and Lead Exposure⁸³.

2.28 Land Reclamation or Remediation

These two words “reclamation and remediation” are usually used interchangeably by many professionals. Reclamation in surface mining is defined as the reinstating of the natural fertility and value of land which otherwise could have been lost as a result of mining activities to normalizing the natural environment while the duo defined remediation as improvement of a contaminated site to prevent, minimize, or mitigate damage to human health or the environment. Notably remediation involves the development and application of a planned approach that removes, destroys, contains or otherwise reduces the availability of contaminants to receptors of concern. The land may be reclaimed into an agricultural land, forestry, tourist attraction, reservoir for different purposes, residential and industrial estates¹⁵.

Land reclamation in surface mining should be carried out simultaneously as mining progresses since is considered as an integral part of mine unit operations. A group of trained specialists are usually assigned to carry out reclamation in all areas of surface mining activities such as waste dump sites, mine site acreage, open – pit field, tailings ponds and so on¹⁶.

2.28.1 Steps for Site Investigation and Remediation Process

Almost all countries with a contaminated site program have a similar stepwise procedure for the contaminated site investigation and remediation decision – making process, namely discovery and intake, preliminary assessment, site investigation, clean-up decision making (including remedial investigation and options development, remedial design), and site completion (including remedial construction and remedy completion)⁵. While some of the process steps have different titles in various countries, they generally appear in the following order with the associated activities.

2.28.2 Site or Contamination Discovery

This step covers the initial time period following discovery of contamination. Recognizing contamination sources and sites, site evaluation based on complaint, citizen's reports, stakeholder interest and government agencies.

2.28.3 Preliminary Assessment/Historical Review

This step usually involves a review of available information and public records with minimal, if any, additional sampling and analysis. Such information might include land use and facility type and operation, including information from environmental or other permits, reports from inspections or other required submissions (chemical management and storage, occupational or safety issues), current and past photographs, hydrogeological information, and existing data from sampling and analysis of soil and groundwater. Analysis of Historical Review activities may be undertaken to: identify potential contaminants and environmental concerns at a site; identify the need for further investigation, particularly at sites where little existing information is available; and/or establish the preliminary site characteristics and develop a program or work plan for the subsequent site.

Site Investigation:

This step is often divided into two levels – preliminary and detailed site investigation.

- a. **Preliminary Site Investigation:** This is used to determine the presence or absence of suspected contaminants and to characterize the physical site conditions, including geology, hydrogeology and hydrology. If the results of the Historical Review have identified a potential environmental concern, a preliminary site investigation should

be undertaken to qualify and quantify those concerns. Where present, the preliminary site investigation will provide the degree, nature and extent of the contamination. The preliminary site investigation should also provide the necessary level of information to support management decisions regarding future investigation needs and requirements.

- b. **Detailed Site Investigation:** If the results of the preliminary site investigation indicate that significant contamination exists at the site, a detailed site investigation may be required. Generally, the detailed site investigation will concentrate only on those areas of concern identified by the preliminary site investigation and address issues such as information gaps and data deficiencies. A detailed site investigation may not be required if the preliminary site investigation was adequate to scrap a remedial action plan; or did not identify contaminants at concentrations that exceed any of the chosen Environmental Quality Guidelines. The specific objectives of the detailed site investigation are: to target and delineate the boundaries of identified contaminants; to define, in greater detail, site conditions required to identify all contaminant pathways, particularly with respect to risk assessment; to provide contaminant and other information necessary to finalize remediation guidelines or risk assessment; and to provide all other information required to develop a Remediation Plan and input to specifications and tender documents.

2.28.4 Investigation of Remedial Design and Development

Based on a detailed site investigation and associated evidence of public health and environmental risks additional information at the level of detail of volumes of soil likely to be contaminated or quantity and flow of groundwater needing remediation may need to be gathered. Such analysis

would also include a review of impacts on site as well as off site from the project. At the same time, engineering options for risk management can be developed¹⁸. For soil and sediments, these may range from excavation and disposal (on or off site) to treatment in place (or off site) with biological, chemical, or physical processes. Similarly, groundwater management options can include pathway interruption (for example by using permeable reactive barriers), in situ (below ground) treatment with biological, chemical, or physical technologies, hydraulic containment involving pumping and treating, partial treatment with long-term restrictions on access or use, and possibly pumping and treating above ground. These options would be influenced by whether the groundwater impacts only the subsurface or also adjacent surface waters.

2.29 Types of Remediation Technology

In order to rehabilitate or reclaim degraded lands, especially mined lands, various methods and technologies have been utilized globally. Remediation technologies of contaminated soils can be classified into three categories of hazard-alleviating measures:

- Gentle In-Situ Remediation;
- In-Situ Harsh Soil Restrictive Measures; And
- In-Situ or Ex-Situ Harsh Soil Destructive Measures.

The goal of the last two harsh alleviating measures is to avert hazards either to man, plant, or animal while the main goal of gentle in situ remediation is to restore the mal-functionality of soil (soil fertility), which allows a safe use of the soil. USEPA has broadly classified remediation technologies for contaminated soils into: source control and containment remedies. Source control involves in situ and ex situ treatment technologies for sources of contamination. In-situ or in-place treatment means that the contaminated soil is treated in its original place (unmoved,

unexcavated) remaining at the site or in the subsurface. The in-situ treatment technologies treat or remove the contaminant from the soil without excavation or removal of the soil⁶.

Ex-situ treatment means that the contaminated soil is moved, excavated, or removed from the site or subsurface to the treatment area. Implementation of ex-situ remedies requires excavation or removal of the contaminated soil. Containment remedies involve the construction of vertical engineered barriers (VEB), caps, and liners used to prevent the migration of contaminants.

Bradshaw⁶ broadly classified reclamation methods into:

- (i) Traditional methods of isolation, covering or removal of contaminated materials; and
- (ii) Decontamination techniques which remove contaminants from contaminated land and water.

2.29.1 Isolation, Covering or Removal of Contaminated Materials

The most commonly used techniques for dealing with contaminated soil is to cover the contaminants while the excavation and removal of the contaminants from the soil are also frequently used. None of the technique degrades, or destroys the contaminants and therefore is not environmentally friendly.

2.29.2 Decontamination Techniques

Interstate Technology and Regulatory Council (ITRC) broadly divided decontamination treatment into three categories for soil and two categories for water while pare broadly classified⁸⁵ decontamination techniques into thermal, separation, solidification/stabilization, chemical and biological techniques⁸⁴. An author stated further that decontamination techniques may be carried out in – situ (decontamination process takes place in the ground) or ex – situ (decontamination takes place in excavated material). Ex – situ techniques may be implemented

on-or off-site. According to ITRC the technical and regulatory guidance and decision trees for contaminated site are given in Figure 2.3.

2.29.3 Thermal treatment

There are three broad categories of thermal treatment: incineration, thermal desorption and vitrification.

I. **Incineration:** This is a destructive technique which destroys both the contaminant and the matrix in which it is contained. So, for contaminated soils treated by incineration, soil structure and function are lost, as well as the contaminant. Incinerator produces waste in the form of emissions and ash¹¹⁸. According to USEPA common incineration methods are given as;

a. **Rotary Kiln:** Refractory-lined inclined tube which is slowly rotated whilst the material within is heated. The rotation ensures that the heating is done under oxidizing conditions by pipes within the kiln or through the shell of the vessel. Retention times are different, depending on the waste being treated and are affected by both kiln angles of inclination and speed of rotation. A variety of wastes can be treated and the kilns are capable of a high throughput, but some wastes e.g. clays can form clods during treatment¹²³. The exhaust gases contain the volatile fractions of the waste undergoing treatment (e.g. Contaminants and water and these are subject to secondary treatment (gas scrubbing and particulate collection) before being emitted to the atmosphere⁸⁶.

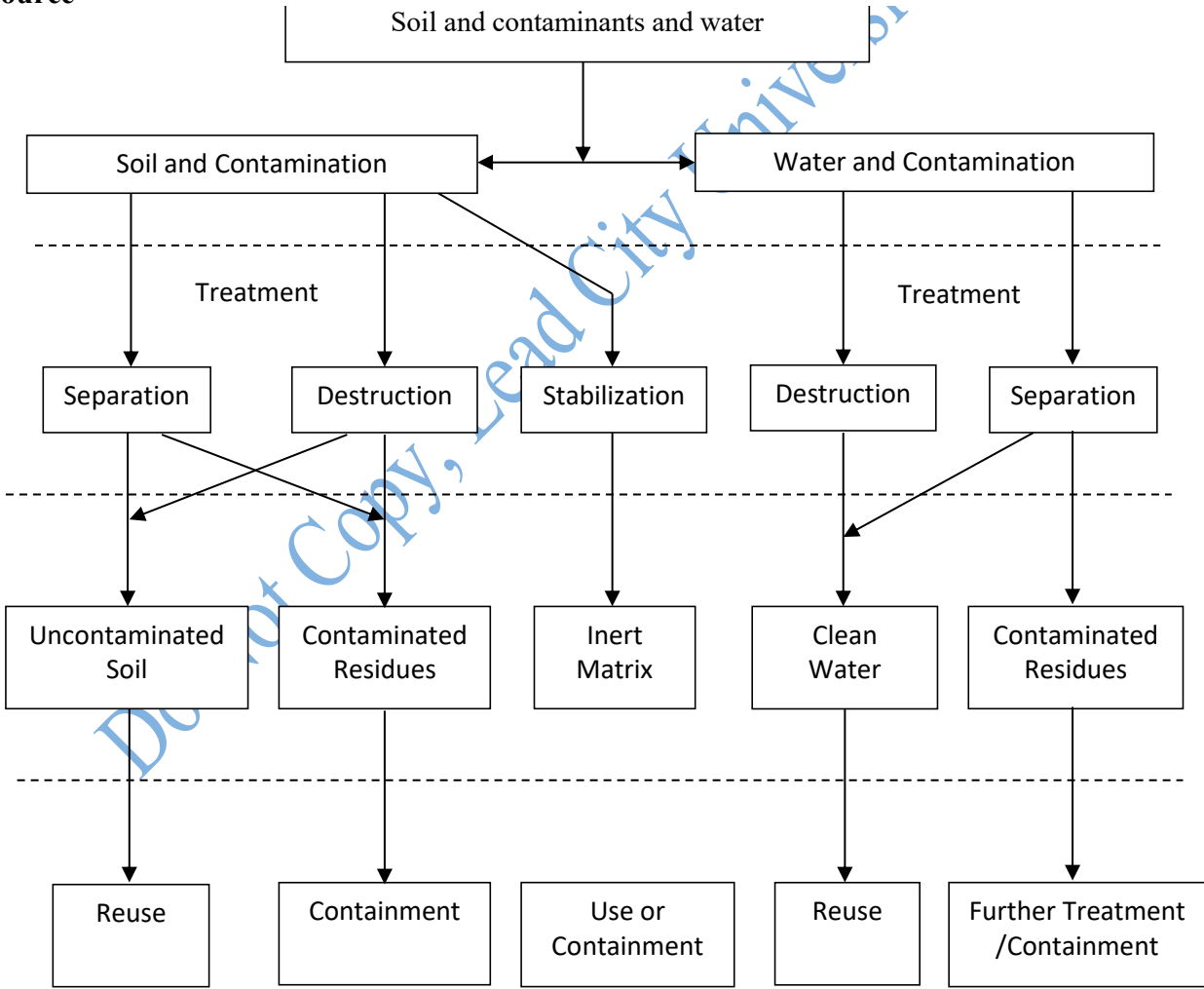
b. **Infrared:** Infrared lamps are used to irradiate contaminated materials passing under them on a conveyor belt. The furnaces are run under oxidizing conditions

and the exhaust gases have to undergo secondary treatment similar to that in rotary furnaces before emission to the atmosphere. The systems can run on transportable units

- c. **Fluidized Bed:** Fluidized bed systems maintain a bed of fluidized solids fuelled as necessary to maintain high temperatures. The retention time is short and any incompletely combusted particles are returned to the bed. These beds have been used in a limited way to treat contaminated soils, but throughputs of 450t/h have been achieved for waste tar from coking plant operation.
- II. **Thermal Desorption:** This is a process of removing volatile and semi-volatile compounds from contaminated materials. As in incineration, desorbed compounds have to be collected before exhaust gases are emitted to the atmosphere. Some common methods of thermal desorption as presented in Table 2.3. Thermal treatments are effective way of destroying the contaminants in soil but their effectiveness is dependent on grinding the feedback to reduce variability and careful control of operational parameters such as temperature and residence time. Disadvantages are that thermal treatments are very energy-intensive, exhaust gases have to be cleaned and soil materials are destroyed or damaged⁸⁹.

Figure 2:4 Treatment Technologies For Contaminated Land And Water

Source⁹⁴



III. **Vitrification Processes:** These involve the mixing of silica particles or other vitrifying materials such as sand or fly ash with contaminated waste and then applying intense heat. The heat drives off the volatile compounds and causes the solid material to vitrify, forming a glass-like compound. The vitrified material is chemically inert and can be used in construction. Vitrification may be performed ex-situ or in-situ although in-situ processes are preferred due to the lower energy requirements and cost.

Vitrified material with certain characteristics may be obtained by using additives such as sand, clay, and/or native soil. The vitrified waste may be recycled and used as clean fill, aggregate, or other reusable materials. As with other methods, the exhaust gases have to be treated before emission to the atmosphere. Vitrification is not a classical immobilization technique. The advantages include

- easily applied for reclamation of heavily contaminated soils (Pb, Cd, Cr, asbestos, and materials containing asbestos),
- in the course of applying this method qualification of wastes (from hazardous to neutral) could be changed.

2.29.4 Separation Techniques

The techniques for separating contaminants from soil particles or groundwater, or more contaminated particles from less contaminated particles include vacuum (or vapor) extraction, soil washing, solvent extraction, electro-kinetics, and leach, pump and treat.

2.29.5 Solidification/Stabilization

Solidification is the fixing of contaminants in a resistant solid matrix. Stabilization is the treatment of contaminants to make them less available or toxic to targets. Solidification most commonly uses concrete-based materials or thermoplastics as the cementing medium, but silicates and lime are also used. The general approach for solidification/stabilization treatment processes involves mixing or injecting treatment agents to the contaminated soils. Inorganic binders, such as clay (bentonite and kaolinite), cement, fly ash, blast furnace slag, calcium carbonate, Fe/Mn oxides, charcoal, zeolite and organic stabilizers such as bitumen, composts, and manures, or a combination of organic-inorganic amendments may be used. The dominant mechanism by which metals are immobilized is by precipitation of hydroxides within the solid matrix. Solidification/stabilization technologies are not useful for some forms of metal contamination, such as species that exist as oxyanions (e.g., $\text{Cr}_2\text{O}_7^{2-}$, AsO_3^-) or metals that do not have low-solubility hydroxides (e.g., Hg). Solidification/stabilization may not be applicable at sites containing wastes that include organic forms of contamination, especially if volatile organics are present.

Pre-treatment of non-solid materials may be necessary to separate the contaminant into a solid phase by, for example, the use of clay minerals. The process of solidification usually involves mixing slurry of contaminated material and solidifying medium, and then solidification in moulds. Stabilization by chemical means is less well used, but the most promising methods use oxidizing agents. Principal limitations are that, because of the antagonistic effect of some contaminants on the solidifying medium, a greater volume of material may result after solidification and that disposal of the solidified material has to be achieved. Heat and gases may be generated during treatment, and these have to be controlled. Solidified materials may have

greater structural properties than the original material and be disposed of on-site, increasing the construction properties of the site.

2.29.6 Chemical Methods

These are the processes of using a chemical to destroy the contaminants in a soil or to make them less toxic. An example is the use of ozone to destroy hydrocarbon contaminants. This technique is expensive because of the energy costs of producing ozone and the fact that ozone will be consuming oxidizing, non-contaminating, organic compounds such as soil organic matter. Dechlorination is another technique which has received limited use. This technique is intended to dechlorinate contaminating halogenated hydrocarbons such as PCBs and dioxins. Dechlorination is carried out using reagents such as potassium hydroxide and polyethylene glycol, but can be adversely affected by high humidity and clay contents of soils.

2.29.7 Biological Methods

Biological treatment uses natural biological degradation processes to degrade organic compounds; the most developed techniques, making use of micro-organisms. The aim of biological treatment is to optimize those factors that stimulate biodegradation. The critical factors are: temperature, water, pH, nutrient supply, the presence of appropriate microBPAI populations and absence of microBPAI inhibitors. The compounds most amenable to degradation are those that have a degree of aqueous solubility, so compounds such as the heavy fractions of coal tar which have negligible solubility are resistant to biological degradation, whereas compounds such as light mineral oils which have some aqueous solubility are amenable to biological treatment. In situ biological treatment is achieved through the circulation of ground-water dosed with amendments to stimulate biological activity. The contaminated area may have to be 'batched' for treatment by use of vertical barriers or boreholes. Off-site treatment is quite

popular in some countries because it allows permanent facilities for treatment of leachates and collected volatile compounds to be installed. Off-site treatment also has the advantage that commencement of other site works does not have to wait until the soil has been treated by biological means which can take some months. Excavated soil may be returned to the same site after treatment or sent to another site or sent to landfill.

2.30 Phytoremediation

Soils that are heavily contaminated by metals may pose health risks to humans and to other living organisms in an ecosystem^{92,93}. Current techniques used to remediate metal contaminated soils include excavation, chemical stabilization, soil washing or soil flushing, but these methods are expensive and impractical. Need to develop cost effective, efficient and sustainable methods for soil remediation is necessitated. The revegetation of these sites proves to be the most suitable method for long term land reclamation since certain plants can improve nutrient soil conditions. This approach can lead to the establishment of a self-sustaining vegetative cover, which in turn can prevent soil erosion⁹⁵. Phytoremediation is a low-cost and solar (sun) driven approach that is performed in situ. Phytoremediation can be employed to remove, stabilize and detoxify organic and inorganic pollutants including heavy metals from air, soil and liquid substrates¹¹⁶. Plant species selected for land reclamation should be able to grow and spread fast and also establish an effective soil cover. Therefore, it is important to search for plants that have spontaneously colonized these disturbed environments. Moreover, heavy metal contaminated mining sites exhibit physiochemical characteristics that are not suitable for the vast majority of plant species; hence the colonization of these sites is slow. However, plants that are resistant to this toxic environment can easily spread since there is a lack of competitors. It has been demonstrated that

annual species have an extensive adaptive capacity compared to perennial genotypes due to their long-term natural selection. Phytoremediation is composed of five main subgroups: phytoextraction, phytovolatilisation, phytostabilization, phytodegradation and rhizofiltration¹⁵². Phytoextraction is a process by which plants extract metals from soil by accumulating them in their aerial biomass. These plants can be harvested and metals can be extracted from their tissues¹⁰⁶. Plants that accumulate metals in their aerial tissues have been involved in the phytoextraction of several metals including Cd, Cr, Cu, Hg, Pb, Ni, Se and Zn¹⁰². The accumulation of metals by plants is interesting from an environmental or agronomic point of view. In mining or industrial sites, as well as their surrounding areas, heavy metals are responsible for severe soil contamination¹⁸⁴. In these cases, accumulator plants could be used for phytoremediation as they are likely able to remove metals from soils. Since some heavy metals are also essential minerals that can be deficient in staple food crops, genetic determinants of hyper-accumulation could be utilized in bio-fortification to improve the nutritional value of these crops.

Through the process is known as phytovolatilization, these metal accumulating plants could also convert metals and release them in a volatile form. Phytostabilization is a method that uses plants with a low ability for metal uptake to stabilize the contaminated soil thus preventing erosion and also limits the metals from entering the food chain. Plants can also be utilized for phytodegradation since they can in combination with microorganisms degrade organic pollutants. Finally, Rhizofiltration is a process by which plant roots absorb metals from waste streams

2.30.1 Coping Mechanisms of Plants to Metal Contaminated Soil

It has been established that heavy metal contaminated environments act as stress factors on plants, which causes physiological reaction change that reduces or inhibits plant vigor and growth. An injured or dying plant due to metal stress is deemed sensitive to its environment. Likewise, resistant plants can survive and reproduce under metal stress conditions^{124,95}. In general, plants can achieve resistance to heavy metals by either one of two ways which are by; Avoidance or Tolerance.

Avoidance

Avoidance occurs when plants restrict the uptake of metals within root tissue by several strategies. In environments where the soil metal contamination is heterogeneously distributed, plants can prevent metal uptake by exploring less contaminated soil¹²⁷. Another avoidance strategy involves mycorrhizal fungi, where they can extend their hyphae outside the plants rooting zone up to several tens of meters and transfer the necessary elements to the plant. Also, these metal tolerant fungi can increase plant metal resistance by changing the metals speciation or by restricting the metal transfer into the plant. It was also found that mycorrhizal *Trifolium pratense* (red clover) plants growing in acid soils had lower levels of Mn in their roots and shoots as compared to the non-mycor-rhizal plants. Certain plants can also restrict contaminant uptake in root tissues by immobilizing metals for example through root exudates in the rhizosphere. A role of root exudates is to chelate metals and stop their entry inside the cell. The cell wall has also been found to be involved in restricting metal uptake into the cell's cytoplasm.

Tolerance

In situations where avoidance strategies cannot be applied, some plants can grow and survive in soil contaminated with toxic levels of heavy metals which are otherwise lethal or detrimental for growth and survival of others genotypes of the same or of different species. Plants exhibiting

tolerance are internally protected from the stress of metals that have entered the cell's cytoplasm¹⁶⁵. Metallophytes (metal tolerant plant) can function normally even in the presence of higher plant-internal metal levels. Plants adapt to their environments by developing heritable tolerance mechanisms. Tolerance to specific metals has evolved independently several times in different species from local non tolerant ancestral plant populations¹⁵⁸. Plants can exhibit tolerance to metals that are present in surplus in the soil. Each metal is under control of specific genes. Most species are in a state of genostasis. It is the restriction of genetic variability which limits the evolution of the population/species. In the absence of avoidance pathways, metal contaminated soil acts as a selection force on a population, where only the plants with tolerant genotype can survive and reproduce. This leads to a bottleneck, where few individuals survive and reproduce. In turn, metal tolerant populations can evolve rapidly following a disturbance such as contamination of soil with heavy metals. Plant adaptation to these sites occurs in populations for which tolerance variability already exists prior to the contamination. Genes for the tolerance of metals are pre-existing at a low frequency in non-tolerant populations of certain plant species¹⁸⁸.

Plants have to modify their physiological processes in order to be able to survive in the environment in which they have germinated. In turn, the survival of a population to the contaminated environment is dependent on the inheritance of favorable traits. Tolerance mechanisms are heritable and variable, resulting from genes and gene products. Variation in the evolution of metal tolerance exists over species, populations and clones. Some species do not show variation in tolerance and accumulations.

2.31 Ground Improvement Techniques

In order to overcome the constraints of contamination, reclamation techniques have to provide suitable ground conditions for new uses of the site. For 'hard' end-uses the techniques for providing suitable conditions for construction are known as ground improvement techniques. The principal aim of these techniques is to decrease the variability in the physical conditions of the ground and provide enough strength to support new construction on-site. Below are details of some of the ground improvement techniques in use.

- i) **Dynamic Compaction:** Deep compaction of the fill is affected by the repeated dropping of a heavy weight using a crane e.g., a 15-tonne weight dropped from a height of up to 20m on a grid pattern. Treatment may be carried out using high-energy impacts for the primary and secondary grids, the latter being offset from the former. Craters formed by the impacts are filled using earth moving equipment and a second stage of more uniform treatment is carried out using a reduced drop height. An alternative method of treatment for shallower fills is to use a rapid impact compactor, which involves dropping a 7-tonne weight from a height of 1.2m onto a circular plate.
- ii) **Vibro Techniques:** Vibro techniques involve the compaction of granular soils or the formation of stone columns using a vibrating cylindrical poker suspended from a crane. The poker may be 300-450mm diameter and can weight up to 4 tonnes. Treatment depths of around 6m are typical, but depths up to 30m have been achieved. The poker penetrates the ground as a result of the vibratory action assisted by flushing jets in the nose cone and sides. Compressed air is generally used for flushing,

although water may sometimes be employed. Vibro treatment is carried out on a grid patten using closer grid spacing where higher bearing capacities are required e.g. beneath pad foundation or edge beams.

‘Vibrocompaction’ is the term generally used to describe the densification of granular soils using vibro techniques. Additional material may be introduced from the top of the hole as part of the compaction process. An alternative in unstable ground is to use the bottom feed process whereby stone is introduced directly from the top of the poker via a feed pipe ‘Vibrated stone columns’ is the term used for stone columns introduced and compacted by the vibro process in order to improve the bearing capacity.

- iii) **Preloading:** Preloading involves over-consolidation of the fill by temporary surcharging to improve the bearing capacity prior to construction taking place. Surcharging is usually carried out using several meters of fill material placed using earthmoving equipment and left in situ over a period of two to three months.
- iv) **Excavation and Re-compaction:** This method involves the treatment of loose granular fill material by excavation and re-compaction in thin layers under controlled conditions using conventional earthmoving equipment.

2.32.1 Stages in Mine Land Reclamation

Reclamation is the process through which the environmental impacts created by mining are minimized and where environmental disturbance caused during mining is remedied¹⁶⁰. The reclamation process starts prior to minerals being removed from the ground, and must be planned from the outset. Reclamation efforts should address issues of land productivity, water and air quality, and the long-term social and economic sustainability of a region¹⁶¹. Assessing the condition of the land, and the land use practices present before mining begins, provides a guide to the options which may be available for future land uses after mine closure. Mining is a temporary land use, and mine planning should be integrated with subsequent land use planning. A mine's potential environmental footprint needs to be determined in the beginning, and the objectives for the post-mining landscape need to be define. Regardless of the final use of reclaimed land, the end goal is to create land that is:

- (i) safe and stable;
- (ii) restored as closely as possible to its pre-mining condition, or to some other useful purpose to meet a specific goal (i.e. recreation); and
- (iii) Safeguards environmental resources.

Government policies based on 'best practices' tend to encourage reclamation projects that are safe, non-polluting, and create stable conditions that can sustain agreed upon land uses¹¹⁴. Successful land reclamation requires professionals with strong expertise and technical skills in soil conservation, slope management, re-vegetation and biodiversity, etc., and it also requires the knowledge, opinions and values of local citizens. Reclamation is a long and complex process involving specialist technical skills and detailed planning. However, it can be summarized in a

number of steps implemented at appropriate stages of a specific mining operation. These steps can be categorized into six major stages as described below.

- (i) Baseline environmental assessment and information gathering;
- (ii) Reclamation strategy planning;
- (iii) Landform design and reconstruction of a stable land surface through grading and soil replacement;
- (iv) Revegetation or development of alternative land use regimes on the reconstructed landform;
- (v) Improvements to drainage and watershed damage and contamination; and
- (vi) Ongoing environmental monitoring of the success and integrity of the reclamation process.

Typical monitoring programs that support a mine closure program can include:

- (a) Baseline monitoring in the early mine life phases;
- (b) Monitoring, recording and understanding of all potential impacts during the operational phase of mining;
- (c) Documentation of the reclamation operations carried out; and
- (d) Initial closure monitoring conducted within one to two years of reclamation.

2.32.2 Determining Effectiveness of Soil Reclamation

It is pertinent that an assessment should be made to determine the next steps once the reclamation plan is complete and vegetation has established. It is to determine how closely the reclaimed site functions, in comparison to similar undisturbed sites, as an ecosystem. Reclamation of mined – out land is a very complex process. Most researchers agree that

reclamation success must be measured by more than the presence of vegetation on the site. Several parameters must be considered in order to determine the state and functionality of the soil system since no individual parameter provides sufficient information for ecosystem reclamation¹⁵⁹. Both the activation of basic soil biological processes and the rearrangement of soil particles into stable aggregates are key factors related to the soil functionality. Soil enzyme activities have been used as sensitive indicators for reflecting the degree of quality reached by a soil in the reclamation process²¹.

2.32.3 Standard Submission Requirements for a Reclamation Plan

Reclamation plans for contaminated sites include the following requirements:

- i. Proposed lifespan of the mine;
- ii. Schedule for progressive mine reclamation;
- iii. Time-line for the completion of final reclamation and closure;
- iv. Existing land use;
- v. Range of post mine land uses to evaluate;
- vi. Technical and socioeconomic factors associated with the range of post mine land uses to evaluate;
- vii. The proposed post-mine land use (natural, conservation or redevelopment);
- viii. Existing features of environmental significance;
- ix. Description of any planned biodiversity offsets (if applicable);
- x. Scaled figures and maps depicting the projected maximum footprint of the proposed mining area over the life of the mine;
- xi. Detailed plans for progressive mine reclamation;
- xii. A conceptual final reclamation plan for the final closure of the mine;

- xiii. A mitigation and monitoring plan for subsidence, spontaneous combustion and acid rock drainage where appropriate;
- xiv. Summary of any public issues raised in relation to mine reclamation and how they have been addressed; and
- xv. A detailed cost estimate associated with reclamation.

Do Not Copy, Lead City University, Nigeria

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Chapter Three

Methodology

3.1 Study Location

The study site is Uke, a town 52 kilometers to Keffi in Nassarawa state, where gold mineralisation and ore processing is prevalent^{5,20}. The project area is situated within Uke Area, Karu Local Government in Nassarawa State, North Central part of Nigeria. It is located within latitudes $8^{\circ} 52' 50''$ and $8^{\circ} 55' 44''$ N and longitudes $7^{\circ} 40' 12''$ and $7^{\circ} 44' 54''$ E. It is very accessible through Keffi – Nyanya – Abuja express road. It is underlain geologically by schist rock. The population of the area is over 20,000 people.

The extraction of gold from primary ore by artisanal miners involves the application of mercury to separate gold. This unregulated discharge of mercury into the environment could lead to contamination of the ecosystem^{23,26}. Exposure of mercury through the conventional pathways of inhalation, ingestion, dermal could results in risk to health of the members of the community.

This research is geared towards evaluating the bioaccumulation of mercury in the ecosystem and the resulting health risk to the community^{47,48}. The work involves the application of multi-disciplinary approach to the assessment of the human and health risk associated with the use of mercury to extract gold ore through amalgamation²². It engaged the use of field questionnaire survey to know the perception of the miners and community residents on the use of mercury.

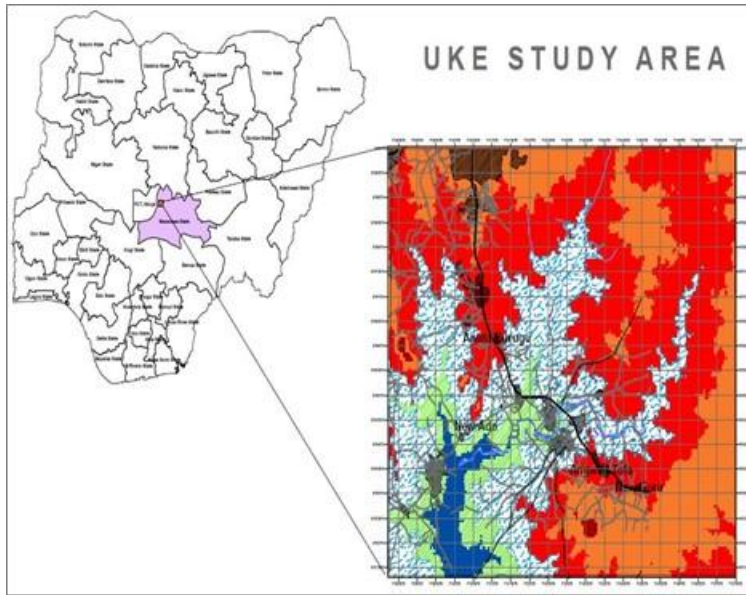


Figure 3.1: Location Map of Study Area

Source: Author's Field Work, 2023

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3.2 Study Design

Field surveys were executed during dry and wet seasons; both seasons entails the analytical phase involving, sampling, and geochemical analysis. Furthermore, in order to deepen the study, transactional approach was adopted involving collection of socioeconomic data to compliment the analytical data. This involved the use of questionnaires probe into the perception of the community and miners' groups living around the immediate vicinity of the area on awareness on risk of mercury usage in terms of knowledge, attitude and perception.

The samples collection was done within a year from June 2021-June 2022. The Samples were carefully chosen to reflect proximity to the processing site and near discharge area to the Uke rivers/streams. The sampling density outside the point sources were located in a 2 km radius from artisanal gold mining area to ensure accuracy of results from anthropogenic discharge. Samples were also collected close to the point sources especially along the effluent receiving water body. The control samples for soil and water were collected at extremes away from the discharge or point source.

3.3 Method of Sampling and Sample Preparation

The stage entailed the collection of different samples to determine their mercury concentrations. Hence, soil samples, edible plants, surface water (river), groundwater, tailings were collected on and around the gold processing site using various convectional standards. They were subsequently sent to the laboratory for analytical examinations and results compared with international standards such as WHO and EPA⁵¹⁻⁵⁶. The sampling points are shown on the map in Figure 3.2.

3.3.1 Sampling of Plants and Preparation

Sampling of vegetables and edible plants were carried out at farmland within the vicinity of the Uke River, the mercury effluent receiving stream. The array of vegetable and edible plants sampled especially at farmland close radius to the point source⁵⁴.

Samplings were done at random and carefully packaged into sample bags for laboratory preparation.

3.3.2 Sampling of Soil, Sediment and Mine Waste (Tailing)

Sampling of river sediments was carried out during this study along river uke . The sediment samples were picked at depths below the water surface and were carefully packaged into sample bags before being sent to the laboratory. Three sediments samples were collected upstream, midstream and downstream section in this regard.

Sampling of soil was carried out at the vicinity of gold processing site using 500m spacing as sample density were used at the extremes.^{7,27,16} The samples were picked at a depth of 50cm using a hand auger. Deliberate efforts was made to sample the soil and plants jointly to

determine bioaccumulation and transfer factors with respect to nutrients uptake and mercury concentration from soil to plants^{26,27,28}. The soil samples were carefully treated, put in clean sample bags and forwarded for laboratory analysis. Mine waste (soil tailings) were collected per season.

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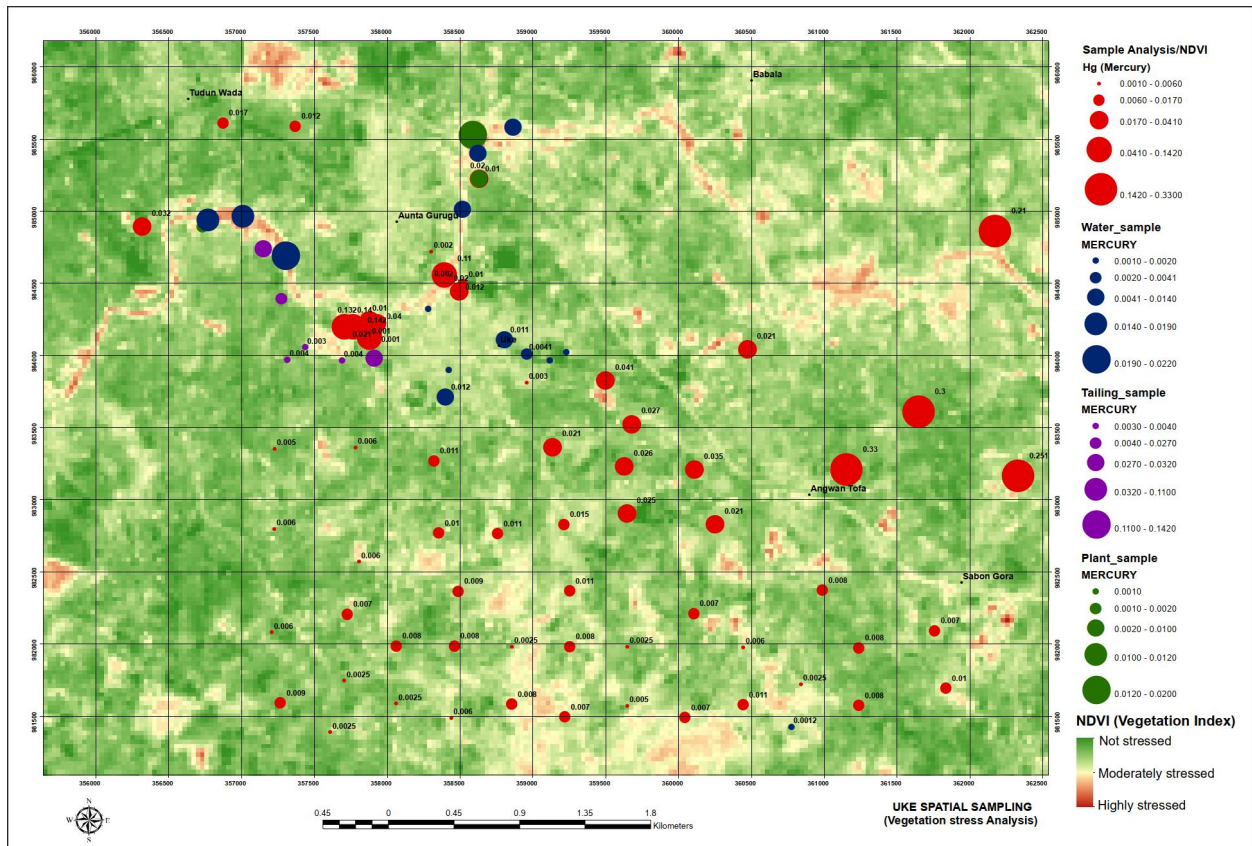


Figure3.2: Samples and Mercury Concentration Distribution on NDVI

Source: Author's Field Work, 2023

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3.3.3 Water Sampling Methodology

The sampling of surface (river)water carried out along the course of River Uke because it is the effluent receiving stream. At each sampling point, water samples were taken at a shallow depth from the river while groundwater sampling was done directly from the borehole or wells. The water samples were put in plastic bottles and sealed with addition of concentrated HNO_3 to preserve it before forwarding to the laboratory. 20 no water samples were collected each for surface and groundwater each season^{5,28,49}.

3.3.4 Fish Sampling

Ten fish samples, Tilapia (3) and catfish (7) species were collected for the purpose of this study. The samples were preserved with ice to preserve the internal organs for accurate mercury evaluation^{20,49}.

3.4 Exposure Assessment Procedure

In this study, exposure to the hazards derived from mercury via the exposure pathways such as inhalation, ingestion and dermal contacts was carried out through quantitative method via direct interviews with miners, health centers and the community. The characterization of the hazards as done after the analysis of the mercury concentration in the environmental media. Pollution indices were used to calculate the contamination factor and geoaccumulation index. These factors to a large extent helped to evaluate the human and health risk to the community. This eventually would help to recognize the danger posed by mercury exposure to the at-risk population^{23,47,48,25,17}.

3.4.1 Hazard Identification

This procedure involved the identification of threats to the ecosystem and human health derivable from mercury contamination. The mercury concentration in each of the eco-media would be compared to convention threshold limits to identify threats to human health. Furthermore, the risk assessment was calculated through the hazard and risk quotients for the community. Hazard index, carcinogenic and non-carcinogenic indexes was calculated for the at-risk population^{20,23,28,48}.

3.4.2 Dose-Response Assessment

This stage of the study involved comparing the magnitude of exposure and how they affects the health of the at-risk population. The refence dose and daily intakes of the metal and toxicity limits became critical at this stage^{16,17,22}.

3.5 Geochemical Analysis of Samples

3.5.1 Heavy Metal Concentration Determination Using Direct Mercury Analyzer

The analytical investigation of the samples were carried out at the University of Port-Harcourt, Department of Animal science and Environmental Biology laboratory. The Direct Mercury analyser (DMA-80) was used to measure mercury contained in the samples^{24,33}. The methodology involves Thermal Decomposition (Gold) Amalgamation Atomic Spectrophotometer (TDA/AAS)^{22 23}. The equipment measures mercury directly devoid of wet chemistry. Results are confirmed within five minutes of application.

3.6 Health Risk Assessment Analysis

The antropogenic release of mercury results into its dispersion into the environment which causes threats to the food chain through biomagnification and becomes lethal to humans. In this work, the risk to human health was estimated using the pollution and risk assessment indices such as geoaccumulation index (Igeo) and contamination factor(CF). The definition of parameters and estimation are as follows^{6,7,23,47,48}.

3.6.1 Geo-accumulation Index (Igeo)

Geo-accumulation index is conventionally engaged in the evaluation of potentially harmful metal contamination⁵⁷ and the formula is expressed as: where C_n = Hg measured in the study area and B_n is the background value of the same element in average crustal values, with 1.5 as a factor for possible variation adjustment in the background values as a result of lithologic differences 14 . The adopted equations are in line with the work of Qingjie⁵⁷ . The degree of contamination can be classified into seven categories based on the Igeo value for each trace elements;

$$I_{geo} = \text{Log}_2 \left(\frac{C_n}{1.5B_n} \right)$$

- $I_{geo} \leq 0$ (practically uncontaminated),
- $0 < I_{geo} \leq 1$ (uncontaminated to moderately contaminated),
- $1 < I_{geo} \leq 2$ (moderately contaminated),
- $2 < I_{geo} \leq 3$ (moderately to heavily contaminated),
- $3 < I_{geo} \leq 4$ (heavily contaminated),
- $4 < I_{geo} \leq 5$ (heavily to extremely contaminated) and
- $I_{geo} > 5$ (extremely contaminated).

In this study exposure and health risk assessment was also calculated by identifying the exposure pathways and calculating the risk to human health using the formulas listed below^{23,46,47,48}.

$$ADD_{ingnc} = \left(\frac{C_{soil} \times IngR \times CF \times EF \times ED}{BW \times AT} \right) \times 10^6$$

$$ADD_{inhnc} = \left(\frac{C_{soil} \times InhR \times EF \times ED}{PEF \times 24 \times AT} \right)$$

$$ADD_{dermalnc} = \left(\frac{C_{soil} \times SA \times CF \times AF \times AABF \times EF \times ED}{BW \times AT} \right) \times 10^6$$

$$ADD_{vapour} = \left(\frac{C_{soil} \times InhR \times EF \times ED}{VF \times BW \times AT} \right)$$

Health risk is also measured when the value of hazards is measured with the formula below.

$$HQ = \left(\frac{ADD_{nc}}{RfD} \right)$$

$$HI = \sum HQI$$

3.6.2 Contamination Factor (CF):

The soil degree of Contamination (otherwise contamination factor) was evaluated for the study area using the formula:

$$CF = C_m/C_b [1]$$

Where C_m is the concentration of the metal and C_b is the baseline concentration of the heavy metal.

The Contamination Factor values classification is as listed ;

$C_f^i < 1$, low contamination;

$1 \leq C_f^i < 3$, moderate contamination;

$3 \leq C_f^i < 6$, considerable contamination; and

$6 \leq C_f^i$, very high contamination.

3.7 Quantitative Analysis

The socioeconomic data research in this study was carried out through the design of a well-structured questionnaire and direct interview involving about 100 respondents. The composition of the target population is largely made up of two main groups: the artisanal miners and the community. The artisanal miners consist of all the women, men and children of all ages. While this work focused on community members living at the proximity of gold processing site. In summary, 50 miners and 50 stakeholders were recruited, giving a total of 100 for this study.

3.7.1 Questionnaire Survey Procedure

The quantitative approach to this study involved the use of semi-structured questionnaires. The target population included 50 miners and 50 members of the community. The Community outreach was carried out through door-to-door surveys to gather socioeconomic data and how the ASM activities affects the environment and the human health.⁵⁸

This research examined the exposure of artisanal miners to workplace hazards and safety ethics were identified. These data were documented through direct interviews and observations. Moreover, the health officials in the three clinics in the town were interviewed and questionnaires administered to have an insight into the health profile of the community.

3.7.2 Statistical Processing of Data

The data collected from the questionnaire survey were analyzed using the statistical software, SPSS. A single dependent variable was used for this study i.e. Mercury and the independent variables are: Social-Demographics (gender, Age, educational level, marital status); Occupational exposure (Number of years on processing site, amalgamating with mercury, use of personal protective equipment); health symptoms and safety measures.

Table 3.1: Description of Water Samples used for Mercury Analysis

Field Number	Y	X	Sample Type Description
UP1	8.090361	7.071294	Surface Water
MS1A	8.090178	7.070747	Surface Water
Borehole Water	8.090056	7.070025	Borehole
AT – 03	962841	360773	Borehole
AT – 04	981426	360773	Borehole
AD- 05	984014	358958	Borehole
AT – 10	983712	358398	Borehole
AT – 23	984110	358804	Borehole
DS 01A	8.903158	7.702833	Surface Water
UPSB3	985583	358863	Surface Water
MSB1	984322	358280	Surface Water
DS2	984692	357303	Surface Water
DS3	984938	356768	Surface Water
DS4	984965	357007	Surface Water
UPSB1	985014	358515	Surface Water
UPSB2	985402	358621	Surface Water
BH1	984021	359227	Borehole
BH2	983964	359115	Borehole
BH3	983899	358420	Borehole

Source: Author's Field Work , 2023

Table 3.2: Description of Soil Samples used for Mercury Analysis

Field Number	Y	X	Sample Type Description
SS1A	8.090361	7.071294	Soil
SS1B	8.090406	7.071322	Soil
SS1C	8.080888	7.078508	Soil
SS3	8.090194	7.070722	Soil
AT - 06 (SS 02)	983814	358958	Soil
AT - 11	985613	356872	Soil
AT - 13	984892	356317	Soil
AT - 15	985590	357369	Soil
AT - 16	984720	358304	Soil
AT- 017A	985224	358630	Soil
AT -018	984575	395162	Soil
AT - 019	983208	360109	Soil
AT - 020	983208	361151	Soil
AT - 21	984042	360473	Soil
AT - 22	983826	359497	Soil
DSS1	984692	357303	Soil
DSS2	984895	356731	Soil
UPSS1	985529	358586	Soil

Source: Author's Field Work , 2023

Table 3.3: Description of Tailing Soil Waste used for Mercury Analysis

Field Number	Y	X	Sample Type Description
TS1	8.090075	7.070746	Tailing Waste
TS2	8.090139	7.070639	Tailing Waste
TS3	8.090139	7.075833	Tailing Waste
TS4	8.090139	7.076556	Tailing Waste
AT - 07 (SS 03)	983967	357688	Tailing Waste
AT – 08A (SS 04)	984058	357436	Tailing Waste
AT – 08B (SS 05)	983972	357314	Tailing Waste
TSS1	984739	357149	Tailing Waste
TSS2	984395	357273	Tailing Waste
TSS3	983980	357911	Tailing Waste

Source: Author's Field Work Data, 2023

Table 3.4: Description of Fish Samples used for Mercury Analysis

Field Number	Sample Type Description
FF1A	Fish Gill
FF1A	Fish Intestine
FF1A	Fish Bone
FF1A	Fish Liver
FF1A	Fish Flesh
FF1B	Fish Gill
FF1B	Fish Intestine
FF1B	Fish Bone
FF1B	Fish Liver
FF1B	Fish Flesh
FF1C	Fish Gill
FF1C	Fish Intestine
FF1C	Fish Bone
FF1C	Fish Liver
FF1C	Fish Flesh

Source: Author's Field Work, 2023

3.8 Geospatial Methodologies

In this study, focus was on the use of remote sensing and geographic information technologies to carry out the assessment of the effect of mercury contamination on the environmental media. The ARCGIS version 10 and ENVI software were used extensively to process the various dataset using different methodologies listed below;

3.8.1 Digital Elevation Model

A digital elevation model, or DEM, is a depiction of the topographic surface of the earth's bare ground (bare earth), devoid of any trees, structures, or other surface items⁶⁰. A DEM is a particular kind of raster GIS layer; it consists of raster grids of the Earth's surface that are referenced to the vertical datum, or the surface at zero elevation, to which scientists, insurers, and geodesists relate heights.

The United States Geological Survey's (USGS) Earth Explorer website was utilized to obtain the elevation data (The DEM) that was utilized. The study area shapefile was used to clip the DEM data, and the clipped DEM raster dataset was then used to create a fill surface. A surface raster called the fill smooths out minor data flaws, producing an elevation surface result that is far more accurate. In order to create the slope and other crucial analyses, the fill result had to be used in place of the normal elevation data that had been clipped.

3.8.2 Slope

The Slope tool identifies the steepness at each cell of a raster surface. The lower the slope value, the flatter the terrain; the higher the slope value, the steeper the terrain. The study area slope surface was created using the slope tool and the fill raster dataset as input.

3.8.3 Flow Accumulation

The Flow Accumulation tool calculates accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster. This parameter considers the zone of accumulation of water flow entering a basin. The flow accumulation is obtained through the processing of DEM data to get the flow direction which is used with the DEM data as input in the flow accumulation tool to generate the flow accumulation zone.

3.8.4 Normalized Differential Vegetation Index

The NDVI process creates a single-band dataset that mainly represents vegetation density and vigor. The differential reflection in the red and infrared (IR) bands enables you to monitor density and relative vigor of vegetation growth using the spectral reflectivity of solar radiation.

The NDVI was created using the google earth engine by importing the image collection (Landsat) and clip the study area, filter the date and cloud cover. The filtered image is then used to calculate the NDVI with the formula $NDVI = ((NIR - R)/(NIR + R))$

- NIR = The Near infrared band (Band 5)
- R = The red band (Band 4)

This scientific index outputs values between -1.0 and 1.0, which represents vegetation density and vigor. Negative values are mainly generated from clouds, water, and snow, and values near zero are mainly generated from rock and bare soil. Very low values (0.1 and below) of NDVI correspond to barren areas of rock, sand, or snow. Moderate values (0.2 to 0.3) represent shrub and grassland, while high values (0.6 to 0.8) indicate temperate and tropical rainforests.

3.8.5 Land Use/ Land Cover Classification

The term "land cover" describes the plants, buildings, water, bare soil, and other surface coverings on the ground (earth). The land cover of a certain study region is observed and identified during several epochs to establish the acquired data for operations like thematic mapping and change detection analyses. Land use refers to the use of land for recreational, wildlife habitat, agriculture, urbanization, or construction purposes.

When the terms "Land Use" and "Land Cover" are used together, the phrase "Land Use Land Cover" (LULC) refers to the categorization or classification of human activities and natural elements on the landscape within a specific time frame based on the techniques and approaches of analysis of appropriate source materials. An examination of land use and cover that is performed more than once yields a single, good record of the changes that have occurred throughout the course of the year up to the present.

The shapefile of study area was imported as assets into google earth engine to define the boundary of the study area. The images were pre-processed due to cloud effect and noise that effects on the imagery.

The Image collections of the different years needed was instantiated using the google earth engine JavaScript API and the data were filter by date and percentage cloud cover of less than 5%. The satellite imagery was classify using the Supervised classification method, training samples were picked using the polygon tool to select pixels of the images that fits the classes define. The classes include Developed area, Bare Lands, Water Body and Vegetation.

The polygons represent the training dataset, the training dataset is a feature with a property storing the class label and properties storing predictor variables. Random forest and Cart Algorithm were used to classify the imagery base on the training set, the result of the two-

classification algorithm was compared and the Random Forest has the highest accuracy. The output of the classification was exported to the google drive as a TIF file format. All the data were imported into ArcMap for better for final processing and visualization. No data value are removed using ArcMap reclassify tool, the class name properties were used to symbolized the maps. All these processes were carried out for each year analysis.

3.8.6 Heatmap

Heat map symbology displays the relative density of points as a dynamic raster visualization using a color scheme to indicate density values. Ideally, the color scheme is a smoothly varying set of colors, ranging from cool (sparse density of points) to hot (high density of points). Select a point feature layer in the Contents pane. Under Feature Layer, on the Appearance tab, in the Drawing group, click the Symbology drop-down arrow and click Heat Map.

3.8.7 Point to Value

This tool is designed to retrieve values (primarily from the tool or another stack/collection of Gaussian Geostatistical Simulations raster's) at specified point locations or within specified raster cell (Slope, Elevation, NDVI). Retrieval is of all the simulated values, not summary statistics, as the current implementation of Gaussian Geostatistical Simulations already has this capability as one of its postprocessing options.

The sample tool can extract values at point locations; however, each record in the output table contains the raster values (Slope, Elevation, NDVI) for each point location which is used for statistics.

3.9 Weighted Overlay Analysis

Overlay analysis is a group of methodologies applied in optimal site selection or Vulnerability modeling. It is a technique for applying a common scale of values to diverse and dissimilar inputs to create an integrated analysis. Vulnerability models identify the best or most preferred locations for a specific phenomenon.

Overlay analysis often requires the analysis of many different factors. the factors in your analysis may not be equally important.

3.9.1 Weighted Table

The table was created on excel with input of the factors considered for the pollutant migration such as topography (Elevation, Slope), hydrology (Flow Accumulation, Flow direction), Ecology (Land Use, NDVI), Distance (Point of Discharge to mercury, distance to community), Mercury value. The input factors value was ranked on scale of (1-5) which represent range of vulnerability, the factors were also weighed based on their percentage of importance in the pollutant migration to sum up 100%.

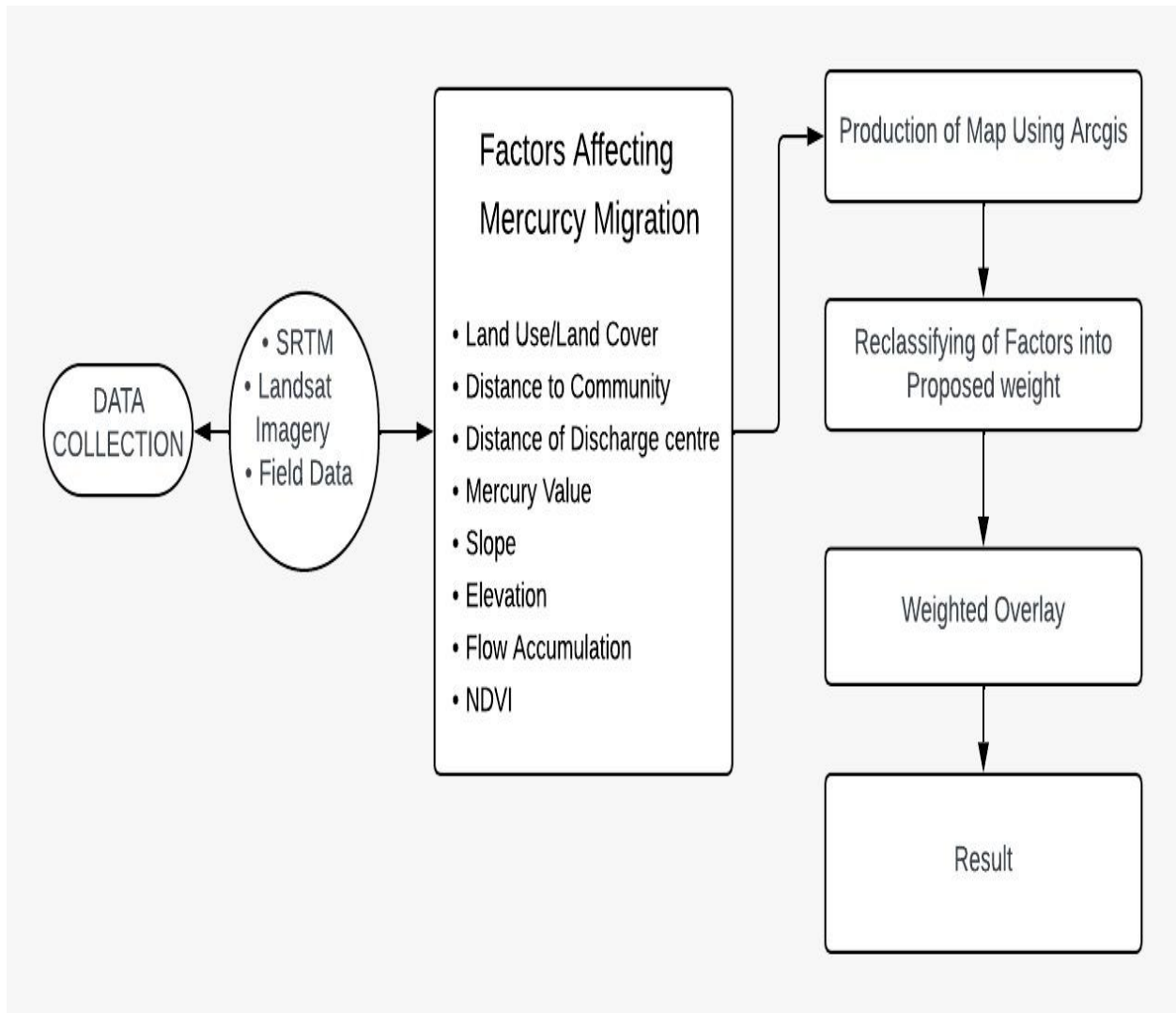


Fig 3.3 Schematic diagram of Overlay Method Procedure

Source: Author's Field Work , 2023

3.9.2 Weighted Overlay Procedure

Based on the ranked scale in weighted table, the input layer values are reclassified using the reclassify raster tool into scale of 1 – 5. The reclassified layers with their weighted percentage are input into the weighted overlay tool to produce the Vulnerability layer.

Overlay analysis is commonly used for optimal site selection or Vulnerability modeling. It is a method involving integration of datasets using a common scale of values to diverse and dissimilar inputs. The datasets are ranked by certain factors and subjected to GIS processing for various outputs. Vulnerability models identify the best or most preferred locations for a specific phenomenon.

The details of steps are elaborated below;

- ❖ Integration of datasets using the weighted overlay method in ARGIS (Elevation, Slope, Flow Accumulation, Flow direction, NDVI, Land Use land cover, Distance to community, Distance to discharge, Mercury value)
- ❖ The value of each factor was grouped into 5 classes and ranked based on the vulnerability of the values.
- ❖ The factors were assigned weight which must sum up to 100% based on their hierarchy in contributing to the contamination and migration.
- ❖ The layer of each factor was reclassified on ArcGIS based on the ranked values assigned. The result of the weighted overlay table gives the risk map of value 1 – 5 in which the values represent their vulnerability.
- ❖ The reclassified layer for each factor was inputted into the weighted overlay tool in ArcGIS toolbox alongside with the weight assigned to each of the factors.

Table 3.5 Ranking Parameters

Feature	Value	Description	Rank	Subdivison
Elevation	256 - 291m	Lowland	1	Very high Vulnerability
	292 – 314	Moderately Low	2	High Vulnerability
	315 – 338	Moderate	3	Moderate Vulnerability
	339 – 368	Moderately High	4	Low Vulnerability
	369 – 443	Highland	5	Very low vulnerability

Source: **Author's Field Work, 2023)**

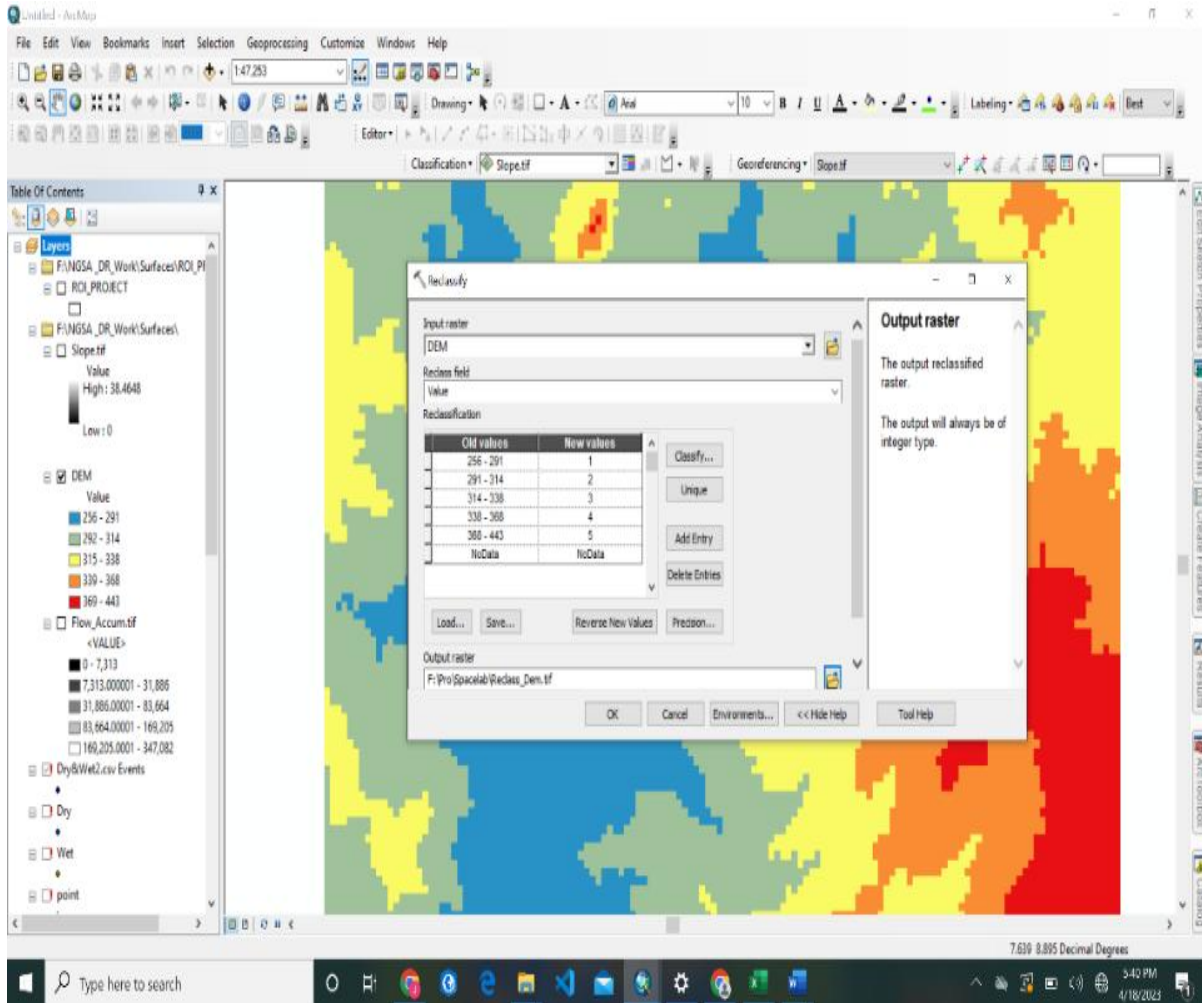


Figure 3.4: Reclassification of Layers in ArcGIS
 Source: Author's Field Work, 2023

Figure 3.5: Weighted Overlay Process in ArcGIS
 Source: Author's Field Work, 2023

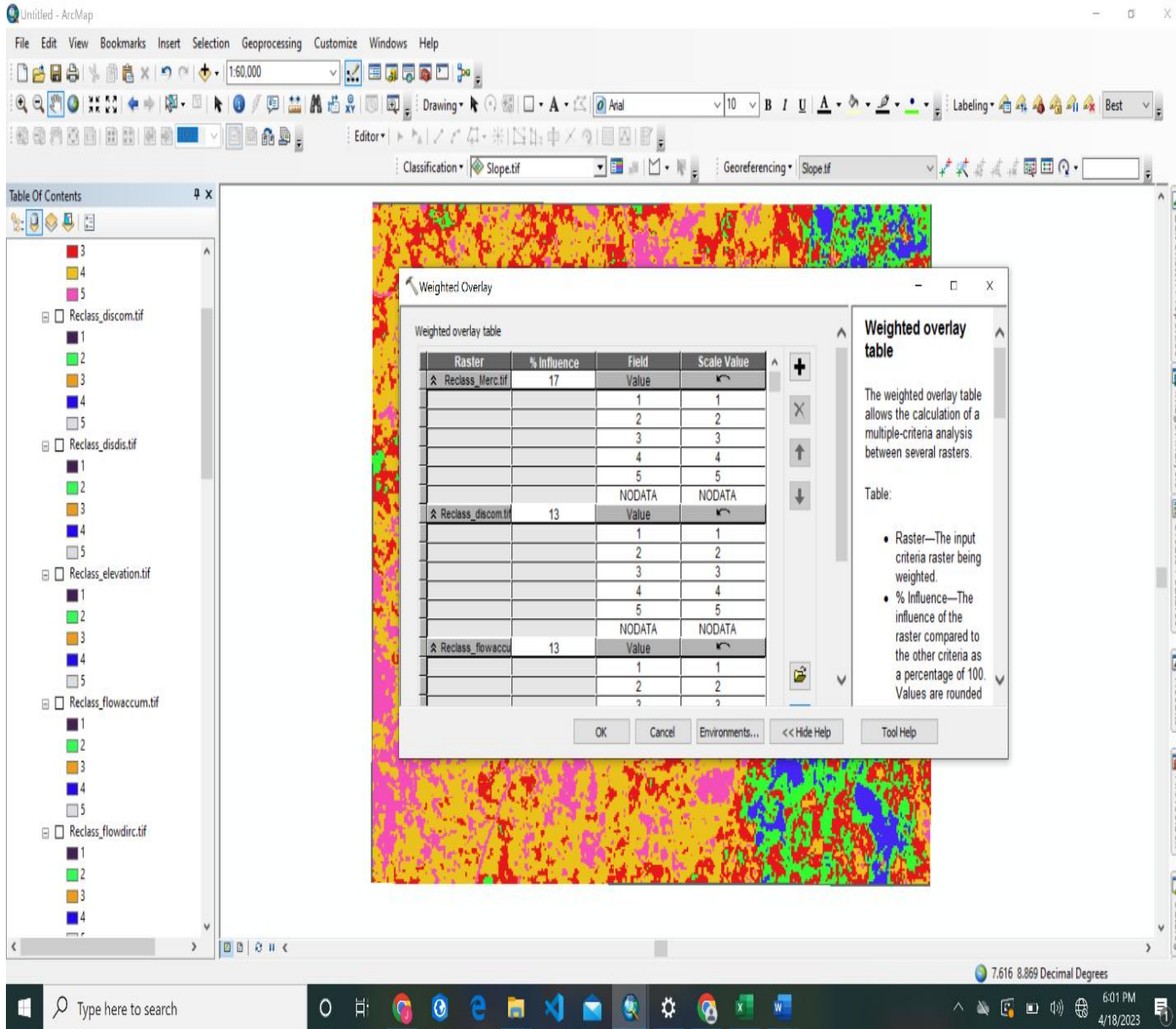


Table 3.6: The Ranking Scale

Rank	Subdivison
1	Very high Vulnerability
2	High Vulnerability
3	Moderate Vulnerability
4	Low Vulnerability
5	Very low vulnerability

Source: Author's Field Work, 2023

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Chapter Four

Results, and Discussion of Findings

4.1 Results of Findings

This chapter enumerates the results derived from the methods employed in the assessment of the mercury in the environment and attempt to benchmark these outputs with conventional standards especially with reference to their impact on human health perspectives. The results were x-rayed along the objectives earlier stated in this work and compared with other similar global researches to ensure best practices; thus presentation of the result is shown below.

4.1.1 Mercury Bioaccumulation in the Ecomedia

The bioaccumulation of mercury in soil, plants, water, fish assessed through analytical methods within the study area are presented in line with the study objectives;

Study Objective 1: To evaluate Mercury Concentration in Soils, Plants, Fish, Surface and groundwater from Uke

One of the associated environmental risks emanating from the uncontrolled discharged of mercury during artisanal and small-scale operations in Uke is the possible contamination of the Aquatic ecosystem especially River Uke where the waste from gold processing is discharged. This waste contains high level of mercury which pose a threat to the environment including the fish and other aquatic organisms present in the river. In several studies on mercury contamination in fish, the elemental mercury easily methylated to organic mercury through a bacterium into methylmercury and biomagnifies at different levels of the food chain with fish as the primary target^{16,20,21,31,32,33,39}. Fish is the major source of protein to the uke communities and

the consumption of mercury contaminated fish will constitute a health risk to the community. Results from the present study revealed that the mercury concentration are within the W.H.O maximum permissible threshold of 0.5 mg/l for humans. A critical examination of the result of bioaccumulation of mercury in the tissues of both species, identified the gill as the tissue with the highest mercury concentration. Results from Uke confirmed the mean concentration for gills to be 0.01774 mg/l with the maximum concentration found in the catfish being 0.047 and the minimum in the tilapia fish 0.0024, as shown in Table 4.1 and Fig 4.1. This mean concentrations of mercury in the gills, intestine, bone, liver and flesh were in the ranges, of 0.01774, 0.00747, 0.00206 , 0.01182 , 0.0071, respectively, with an overall mean of 0.009248 compared to that of the surrounding water of river Uke 0.0092429. Moreover, the simple explanation for the high mercury value in the gills could be as a result of the fact that the gill is the organ that filters the mercury directly from the contaminated water in the river and act as an interface. Gills are pathway for metal/ion exchange from water, because gills have very wide surface area that fastens diffusion of metals rapidly ^{31, 54}. Hence, it is suggested that metals bioaccumulated in gills are basically concentrated from water. This is in agreement with the results of other authors^{75,76,78,82}. In other studies carried out, the biomagnification of mercury through trophic levels revealed that mercury concentration were higher in the muscles or flesh but factors such feeding habits, specie, age, weight could be a determinant in the uptake of mercury by the different tissues in the transfer and biomagnification of mercury^{2,20,36,37,71}. In the study area, mercury gradation in the tissues and organs of fish are as follows Gill>Liver>intestine>Muscle>Bone. In a similar study, carried out in the Manyera river in Niger state, Nigeria, where gold activities is also ongoing, the mean concentration of mercury was 0.008, which is near to the 0.009248 derived in this study¹².

Several similar research works in other countries have demonstrated a correlation between gold mining activities, environmental contamination of Hg, and the human exposure through consumption of local fish, e.g., Ghana¹⁰⁰, Peru⁷⁶, Brazil³³ and Malaysia³². Subsequently, this does not merely deserve attention in the Amazon as evaluated in the present study, but also in other areas with (historical) gold mining activities.

Variations in metal concentrations were recorded in the internal organs of the studied fish species. Metal accumulations were higher in the liver followed by gills and flesh. Health risk analysis of heavy metals in the edible parts of the fish indicated safe levels for human consumption and concentration in the flesh are generally accepted by the international legislation limit for essential metals.

In conclusion though the mercury accumulation in the various tissues differs, the health risk assessment of the fish from the river could be safe in the interim but continuous discharge of mercury into river Uke can lead to increase in biomagnification and bioaccumulation and thus pose as a threat to the immediate communities.

Table 4.1: Mercury Concentration in Different Organs of Fish from River Uke

Components	Gill	Intestine	Bone	Liver	Flesh	
Catfish 1	0.0041	0.0033	0.0011	0.034	0.025	
Catfish 2	0.0039	0.0022	0.0012	0.0027	0.0019	
Catfish 3	0.021	0.0018	0.0008	0.0017	0.0012	
Catfish 4	0.047	0.011	0.01	0.024	0.005	
Catfish 5	0.032	0.015	0.002	0.017	0.03	
Catfish 6	0.026	0.012	0.002	0.014	0.003	
Tilapia 1	0.035	0.023	0.001	0.0024	0.0015	
Tilapia 2	0.0024	0.0019	0.0012	0.017	0.0013	
Tilapia 3	0.0031	0.0022	0.0002	0.0027	0.0013	
Tilapia 4	0.0029	0.0023	0.0011	0.0027	0.0013	Total Average
Minimum	0.0024	0.0018	0.0002	0.0017	0.0012	0.0002
Maximum	0.047	0.023	0.01	0.034	0.03	0.047
Average	0.01774	0.00747	0.00206	0.01182	0.00715	0.009248
Median	0.01255	0.0028	0.00115	0.00835	0.0017	0.00531
Std. Dev.	0.016612325	0.007406	0.002839	0.011252	0.010853	0.009792563

Source: Author's Field Work, 2023

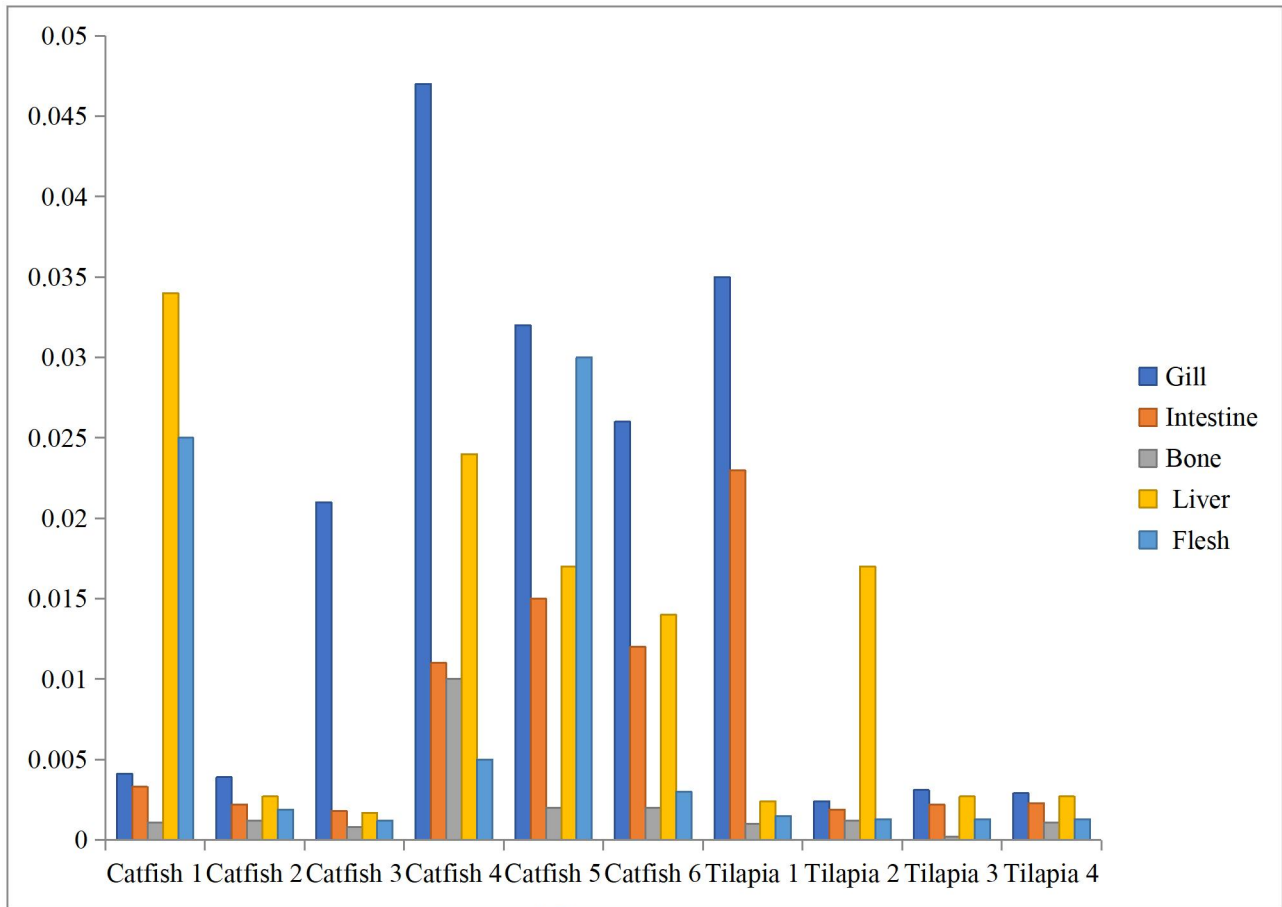


Figure 4.1: Mercury Concentration in Fish Organs

Source: Author's Fieldwork, 2023

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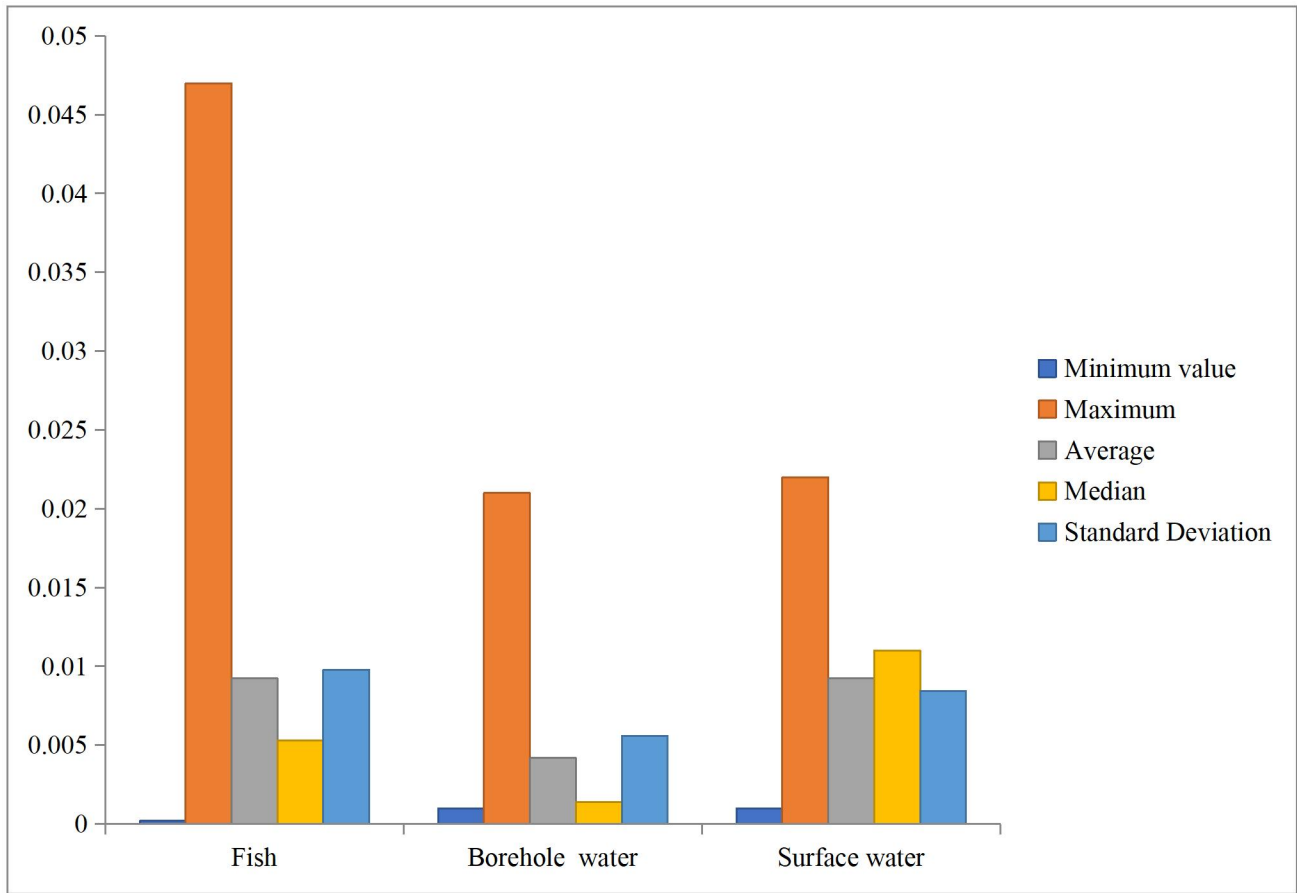


Figure 4.2: Combination of Mercury Concentration in Fish, Groundwater and Surface Water

Source: Author's Fieldwork, 2023

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4.2 Mercury Values in Soil, Sediments and Mine Waste (Tailings) within the Uke and its Environs

The soil is one of the environmental media that is under threat during mercury pollution. It is usually reported as a sink for heavy metals during pollutant migration. The results are contained in Table 4.1 while Fig 4.3 and 4.4 showed the graph for the two seasons. In the dry season samples, recorded very low mercury concentrations with sample AT20 has a conspicuously high contamination of mercury (0.046 kg/mg) in contrast to the low values observed in other samples. A sharp demarcation as observed in the wet season which has a mercury value range of 0.0013-0.031kg/mg with average mean of 0.0172 kg/mg with standard deviation value of 0.0097 mg/kg. Most of the results derived in both seasons are above the crustal abundance average threshold limits of 0.003 mg/kg and the USEPA residential Soil screening level of 0.0023 mg/l. In particular, the maximum mercury concentration in dry season and majority of the samples in the wet season are above the threshold WHO limit of 0.05kg.it is important to stress that soil is a critical resource in food supply. The seasonal variation in the bioaccumulation of soil in the area, especially the low mercury content in the dry season could be as a result of low gold processing activities while the high content in the wet season could be accentuated by the runoff and the porosity of the soil in the area. This result was compared with similar studies but locally and globally and are within considerable limits^{14,30,44,46,65,79,45}.

4.2.1 Mining Waste (Tailings):

In an effort to identify the risk due to human exposure to mine waste, 20 samples of mine waste or tailings were analyzed for mercury content. The results are contained in Table 4.3 and Figures 4.5,4.6 . The statistical variation also shows a minimum value of 0.011mg/kg to a maximum of

0.314 mg/kg in the dry season while 0.003mg/kg to 0.142mg/kg in the wet season and a mean value of 0.0871mg/kg to 0.0625mg/kg in the dry season (Table 4.3).

The tailings samples collected from within the research area are contaminated with high mercury from 0.11 to 0.142mg/kg (Figure 4.5) above the WHO limit in the dry season sampling. The wet season results equally showed high mercury content from 0.12mg/kg up to 0.30mg/kg (Figure 4.6). This has a dangerous implication to human health in the study area.

4.2.2 Sediments

Mercury content in the sediments are derived from eroded soil into the river which contains mercury particulate and mercury discharged directly from the artisanal miners into the uke river. The mercury accumulates in the river sediments and ultimately affects the aquatic ecosystem especially plants, fish and animals. In this study three (3) stream sediments samples were collected to reflect the midstream which is the point source, the downstream and upstream. The results of the mercury concentration are contained in (Figure 4.7 and Table 4.5). The mercury value 0.018 is the highest value and represent the point of discharge of mercury into the uke river during gold processing. It is worthy to note that mercury concentration in the river sediments is a pointer to the exposure of communities and especially those that consume fish. The aquatic ecosystem health is usually dictated by the mercury value in the sediments because it serves as a sink for mercury. The values for the three sites indicates that the mercury value increases upstream. The results obtained is similar to the value of sediments in the Manyera river in Niger State while the mercury value is lower than other locations with similar researches^{12,35,50,72},

Table 4:1 Statistical Variation of Mercury in the Soils for Wet and Dry Seasons

	Soils (mg/kg)	
	Wet season	Dry season
	0.012	0.02
	0.022	0.01
	0.014	0.002
	0.0013	0.004
	0.031	0.003
	0.03	0.017
	0.021	0.032
	0.012	0.012
	0.023	0.002
	0.025	0.02
	0.0023	0.003
	0.013	0.427
Minimum	0.0013	0.002
maximum	0.031	0.427
Average	0.017216667	0.046
Median	0.0175	0.011
STDEV	0.009737541	0.120354023

Source: Author's Field Work, 2023

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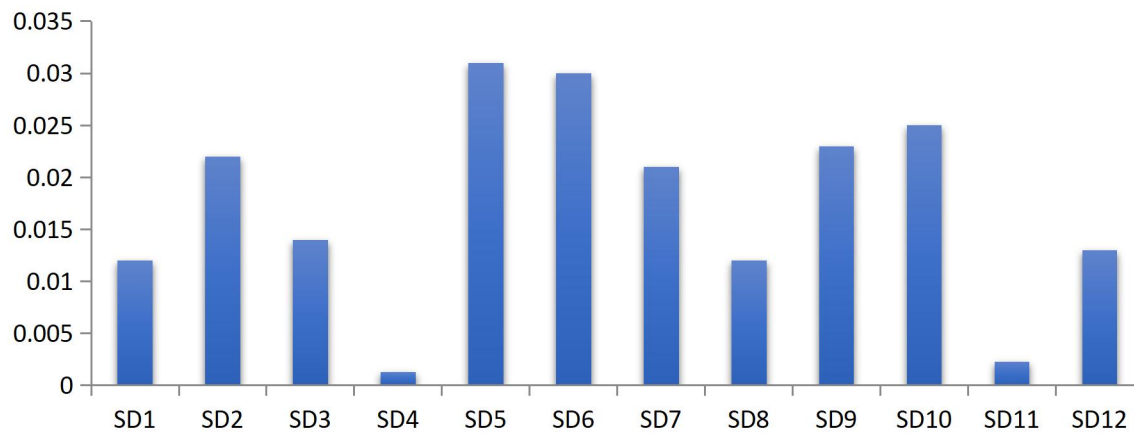


Figure 4.3: Bar Chart of Mercury Concentration in Soil-Wet Season

Source: Author's Field Work, 2023

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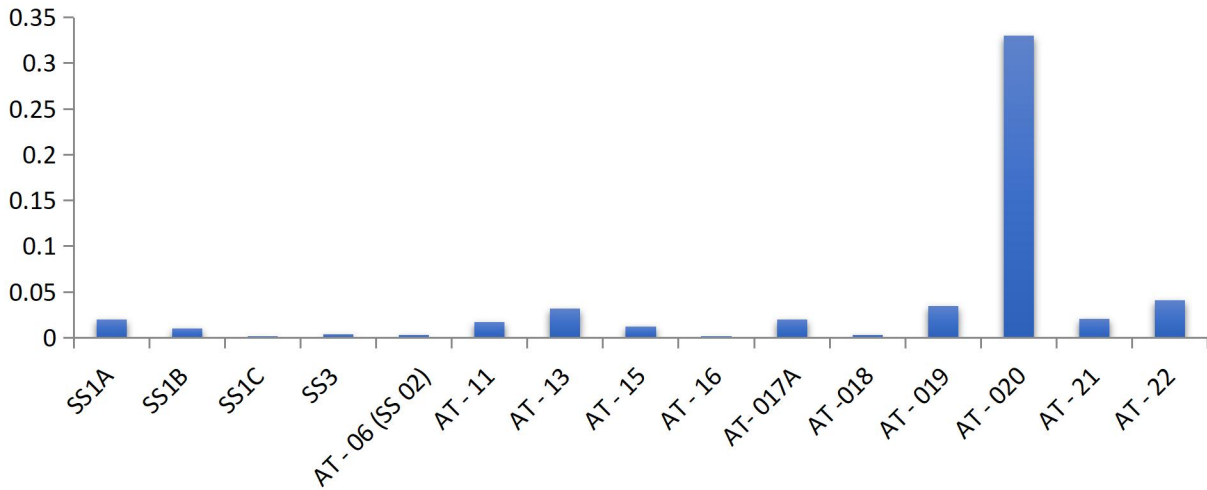


Figure 4.4: Mercury Values in Soil during Dry Season

Source: Author's Field Work, 2023

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Table 4.3: Mercury Concentration in Tailings all Season

	Tailings (mg/kg)	
	Wet season	Dry season
	0.034	0.142
	0.024	0.132
	0.314	0.14
	0.114	0.11
	0.014	0.004
	0.015	0.003
	0.111	0.004
	0.12	0.031
	0.114	0.027
	0.011	0.032
Minimum	0.011	0.003
Maximum	0.314	0.142
Average	0.0871	0.0625
Median	0.0725	0.0315

Source: Author's Field Work, 2023

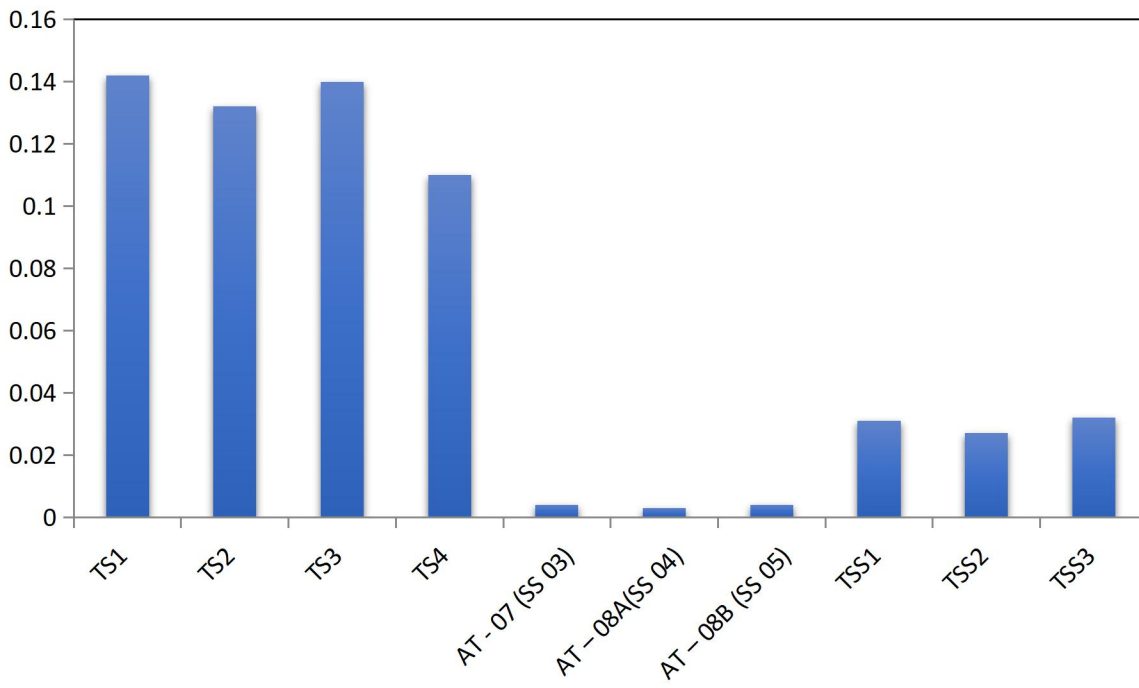


Fig 4.5: Mercury Values in Tailings during Dry Season

Source: Author's Field Work, 2023

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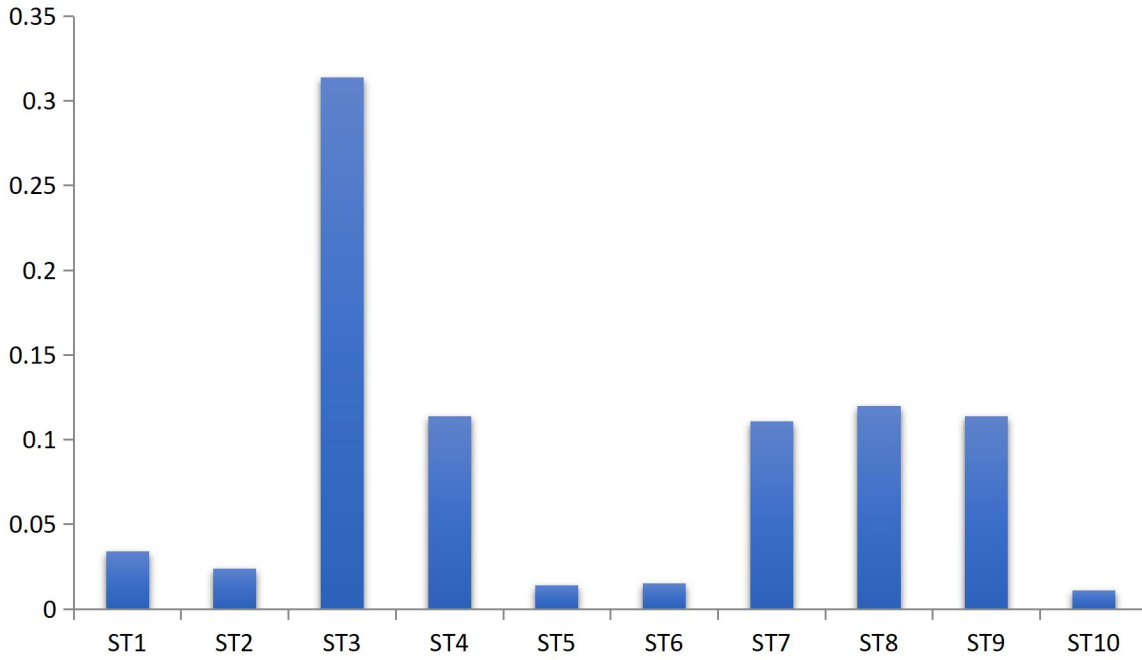


Figure 4.6: Determined Mercury Contamination in the Tailings for Wet Season

Source: Author's Field Work, 2023

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Table 4.4: Determined Mercury Level in River Sediment

River Sediment	
Sample ID	Determine Mercury level (mg/kg)
RD1	0.012
RD2	0.018
RD3	0.014

Source: Author's Field Work, 2023

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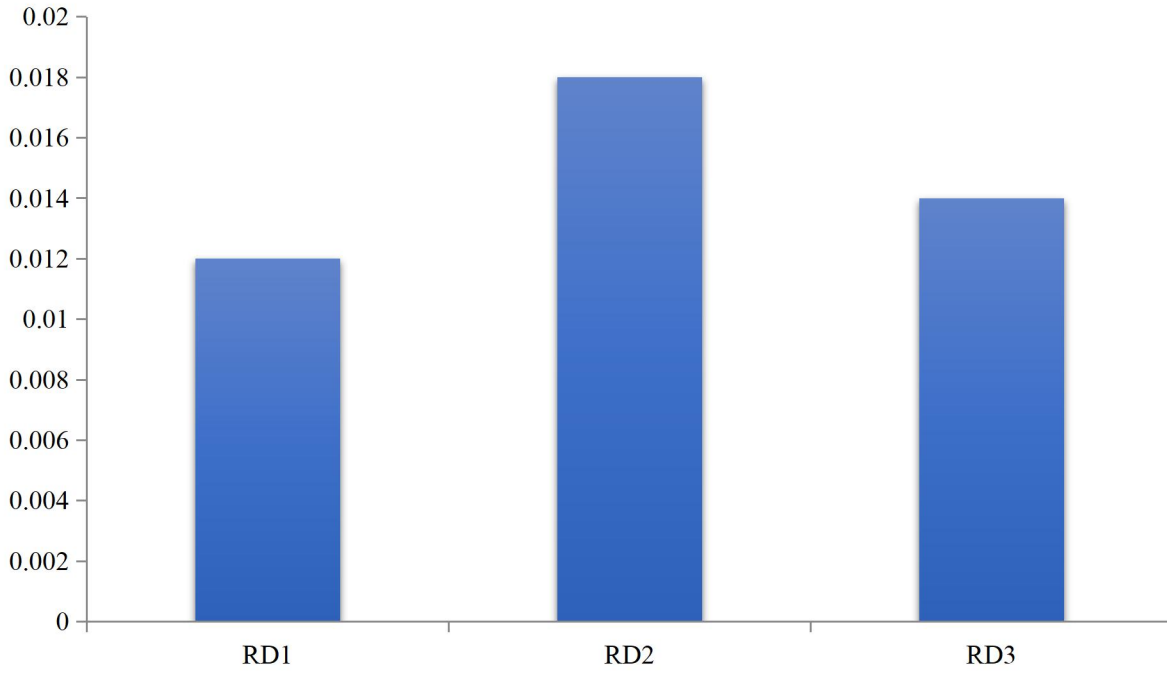


Figure 4.7: Mercury Values in River Sediments in mg/kg

Source: Author's Field Work, 2023

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4.2.3 Mercury Values in Plants

The uke community is agrarian as such most members of the community engage in farming. In line with this fact, this study critically examined the effect of mercury discharge from ASM operation of gold processing especially along the banks of the Uke river to adjacent farmlands. Mercury bioaccumulation in plants may come as a result of uptake through the soil or mercury particulate from atmospheric mercury. Moreover, the result from analysis of surface water from the Uke river showed mercury concentration above the WHO limits of 0.002 mg/kg. This work collected plants samples from farmlands within a radius of 1km to the river bank and investigated mercury absorption and health risk assessment to the community. The absorption of mercury by plants in the study area are contained in Table 4.5. The results of twenty-four (24) different varieties of plant for all seasons (dry and wet) were presented. The edible plants examined includes: Groundnut and Ugwu leaf. Both have concentration of mercury of 0.0057ppm for the dry season (Figure 4.8). Cassava a root tuber is 0.01ppm, waterleaf 0.012ppm and 0.011ppm for pepper, 0.02mg/kg for rice and spinach, while garden egg has 0.011mg/kg. Other such as scent leaf, bitter leaf potatoes and watermelon has least mercury contamination in 0.002mg/kg, 0.002 mg/kg, 0.001mg/kg and 0.0015mg/kg. The edible plants samples analyzed in the wet season includes, Guava, cassava, bitter leaf, jatrop, amaranth, corn and sweet potatoes. These all have a high threshold of mercury contamination (Figure 4.8 and 4.9). The differences in the mercury concentration are depicted as seen from the statistical distribution (Table 4.5), from minimum value of 0.0012mg/kg to maximum value of 0.1044 mg/kg for the wet season and 0.001 to 0.02 kg/mg for the dry season, whereas the mean value of 0.0177 mg/kg in the wet season to 0.0075mg/kg in the dry season. The Uke River provides all season water source for farming during the dry season and thus since it has been established in this work that mercury

contamination is evident within the river, using the water from the river for irrigation would contaminate the plants. This is buttressed by the high mercury value in the rice, pepper and sweet potatoes. Consequently, variety of the plants have mercury contamination high above the expected WHO standards which is 0.03mg/kg. This result is in consonance with the work of several authors, some of who confirmed some of the crops such as beans, groundnut and corn as bio accumulators, an indication that mercury will be bioavailable can easily be absorbed by these plants and transferred to humans through the food chain via consumption. This could pose a health risk to such communities^{14,24,20,59,60,68,90}.

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Table 4.5: Mercury Concentration (mg/kg) in the Plants

	Plants (mg/kg)	
	Wet season	Dry season
	0.1044	0.009
	0.014	0.01
	0.015	0.012
	0.026	0.011
	0.0024	0.002
	0.0012	0.002
	0.022	0.002
	0.003	0.02
	0.0022	0.001
	0.019	0.002
	0.0022	0.01
	0.0015	0.01
Minimum	0.0012	0.001
Maximum	0.1044	0.02
Average	0.017741667	0.00758333
Median	0.0085	0.0095
STD	0.028750161	0.0058225

Source: Author's Field Work, 2023

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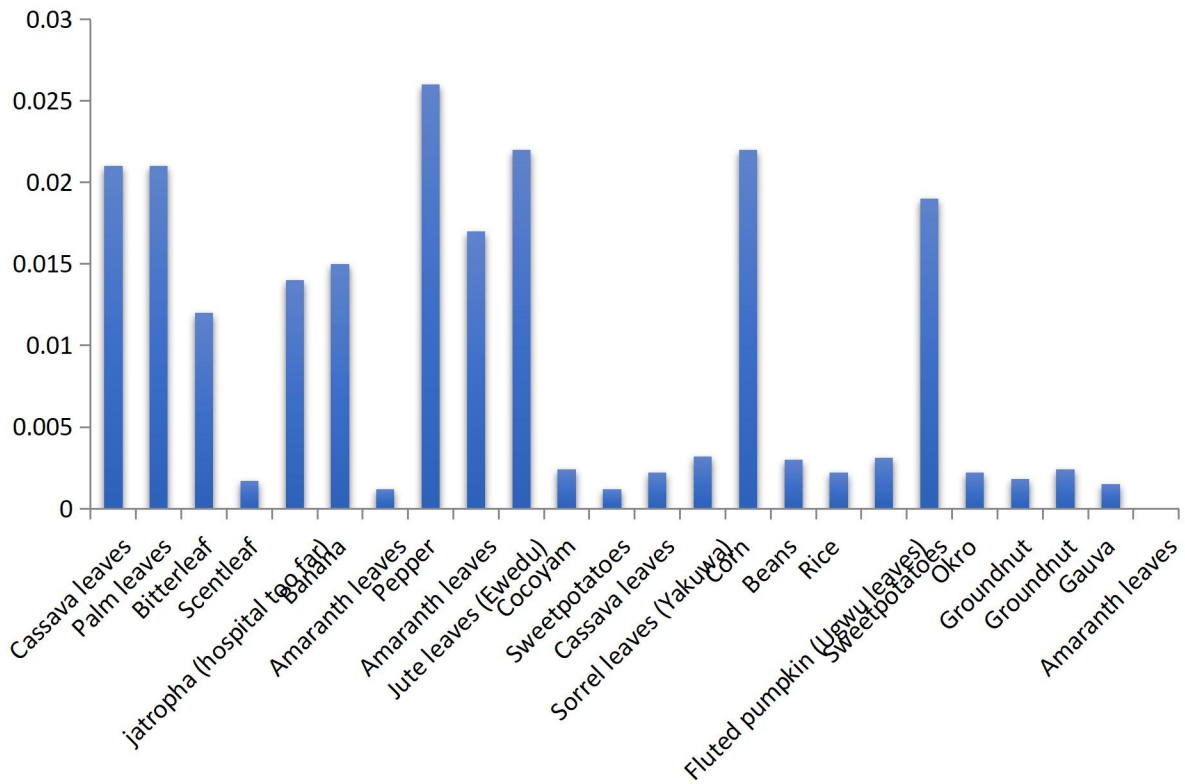


Figure 4.8: Determined Mercury Values in Plants for all Season in Uke and its Environs

Source: Author's Field Work, 2023

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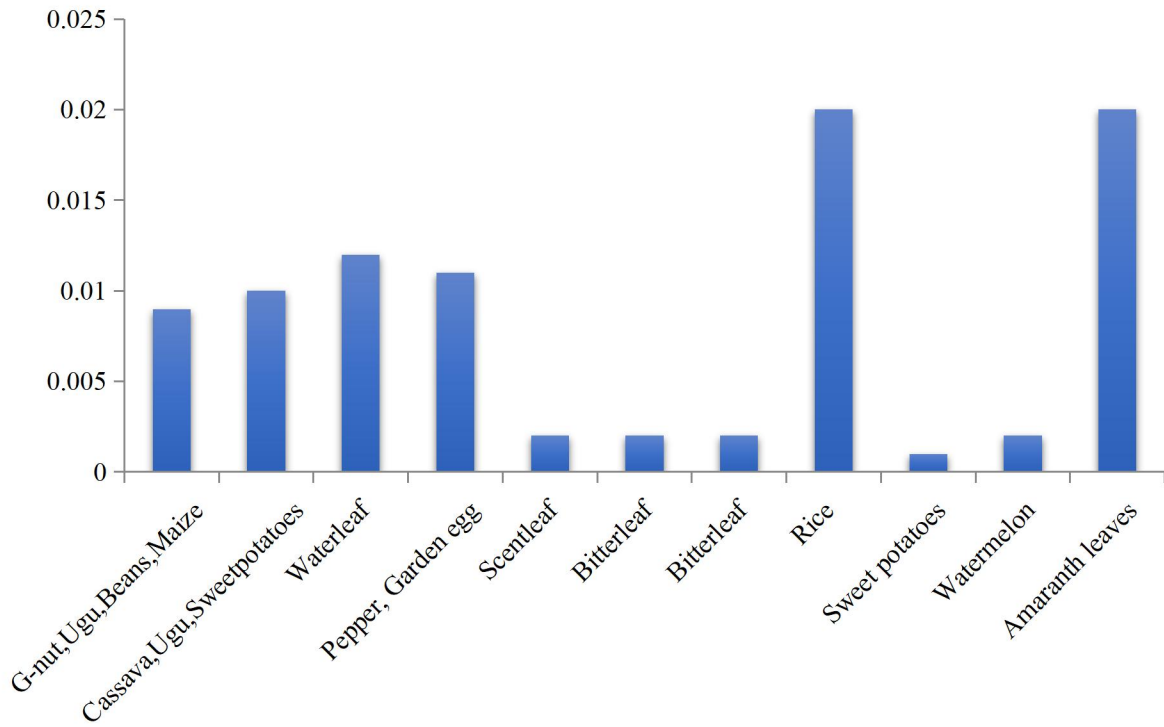


Figure 4.9: Mercury Values in Plants in Dry Season

Source: Author's Field Work, 2023

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4.2.4 Mercury Values in Surface Water (River Uke) and Groundwater

The results revealed that during the dry season, samples 1, 2, 7,8,9,10,13,14,15,16 of the total 19 samples has high mercury concentration, mostly as surface water collected from river Uke (Table 4.6 and Fig 4.3). Most of the results from Ground water (Boreholes and wells) such are within acceptable threshold limits. The results of the surface water(river) also show concentration above the WHO limits with mercury concentration of 0.021ppm, 0.017ppm, 0.021ppm, 0.022ppm, 0.012ppm, 0.012ppm, 0.012ppm and 0.014ppm (Figure10 - 14).

This study was compared to other similar results and the results is moderate.^{17,37,52,66,82,85,86}

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Table 4:6 Statistical Parameter for the SurfaceWater and Groundwater

Surface Water	Hg(mg/kg)	Borehole Water	HG(mg/kg)
WS1	0.001	WB1	0.0021
WS2	0.0011	WB2	0.002
WS3	0.0011	WB3	0.0011
WS4	0.0013	WB4	0.0013
WS5	0.0012	WB5	0.0011
WS6	0.0011	WB6	0.012
WS7	0.0013	WB7	0.021
WS8	0.001	WB8	0.0012
WS9	0.021	WB9	0.0021
WS10	0.001	WB10	0.0014
WS11	0.011	Borehole Water	0.001
MS1A	0.021	AT – 03	0.001
DS 01A	0.022	AT – 04	0.0012
DS2	0.021	AD- 05	0.0041
DS3	0.017	AT – 10	0.012
DS4	0.019	AT – 23	0.011
MSB1	0.002	BH1	0.001
UPSB3	0.014	BH2	0.002
UPSB1	0.012	BH3	0.001
UPSB2	0.012	Minimum	0.001
UP1	0.012	Maximum	0.021
Minimum	0.001	Average	0.0041895
Maximum	0.022	Median	0.0014
Average	0.0092429	Standard Deviation	0.0055931
Median	0.011		
Standard deviation	0.0084481		

Source: Author's Field Work, 2023

Study Objective 3: To Carry out the Risk and Exposure Assessment of the Uke Community

The risk assessment of mercury contamination was examined in this study amongst the miners and community by studying the mercury characteristics in the environment and evaluating their potential threat. In the previous section, the mercury values in the various eco-media were compared to global standards. This in turn facilitate the derivation of the exposure assessments through responses from questionnaires and the use of exposure assessment tools such as geoaccumulation index and Contamination factor. Uke is highly vulnerable to this mercury ecosystem threat because highly densely populated settlements in such areas as Angwan Tofa, and Tundun wada respectively (Figure 4.10). The veritable results from this work have confirmed that the tailings are the major source of contamination^{7,17,38,87}. This poses a major health alert because of, the rate of tailing re-usability in building and construction. Most of the innocent community members used this soil tailings to plaster their huts and hence become very exposed to high indoor mercury. Consequently the exposure assessment in this study was calculated for soil and tailing using the hazard index and quotients^{15,17,66}.

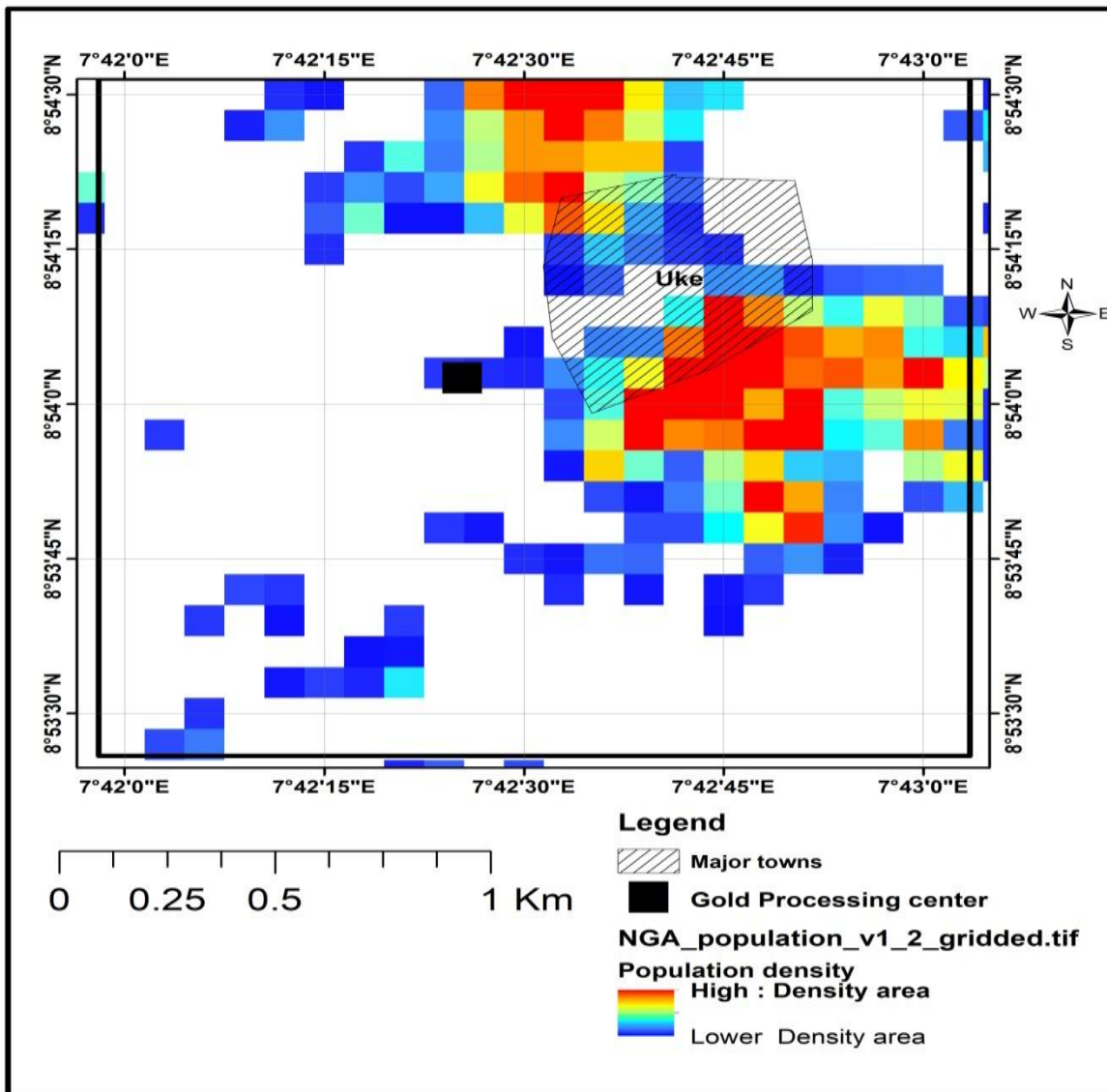


Figure 4.10: Exposure Assessment at Risk Population Map

Source: Author's Field Work, 2023

4.3 Human and Health Risk Assessment

Objective: To Identify and Characterize any Associated Human Health Risk Assessment

This objective was achieved in this research as stated below:

4.3.1 Human and Health Risk Assessment of Uke

The assessment of the health and risk exposure are in most case derived through various methods as stipulated in many studies in this particular context the contamination factor and geoaccumulation index have been applied to carry out these tasks^{51, 52, 60, 64, 70, 71, 73}.

Degree of Contamination (otherwise contamination factor) was evaluated for the soils using the formula is:

$$CF = C_m/C_b [1]$$

Geoaccumulation index was adopted to evaluate the harmful potential of the metal mercury in accordance with the work of Qingjie⁶⁸

4.3.2 Health Risk Assessment of Uke Soils

The exposure assessment of the community to the soil in uke was carried using pollution indices such as Geoaccumulation index (I-geo) and Contamination factor. The results are expressed in Table 4.7

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Table 4.7: Soil Wet Season Result CF and I-geo

ID	Hg level	CF	I-geo	
SD1		0.012	0.15	-3.3219
SD2		0.022	0.275	-2.4475
SD3		0.014	0.175	-3.0995
SD4		0.0013	0.01625	-6.5284
SD5		0.031	0.3875	-1.9527
SD6		0.030	0.375	-2
SD7		0.021	0.2625	-2.5146
SD8		0.012	0.15	-3.3219
SD9		0.023	0.2875	-2.3833
SD10		0.025	0.3125	-2.263
SD11		0.0023	0.02875	-5.7053
SD12		0.013	0.1625	-3.2065
	Min		0.01625	-6.5284
	Max		0.3875	-1.9527
	Average		0.2152083	-3.2287

Source: Author's Field Work, 2023

Table 4.8: Soil Dry Season result CF and I-geo

ID	Hg level	CF	I-geo	
SS1A	0.02	0.25	-2.585	
SS1B	0.01	0.125	-3.585	
SS1C	0.002	0.025	-5.9069	
SS3	0.004	0.05	-4.9069	
AT - 06 (SS 02)	0.003	0.0375	-5.3219	
AT – 11	0.017	0.2125	-2.8194	
AT – 13	0.032	0.4	-1.9069	
AT – 15	0.012	0.15	-3.3219	
AT – 16	0.002	0.025	-5.9069	
AT- 017A	0.02	0.25	-2.585	
AT -018	0.003	0.0375	-5.3219	
AT – 019	0.035	0.4375	-1.7776	
AT – 020	0.33	4.125	1.45943	
AT – 21	0.021	0.2625	-2.5146	
AT – 22	0.041	0.5125	-1.5493	
	Min		0.025	-5.9069
	Max		4.125	1.45943
	Average		0.46	-3.2366

Source: Author's Field Work, 2023

4.3.3 Health Risk Assessment of the Tailings in Uke

The exposure assessment and vulnerability of the community to mercury contamination via tailings was carried out using standard pollution indices such as Contamination factor and geoaccumulation indexes. The results are contained in Tables 4.9 and 4.10.

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Table 4.9: Tailings Wet Season Result CF and I-geo

ID	Hg level	CF	I-geo
ST1	0.034	0.425	-1.81943
ST2	0.024	0.3	-2.32193
ST3	0.314	3.925	1.38773
ST4	0.114	1.425	-0.074
ST5	0.014	0.175	-3.09954
ST6	0.015	0.1875	-3
ST7	0.111	1.3875	-0.11247
ST8	0.120	1.5000	0
ST9	0.114	1.425	-0.074
ST10	0.011	0.1375	-3.44746
	Min	0.1375	-3.44746
	Max	3.925	1.38773
	Average	1.08875	-1.25611

Source: Author's Field Work, 2023

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Table 4.10: Tailings Dry Season Result CF and I-geo

ID	Hg level	CF	I-geo
TS1	0.142	1.775	0.242857
TS2	0.132	1.65	0.137504
TS3	0.14	1.75	0.222392
TS4	0.11	1.375	-0.12553
AT - 07 (SS 03)	0.004	0.05	-4.90689
AT – 08A(SS 04)	0.003	0.0375	-5.32193
AT – 08B (SS 05)	0.004	0.05	-4.90689
TSS1	0.031	0.3875	-1.95269
TSS2	0.027	0.3375	-2.152
TSS3	0.032	0.4	-1.90689
	Min	0.0375	-5.32193
	Max	1.775	0.242857
	Average	0.78125	-2.06701

Source: Author's Field Work, 2023

In the same vein, the Human health risk assessment of toxic elements on children and adults for Uke soils and tailings expressed through the Hazard quotients and Hazard index are contained in Table 4.11 and Fig 4.14 below.

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Table 4.11: Health Risk Assessment of Hg in the Study Area Calculated for Child and Adult

	ADDingnc	ADDinhnc	HQ-ING	HQ-INH
Adult				
Min	0.0023	2.291E-11	3.17E+10	2.67E-07
Max	0.025	5.464E-10	7.55E+11	6.38E-06
Average	0.015825	3.035E-10	4.19E+11	3.54E-06
Child				
Min	9926.4333	2.291E-12	33088111	2.67E-08
Max	236707.26	5.464E-11	7.89E+08	6.38E-07
Average	131461.61	2.878E-11	4.38E+08	3.36E-07

Source: Author's Field Work, 2023

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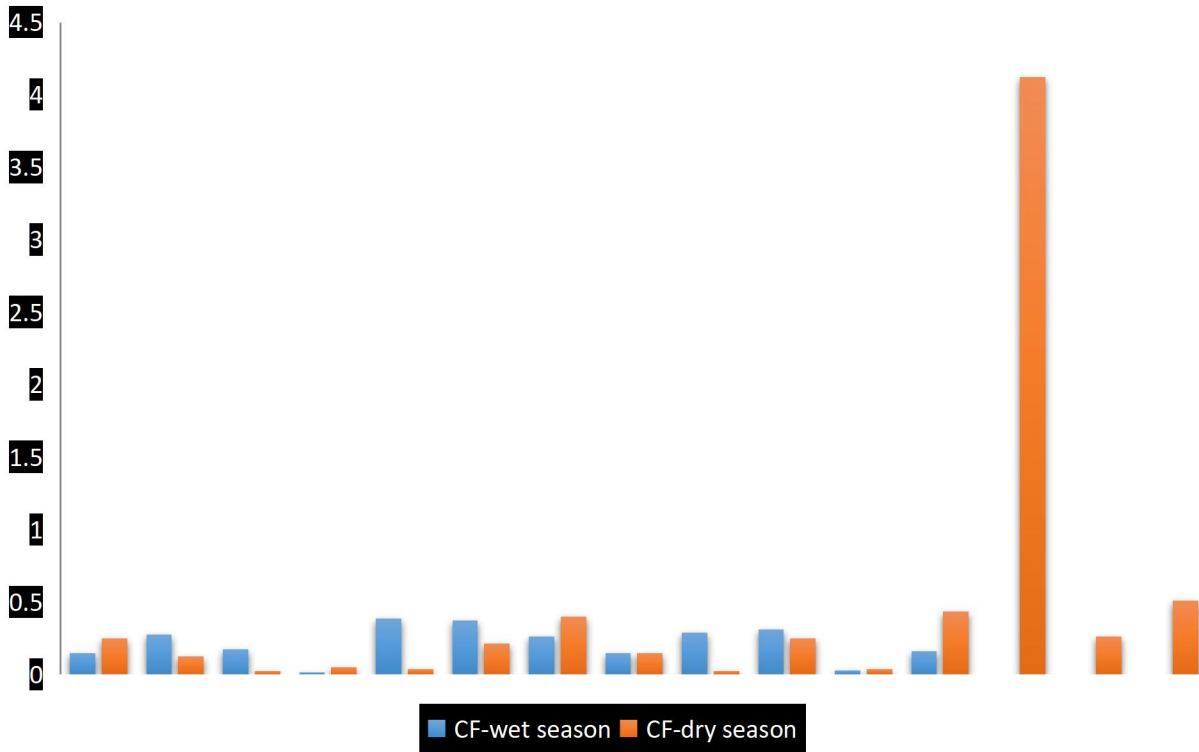


Figure 4.11: Contamination Factor for Soil

Source: Author's Field Work, 2023

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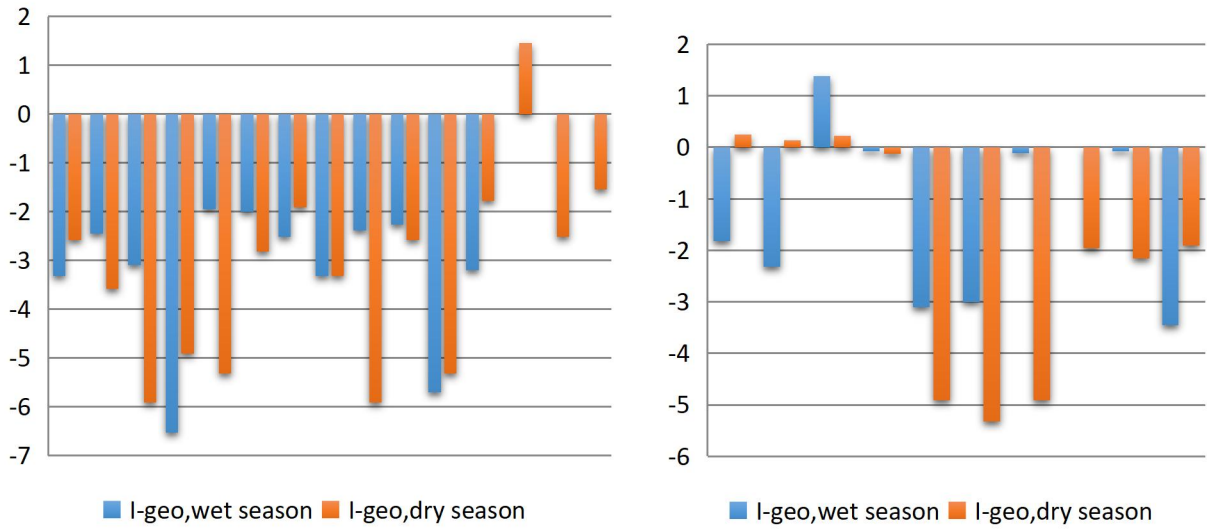


Figure 4.12: Geo-accumulation Index for Soil and Geo-accumulation Index for Tailings
Source: Author's Field Work, 2023

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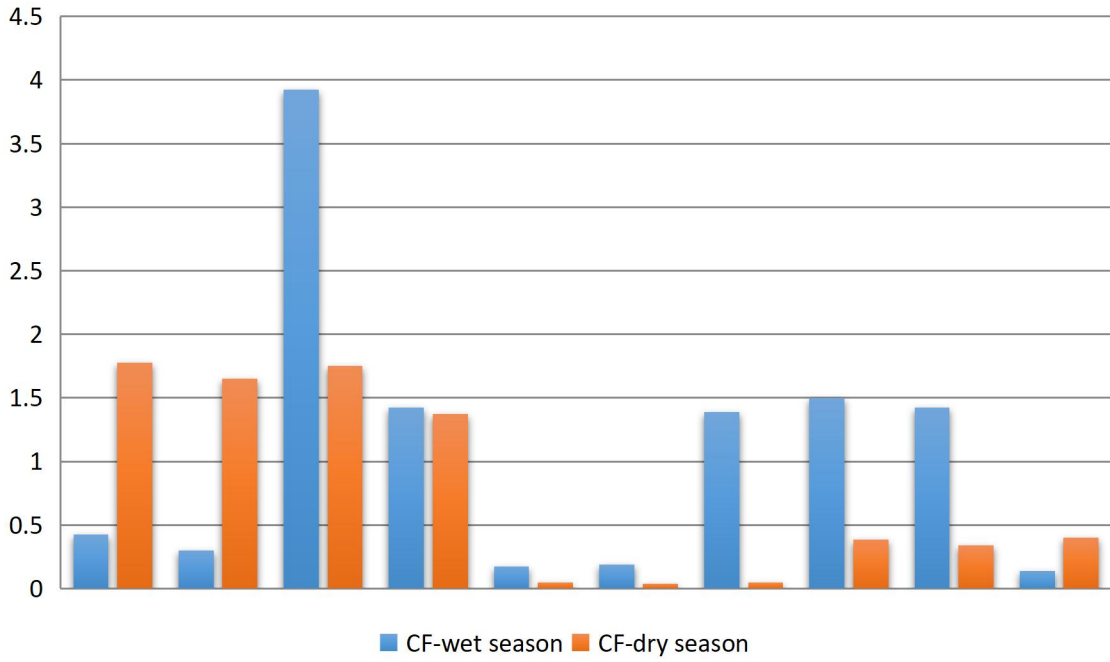


Figure 4:13 Contamination Factor Tailings

Source: Author's Field Work, 2023

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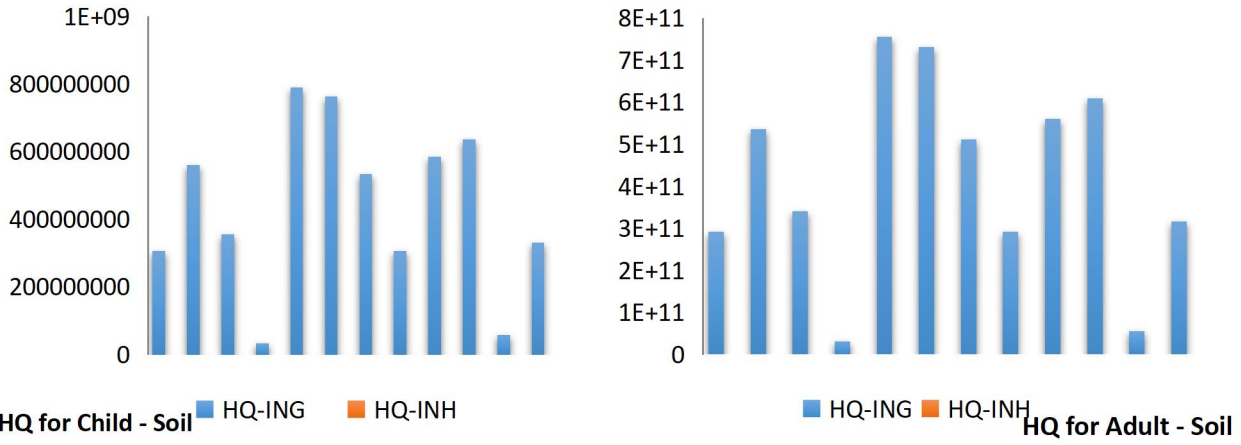


Figure 4.14 Hazard Quotient for Soil for Health Risk assessment for Child and Adult
Source: Author's Field Work, 2023

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Table 4.12: Sample Distances to Mercury Discharge Point

ID	Medium	Hg Conc	Distance
WS1	Surface Water	0.001	1318.019
WS2	Surface Water	0.0011	1609.549
WS3	Surface Water	0.0011	1679.222
WS4	Surface Water	0.0013	810.5277
WS5	Surface Water	0.0012	685.2218
WS6	Surface Water	0.0011	858.305
WS7	Surface Water	0.0013	973.5269
WS8	Surface Water	0.001	1118.292
WS9	Surface Water	0.021	450.8523
WS10	Surface Water	0.001	509.5852
WS11	Surface Water	0.011	618.0215
WB1	Borehole	0.0021	3362.573
WB2	Borehole	0.002	1150.192
WB3	Borehole	0.0011	1492.359
WB4	Borehole	0.0013	249.8994
WB5	Borehole	0.0011	1184.036
WB6	Borehole	0.012	1184.036
WB7	Borehole	0.021	1882.549
WB8	Borehole	0.0012	1731.01
WB9	Borehole	0.0021	1590.12
WB10	Borehole	0.0014	1189.619
SD1	Soil	0.012	1318.019
SD2	Soil	0.022	1609.549
SD3	Soil	0.014	1521.732
SD4	Soil	0.0013	810.5277
SD5	Soil	0.031	783.8168
SD6	Soil	0.03	785.0478
SD7	Soil	0.021	811.9861
SD8	Soil	0.012	973.5269
SD9	Soil	0.023	1087.332
SD10	Soil	0.025	1147.562
SD11	Soil	0.0023	2507.984
SD12	Soil	0.013	509.5852
ST1	Tailings	0.034	616.0431
ST2	Tailings	0.024	616.0431
ST3	Tailings	0.11	685.2218
ST4	Tailings	0.114	685.2218
ST5	Tailings	0.014	685.2218
ST6	Tailings	0.015	450.8523
ST7	Tailings	0.111	450.8523
ST8	Tailings	0.12	542.5514

Table 4.12 Contd: Sample Distance to Mercury Discharge Point

ID	Medium	Hg	
		Conc	Distance
ST9	Tailings	0.114	542.5514
ST10	Tailings	0.011	618.0215
VG1	Plant	0.011	1521.732
VG2	Plant	0.021	810.5277
VG3	Plant	0.021	810.5277
VG4	Plant	0.012	783.8168
VG5	Plant	0.0017	783.8168
VG6	Plant	0.014	783.8168
VG7	Plant	0.015	783.8168
VG8	Plant	0.0012	783.8168
VG9	Plant	0.026	785.0478
VG10	Plant	0.017	785.0478
VG11	Plant	0.022	785.0478
VG12	Plant	0.0024	785.0478
VG13	Plant	0.0012	785.0478
VG14	Plant	0.0022	785.0478
VG15	Plant	0.0032	785.0478
VG16	Plant	0.022	785.0478
VG17	Plant	0.003	785.0478
VG18	Plant	0.0022	811.9861
VG19	Plant	0.0031	811.9861
VG20	Plant	0.019	811.9861
VG21	Plant	0.0022	811.9861
VG22	Plant	0.0018	811.9861
VG23	Plant	0.0024	1147.562
VG24	Plant	0.0015	1147.562
VG25	Plant	0.026	811.9861
WW1	Well water	0.001	1763.858
WW2	Well water	0.001	616.0431
RD1	River sediment	0.012	973.5269
RD2	River sediment	0.018	1118.292
RD3	River sediment	0.014	1306.842

Source: Author's Field Work 2023.

4.4 Observation and Interpretation of Results on Risk Exposure and Health Assessment

The Contamination Factor for the soils and tailings were carried out because soil is regarded as the sink for metals during pollution. The evaluation of the degree of contamination for soil obtained during the wet season indicated that the minimum value was 0.0162 mg/kg while the high value was 0.3875 mg/kg which is classified as unpolluted under the categories earlier discussed. On the other hand, the values obtained during the dry season indicated the lowest degree of contamination to be 0.025 while the maximum contamination was found at the sample AT-20 close to the mineral processing site with a value of 4.124 mg/kg. This is an indication of considerable contamination. This is close to the point source and is a confirmation of the direct impact of the mercury processing activity at the site. The contamination pattern with respect to distance to the discharge point is contained in Table 4.12. It shows a general pattern of outward increase of mercury contamination away from the discharge point.

1. The appraisal of contamination evaluation of the tailings is even more interesting. The results in Table 4.9 confirmed high spike in the contamination value in both the wet and dry seasons. The maximum value derived in the wet season was 3.925mg/kg with the minimum value at 0.1375mg/kg with an average mean of 1.0875 mg/kg. The value during the dry season also indicated the highest factor to be 1.775 at ST1, with other high values at TS2-1.65, TS3-1.75; TS4-1.375mg/kg with 0.0375mg/kg as minimum and 0.78125 mg/kg as average. The overall implication is that the tailings are the major sources of mercury contamination especially during the wet season.

2. The geoaccumulation table in Figure X for soil revealed maximum i-geo index value to be -1.9527 with an average value of -3.2287. This is an indication that the geoaccumulation index for the soil in wet season is very low and confirmed that the soil is unpolluted. In the dry season the highest geoaccumulation index maximum value 1.45943 at the AT020 sample site, which confirmed the site to be moderately polluted and encroachment of anthropogenic influence. The average value for soil in the dry season is -3.2366 which is classified as unpolluted overall.
3. The geoaccumulation for the tailings confirmed minimum value to be -5.32193, average -2.06701 and maximum value 0.242857 for dry season. In the wet season the highest geoaccumulation index value 1.38773 at site ST3; average -1.25611 and minimum -3.44746. The implication of the result is moderate pollution at site ST3.
4. The health risk and exposure assessments of the study area was assessed using contamination indices capable of determining the exposure dimension to mercury which could be from average or high level of contamination. To this end, hazard quotient was calculated for children and adult in the study area to reflect the ADD_{ingestion} and ADD_{inhalation}. Moreover, the non-carcinogenic health risk index (HI) of Hg calculated for the adults and children were both above 1. This is an indication that Hg pose a threat to the health of the people.

4.5.1 GIS Environmental Risk Maps

In this study, the geospatial technologies, especially the remote sensing and GIS technologies were deployed to examine risk assessment of uke and environs^{18,22,49,53}. Specifically the NDVI (Normalized Difference Vegetation Index) was adopted to determine the vegetation stress factor

to measure the greenness and health based on the reflectance of near-infrared and red light. To this end, NDVI processing for the test site uke was carried out with the mercury values plotted on them for a period of ten years. The observation in Figures (16,17, 20, 21 and 22) revealed that the mercury high values correlate with the white patches which are indication of vegetation with NDVI values below one. This is a confirmation that NDVI can be used to effectively assessed mercury contamination as was done in similar studies which buttress the fact that satellite image processing and GIS technologies are effective in monitoring the state of the environment. Furthermore, the Landsat imageries of the test site uke and a control site (Keffi) which is devoid of ASGM gold processing subjected to NDVI processing to derive NDVI values and comparison. It worthy to note that the standard classification of NDVI values implies that values less than one is an indication of a stressed vegetation while values above one is for healthy vegetation.

In view of the above, equal spacing of 30 sample points on Uke and Keffi NDVI map (Figure 4.18- 4.19) and extracted values to point and examined the NDVI statistics for Keffi and Uke during both the dry and wet seasons. The results of this activities especially the statistical variations between the test and control sites are narrated in details in the next section of this write up.

Descriptive statistical measures for each season and location based on the mean, showed that Keffi has higher NDVI values compared to Uke in both the dry and wet seasons Table 4.12 showed details of the extracted NDVI vales for both Uke and Keffi while Figure 4.18 and 4.19 presents a graphical display of the two sites with respect to their NDVI values. These results clearly showed the control site(keffi) having a higher measure of vegetation greenness and health based on the reflectance of near-infrared and red light due to more green plant cover. The

implication is that the NDVI values are more than one cumulatively and the reason being no pollutant interference such as mercury. This is contrary to the Uke test site where the average NDVI value are lower. This implied that the vegetation in Uke showed signs of stress which could possibly be as a result of the mercury discharge into the ecosystem. This assertion is buttressed from the other elements of the statistics as the median NDVI values generally follow the same pattern as the mean values, with Keffi having higher values compared to Uke in both seasons. Although the median represents the middle value in a set of data and is less affected by extreme values however, it provides an alternative measure of central tendency. The standard deviation measures the dispersion or variability of the NDVI values around the mean. Higher values indicate greater variability. In this case, Keffi has higher standard deviations for both the dry and wet seasons compared to Uke, indicating a wider range of NDVI values and potentially more variability in vegetation cover. The sample variance is a measure of the spread or dispersion of the data. It is calculated as the squared standard deviation. Similar to the standard deviation, the sample variance is higher for Keffi in both seasons compared to Uke, indicating a wider range of NDVI values. Kurtosis measures the shape of the distribution. Positive values indicate a relatively peaked distribution with heavy tails, while negative values indicate a flatter distribution. In this case, Keffi has higher kurtosis values in both seasons compared to Uke, suggesting that its NDVI distribution may be more peaked and have heavier tails. Skewness measures the symmetry of the distribution. Negative values indicate a left-skewed (asymmetric with a longer left tail) distribution, while positive values indicate a right-skewed distribution. In this case, Keffi has negative skewness values in both seasons, indicating a tendency towards lower NDVI values. Uke, on the other hand, has negative skewness in the dry season but positive skewness in the wet season, suggesting a shift towards higher NDVI values during the wet

season. The range represents the difference between the maximum and minimum values in the dataset. It provides an indication of the spread of the NDVI values.

In this comparison, we can observe that Keffi generally has a wider range of NDVI values compared to Uke in both the dry and wet seasons. This suggests that Keffi exhibits a greater variation in vegetation cover. The minimum value represents the lowest NDVI value observed in the dataset. It indicates the presence of areas with minimal vegetation cover. In this case, Keffi generally has lower minimum NDVI values compared to Uke in both seasons, suggesting that Keffi may have areas with relatively less vegetation during the dry and wet seasons. The maximum value represents the highest NDVI value observed in the dataset. It indicates areas with dense and healthy vegetation cover. In this case, Keffi generally has higher maximum NDVI values compared to Uke in both seasons, suggesting the presence of areas with more abundant and healthier vegetation. The sum represents the total accumulation of NDVI values in the dataset. It provides an overall measure of the amount of vegetation in the area. In this case, Keffi has higher sums of NDVI values compared to Uke in both seasons, indicating a larger overall extent of vegetation. The count represents the number of data points or observations in the dataset.

For both Keffi and Uke in both the dry and wet seasons, the count is 30. The count indicates the sample size used to calculate the statistics. In this case, both Keffi and Uke have the same number of observations, ensuring a fair comparison between the two locations and seasons.

In summary, the comparison of NDVI statistics between Keffi and Uke during the dry and wet seasons reveals that Keffi generally exhibits higher mean, median, standard deviation, sample variance, range, maximum, and sum of NDVI values compared to Uke. Additionally, Keffi

shows higher kurtosis and negative skewness in both seasons, indicating a potentially more peaked and left-skewed distribution of NDVI values. These findings suggest that Keffi has a greater extent and variability of vegetation cover compared to Uke in the given seasons. There could also be a pointer to the variability in land, use land cover; whereas the dispersion in NDVI within Uke may have nose-dived in both seasons, results have linked this to the rate of leaching of contaminants within the A and B horizon where water infiltrates through the soil pore spaces that have leached more elements as distributed from the main Uke Water catchments. This however may not have been common within Keffi where the place is extremely a built-up area and where least activity of mining is seen around to spur up release of contaminants.

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4.5.2 Results and Findings of Mercury Risk Vulnerability Map of Uke

This work attempted the use of the mercury concentration derived from all the environmental media and fish to predict vulnerability of possible hazards emanating from gold processing in this area. Consequently, the weighted overlay method in ARCGIS was used to integrate input dataset such as flow accumulation, slope, elevation, distance from point source for mercury discharge, NDVI, land use cover, distance to community and mercury value. In similar studies carried out to design dispersion models using the emission, topographic inputs and mercury releases to the eco-media, the location of the mercury discharge point sources played a crucial role in the prediction of mercury dispersal patterns and exposure assessment. This study concurred with this assertion as the mercury vulnerability risk map has proved valuable in identifying population at risk from exposure. A close examination of the risk map (Fig 4.15) pointed out that the most vulnerability to mercury contamination is shown in red color which is the area around the gold processing Centre. The other colors as indicated in the legend shows the degree of vulnerability and can be used as a veritable tool to monitor and communicate mercury risk by regulators. This model will also help to understand the correlations between the different factors such as land cover, vegetation, climate, topography in the identification of mercury hotspots and predicting the mercury transport model necessary for effective management of the menacing side effect of mercury contamination in community. In a similar development a study conducted in Peru⁷⁶ examining wildlife vulnerability to mercury pollution from artisanal and small-scale gold mining, a geospatial model was designed to identify pollution risk from mining sites. Similar multicriteria evaluation was carried out using datasets such as flow accumulation, distance from mining area, sediments to arrive at the vulnerability risk map^{42,56,58}. The results opined that there is need for further research in these areas⁹¹ to protect with high biodiversity

vulnerability. In particular this work engaged the used of satellite imagery Landsat 7 and 8 to carried out a land cover time series analysis of the uke area. The results revealed that from 2010-2022 (appendices 2-4) and discovered that In 2010, the area land use distribution pattern were as follows bare land 67,700,191 sq/km; water 18,895245 sq/km; vegetation 2,313129 sq/km; developed area 14,583812 sq/km. on the other hand in 2022 when this work was carried out the bare land covered an area of 73,956256 sq/km and vegetation 2,522514 sq/km while the develop area covered about 25,449,602 sq/km; water 1,565556 sq/km. It would be recall that serious gold mining started in Uke about 5 years ago which is indicated by increase in developed areas from 14,583,812 possibly due to migration of miners to the site and bare land also increasing from 67,700,191 sq/km to 73,956256 sq/km. The increase in these parameters is an indication of increasing mining in the area. Moreover, deforestation according to similar studies carried out globally also can exacerbates soil mercury mobilization^{10,92}.

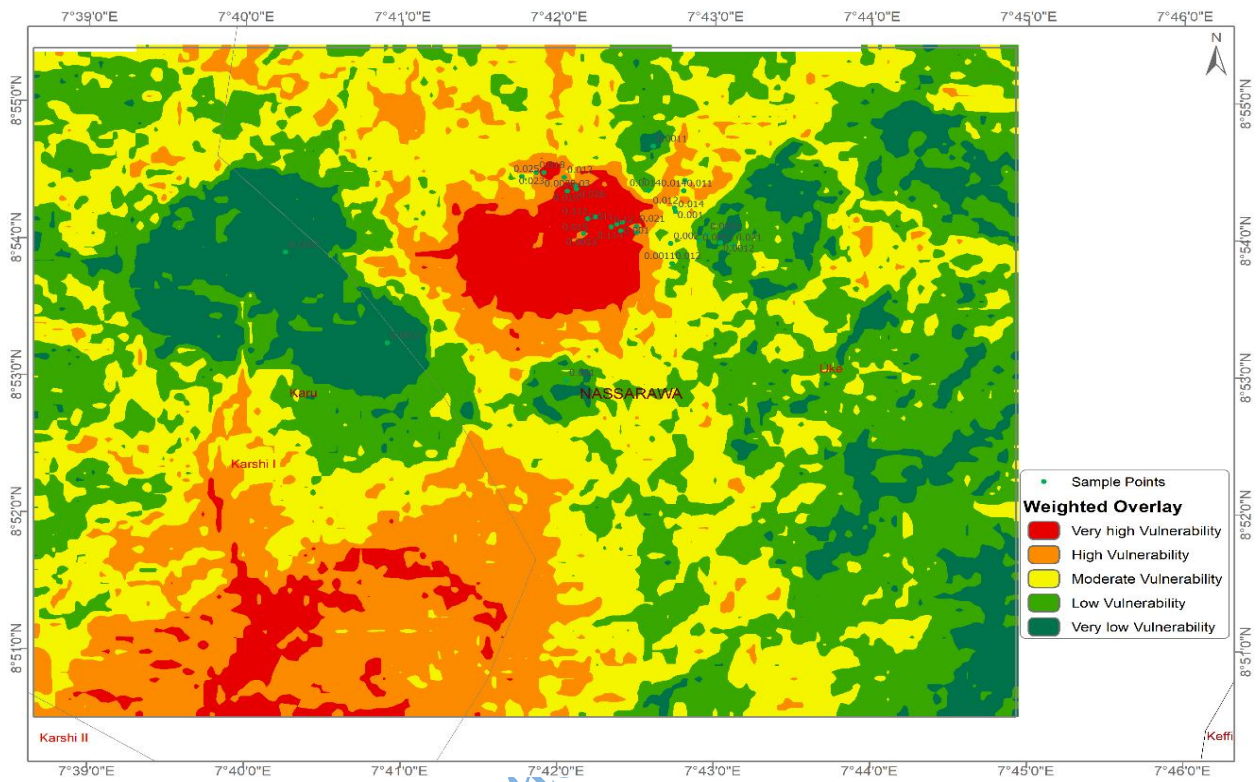


Figure 4.15: Vulnerability Map of Uke

Source: Author's Field Work, 2023

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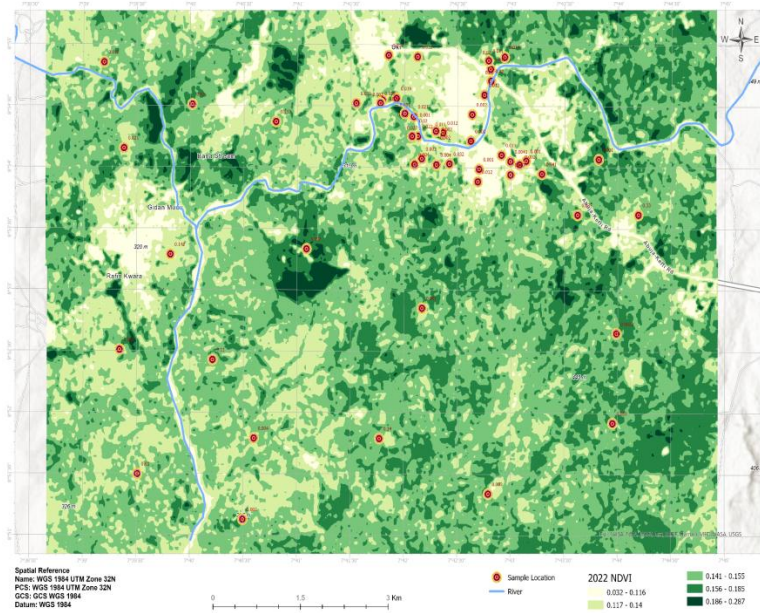


Figure 4:16 Integration of Mercury Sample Points on NDVI map

Source: Author's Field Work, 2023

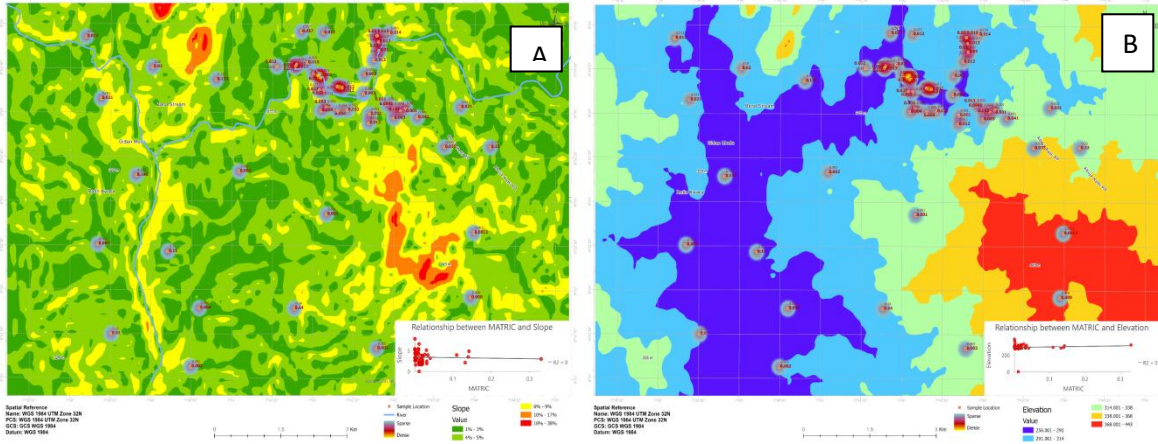


Figure 4.17: Integration of Mercury Locations with Elevation(A) and Slope (B)

Source: Author's Field Work, 2023

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Table 4.12: Statistical Comparison of NDVI Values at Uke and Keffi for Wet and Dry Seasons

Keffi Dry	Keffi Wet	UKE Wet	UKE Dry
0.22843	0.407525	0.151542	0.142764
0.224269	0.344904	0.16111	0.142553
0.225	0.41259	0.142553	0.15106
0.235037	0.507544	0.262057	0.145707
0.219188	0.415013	0.312017	0.176923
0.206066	0.296373	0.129596	0.145024
0.218049	0.369831	0.170355	0.147145
0.242152	0.511418	0.162908	0.151413
0.234653	0.4777	0.202655	0.143982
0.204778	0.416829	0.210069	0.16664
0.219928	0.380223	0.127737	0.129134
0.239691	0.366476	0.14095	0.144647
0.236617	0.377371	0.154413	0.128463
0.260784	0.418605	0.203001	0.128953
0.32854	0.533349	0.203427	0.146058
0.245787	0.435442	0.182628	0.10951
0.186959	0.329344	0.114498	0.146628
0.091465	0.089783	0.163515	0.160885
0.222825	0.35866	0.148956	0.13988
0.222465	0.416935	0.163503	0.113698
0.238589	0.36076	0.182553	0.150559
0.103163	0.132007	0.16212	0.142197
0.213939	0.289942	0.148131	0.12952
0.281325	0.521423	0.169606	0.138534
0.251506	0.350791	0.236898	0.142664
0.219763	0.378589	0.154046	0.145374
0.279593	0.435741	0.175155	0.146636
0.217061	0.384179	0.15776	0.130445
0.199431	0.435544	0.156311	0.145692
0.214676	0.395912	0.206151	0.146553

Source: Author's Field Work, 2023

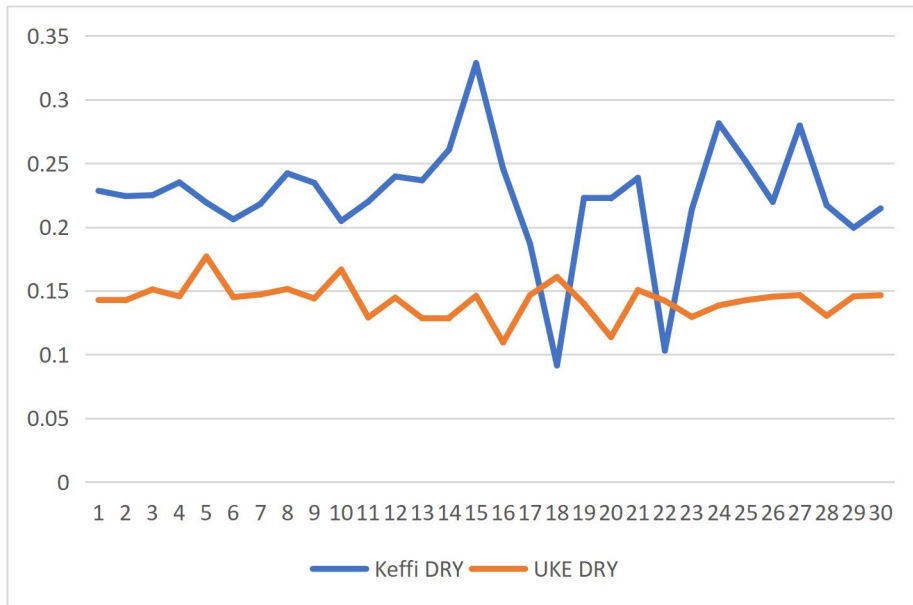


Fig 4.18 NDVI Comparison between Uke and Keffi Sheets Dry Season

Source: Author's Field Work, 2023

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y, Nigeria

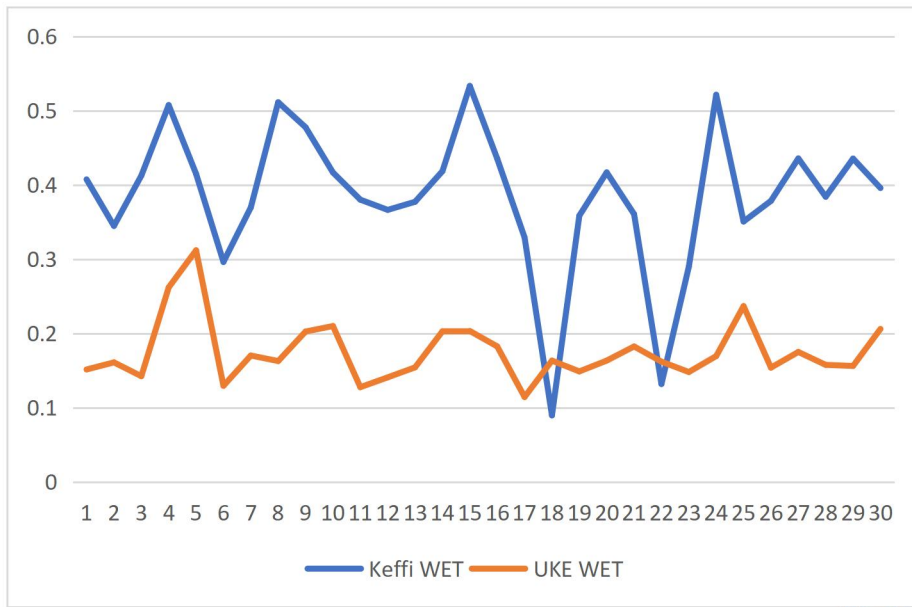


Fig 4.19: Comparison of NDVI Values Wet Season for Uke and Keffi Wet Season

Source: Author's Field Work, 2023

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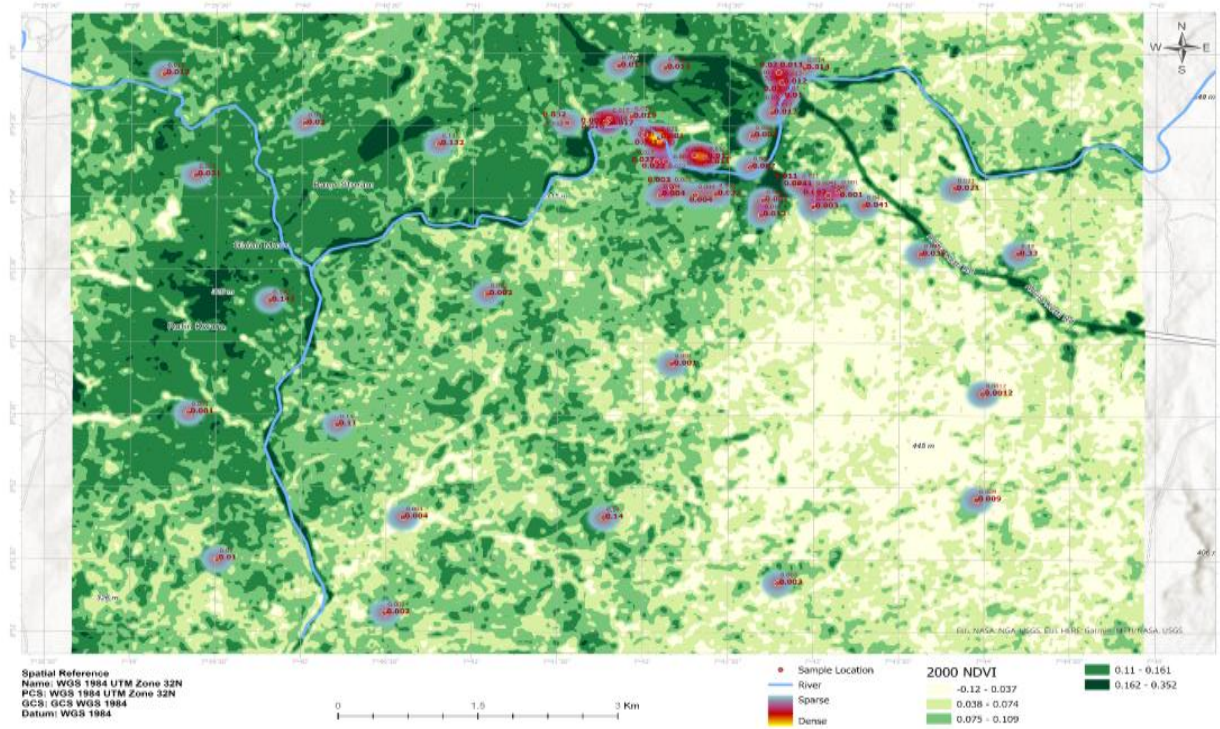


Figure 4.20: 2000 NDVI Map of Uke

Source: Author's Field Work, 2023

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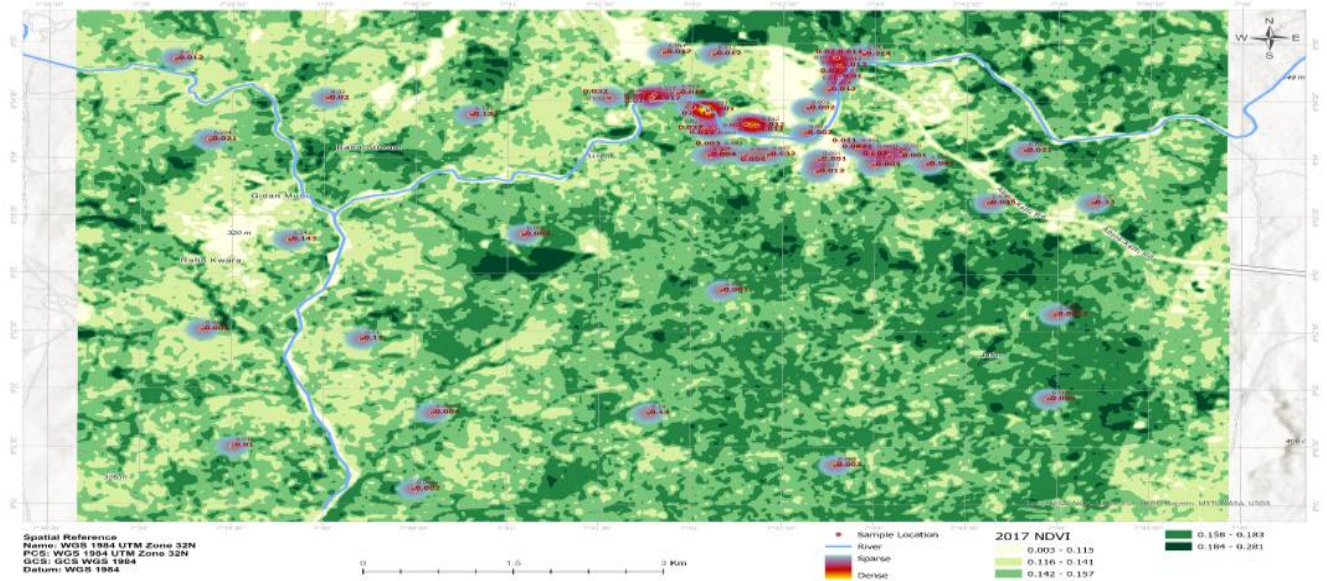


Figure 4:21 2017 NDVI map of Uke

Source: Author's Field Work, 2023

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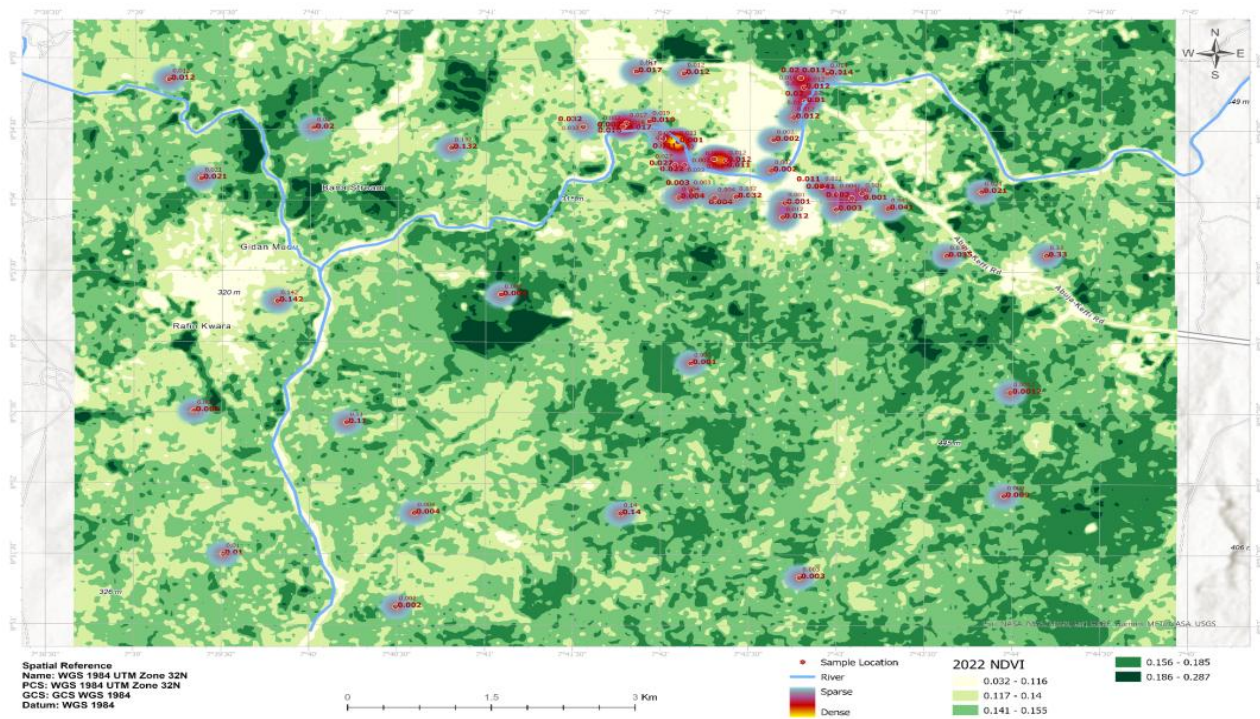


Figure 4.22 2022 NDVI Map of Uke integrated with Mercury Sample Points,

Source: Author's Field Work, 2023

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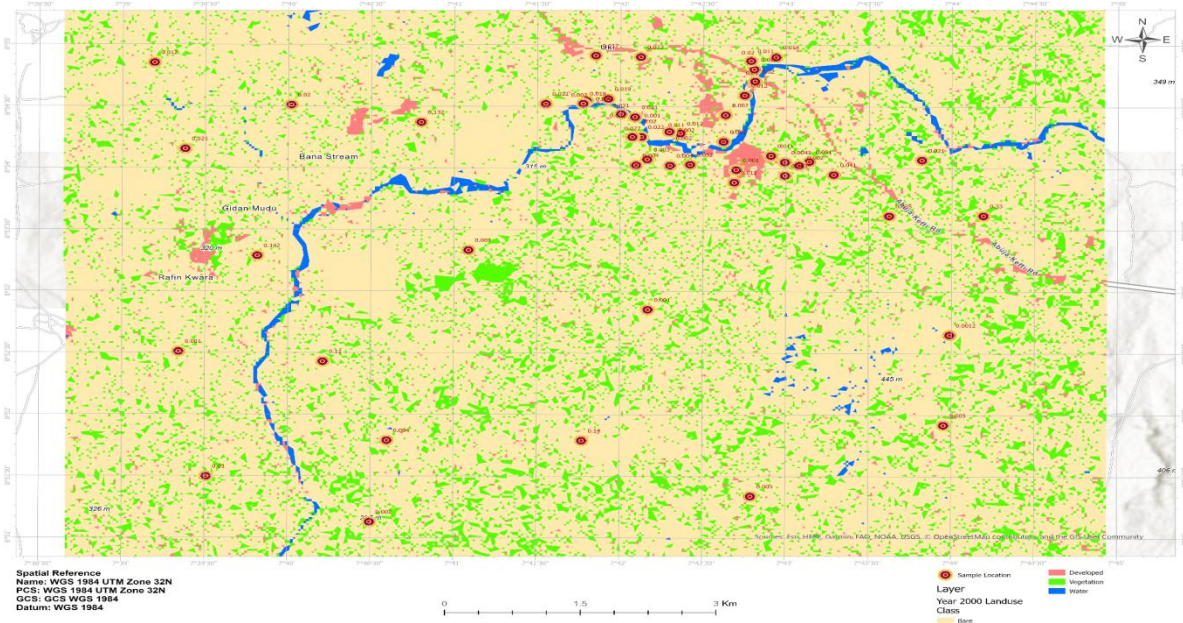


Figure 4.23 Mercury Values Plotted on Land Use (2010map)

Source: Author's Field Work, 2023

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4.6 Descriptive Statistics of Uke Community Research Questionnaire

4.6.1 Ethical Considerations

Permission was sought from Ministry of Mines and Steel Development and the Ministry of solid Minerals in Lafia. Moreover, the Community Chiefs in Uke were also informed. Informed consent was sought from the individual participants after explaining to them the objective of the study (Appendices 5-10). Confidentiality was ensured throughout the study.

4.6.2 Data Management and Analysis

The mercury values derived in the analysis of the eco-media were subjected to statistical processing using the Microsoft excel and SPSS version 26 software. The summary of results of the cross-sectional survey of correspondents are presented in Fig.4.22 while details of the descriptive statistics and other results are contained in the appendix section.

This is output of the survey identified that majority of the miners about 86% do not have basic education, this is an indication that this factor may be contributory to the abuse of mercury usage and eventual contamination of the environment. The result also confirmed that 78% of the Miners are camp dwellers, meaning they must have migrated from a distance to this present venue. This has a lot of implication on the socio-cultural nature of the miners and design of a remediation strategy for mercury control. The survey also confirmed that the prevalent age group among showed that (about 60%) the miners are between the age group 18-34. This is an indication that the youth are largely involved in artisanal mining. About 66% are married which further escalate the potential at risk population to include their immediate families. The survey showed that occupational hazards is a high risk since about 98% do not use PPE. The apparent

lack of awareness of mercury hazard is further confirmed since about 56% of the miners are not aware of government policies put in place to mitigate mercury exposure. The results of the survey are summarized in Table 4.13 and will be adequately discussed in the next chapter.

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Table 4.13: Results of Socioeconomic Statistical Survey with Miners and Community

Questionnaire Survey

Questions	Miners	Percentage (100%)
Age group	25-34	32
Gender	Male	92
Marital status	Married	66
Level of Education	Secondary school drop out	30
Are you mining	Full time	78
Source of mercury	Buy	95
Mercury storage	Site	73
Mercury daily usage	Two days	46
Years of mining	1-5 years	80
Do you use PPE	No	98
Is PPE important	Yes	90
How often do you use PPE	Never	68
Daily work per week	Seven days	54
Hours per day	08-Oct	48
How do you suck excess mercury	Dry cloth	88
Sources of drinking water	Sachet water	86
Do you eat fish	Yes	64
How often do you eat fish	More than once a week	76
Source of fish	Market	91
Do you prefer any part of the fish	No	82
If yes, which part	Head	86
Hazard using mercury	No	90
Red eyes health issues	No answer	94
Cough Health issues	No answer	91
Fever Health issues	No answer	87
Headaches Health issues	No answer	79
Fatigue Health issues	No answer	96
Weight loss health issues	No answer	96
Vision Problem Health issues	No answer	98
Skin rashes Health issues	No answer	75
Muscle weakness Health issues	No answer	85
Dizziness Health issues	No answer	89
Symptoms frequency	SOMETIMES	64
Symptoms within last six months	Yes	69
Where do you go to for help	Traditionalist	43
Typhoid Disease	No answer	57
Diarrhoea Disease	No answer	94
Cough Disease	No answer	92
Work Accident	No answer	63
Conditions related to your work	Yes	67
Can PPE prevent these diseases	Yes	78
Are you aware of Government policy	Yes	57
Government sensitization	No	71
Training on Safety and Health	No	80

Source: Author's Field Work, 2023

Table 4.14: Results on Socioeconomic Statistical Survey of Miners and Community

Questions	Miners	Percentage (100%)
Age group	25-34	32
Gender	Male	92
Marital status	Married	66
Level of Education	Secondary school drop out	30
Are you mining	Full time	78
Source of mercury	Buy	95
Mercury storage	Site	73
Mercury daily usage	Two days	46
Years of mining	1-5 years	80
Do you use PPE	No	98
Is PPE important	Yes	90
How often do you use PPE	Never	68
Daily work per week	Seven days	54
Hours per day	08-Oct	48
How do you suck excess mercury	Dry cloth	88
Sources of drinking water	Sachet water	86
Do you eat fish	Yes	64
How often do you eat fish	More than once a week	76
Source of fish	Market	91
Do you prefer any part of the fish	No	82
If yes, which part	Head	86
Hazard using mercury	No	90
Red eyes health issues	No answer	94
Cough Health issues	No answer	91
Fever Health issues	No answer	87
Headaches Health issues	No answer	79
Fatigue Health issues	No answer	96
Weight loss health issues	No answer	96
Vision Problem Health issues	No answer	98
Skin rashes Health issues	No answer	75
Muscle weakness Health issues	No answer	85
Dizziness Health issues	No answer	89
Symptoms frequency	SOMETIMES	64
Symptoms within last six months	Yes	69
Where do you go to for help	Traditionalist	43
Typhoid Disease	No answer	57
Diarrhoea Disease	No answer	94
Cough Disease	No answer	92
Work Accident	No answer	63
Conditions related to your work	Yes	67
Can PPE prevent these diseases	Yes	78
Are you aware of Government policy	Yes	57
Government sensitization	No	71
Training on Safety and Health	No	80

Source: Author's Field Work, 2023

It is very obvious from the analysis of the questionnaires that the perception^{13,29,48,88} index of the miners and the community on the hazard of mercury usage is very low. This will help in the design of a template for managing the environmental risk for the remediation of the hazard.

Comparative studies locally revealed that River Kaduna had a concentration ranging between 1.72-.2.50 while the values from others studies globally are far higher than this study. Table 5.1 lists such values for proper comparison. The values from uke river is far less than in most areas studied.

The mercury values of similar studies globally are contained in Table 5.1 and the values in the current study are lower.

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Table 4.17: Global Comparison of Mercury Contamination in Ecomedia with Present Study

Sample Type	THg	Location	References
Gold tailing ng/g	5.2-200	Suriname	108
	77-2917	Ghana	100
	10-18	Brazil	112
	100-27,610	ASGM Indonesia	101
	16-4230	ASGM West Coast India	113
	13-600	Chile	109
	15-21	Nigeria, Minna	12
	0.314	Nigeria, Uke	This Study
	2580	Guateng South Africa	111
	5.8-1759	Tanzania	103
	140-8900	Kenya	110
	196-1187	Columbia	115
	3770-54,600	Ghana	114
	7500	ASM Senegal	104
	20-2400	Senegal	106
	38-726	ASM Cote D'Voire	107
1200-8470	Egypt	116	

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Table 4.17(continued): Global Comparison of Mercury Contamination in Ecomedia with Present Study

Sample type	THg	Location	References
Surface water	8-10	Costa Rica	87
	28.7-420	Ghana	100
	0.022	Nigeria,Uke,Nassarawa State(This Study)	This Study
	14-25	Nigeria (Manyera River,Niger.)	12
	220	Gauteng, South Africa	111
	400-21,380	Burkina Faso	102
	1000-47,800	Tanzania	103
	22	ASGM Senegal	104
	5.8-36-3	Senegal	105
	6.6-53	Cote d'voire	106
Groundwater	14	ASGM Indonesia	101
	223	Gauteng ,South Africa	111
	0.021	Nigeria, Uke	This Study
Sediments	0.7-9.3	Pra River	100
	0.10-0.017	Indonesia	117
	0.096-0.402	Thailand	119
	0.103-0.402	Kerala,India	120
	0.018	Nigeria(mayera river)	12
	0.3-0.9	Shaanxi,China	118
	0.018	Nigeria , Uke	This Study
Soil	0.26-5.553	Amazon, Brazil	99
	0.427	Nigeria, Uke	This Study
Fish	0.008	Nigeria,Mayera River	12
	0.047	Nigeria, Uke River	This Study

Source: Authors Field Work, 2023

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Endnotes

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Do Not Copy, Lead City University, Nigeria

Chapter Five

Summary and Conclusion

5.1 Summary of Findings

This thesis has made an attempt to evaluate the environmental risk associated with the use of mercury in the processing of gold in Uke, Nasarawa State, Nigeria. This work adopted a multi transaction research approach which entailed the use of analytical, geospatial, and quantitative methodologies to assess the threat posed to the ecosystem and the communities within the jurisdiction of the study area.

The analytical method carefully identified possible risk within each of the environmental media examined. The mercury concentration in the soil derived during this study ranges from 0.0013-0.031 with an average concentration of 0.0172mg/kg during the wet season while the dry ranges from 0.002-0.427 mg/kg with an average concentration of 0.046mg/kg. The environment significance of the soil in pollution management has been emphasized earlier in this work since it serves as an important sink for heavy metals such as mercury and is a very critical resource in the dispersion of mercury into the aquatic ecosystem. Moreover, biosorption of metals is facilitated through uptake of vital metals by plants. Hence, the crop growth is heavily reliant on the metal composition of the soil. The results in the wet season clearly revealed that most of the soil samples are above the WHO threshold limits of 0.05mg/kg and the crustal average value of 0.003. Most of the mercury in the soil are deposited as particulates from atmospheric mercury and are further dispersed into the surface ecosystem through run off. Hence, the high mercury value must have been as a result of the increase in gold processing activities by the artisanal miners during the rainy season. It is also important to note that the mobility and toxicity of mercury is a

direct function of its form. The high mercury value could also be attributable to the structure of the soil such as the porosity and permeability factors which are critical to the migration of mercury during the wet season. It should be noted that the soil samples considered in his work were taken at a depth of 0.5m which literarily make it top soil usually susceptible to high mercury concentration as confirmed in other related studies. The concentration of mercury obtained in this study.

In a similar development, 20 samples of the mine waste derived from crushing the ore which got accumulated as soil heaps or tailing were analysed during this study and the results confirmed high mercury values ranging from 0.011 to 0.34mg/kg with average mercury concentration of 0.08 during the wet season. The values in the dry season also revealed the average concentration to be 0.0625 while the mercury values ranges from 0.002 to 0.427 mg/kg. The high mercury value recorded in the dry season is due to the inability of the artisanal miners to extract most of the gold due to the mechanical approach used during amalgamation. This research has confirmed the tailings as the main source of mercury contamination in Uke. The results when compared with other global studies is still lower.

The maximum geoaccumulation index for the tailing in the wet season was 1.387 which is an indication that there were spots of moderate contamination while the value recorded in the dry season showed traces of contamination with a value of 0.242 The contamination factor calculated for the wet season was 1.088 and the dry season 1.77, this clearly reflect a moderately contaminated soil.

The work also observed that the stream sediments also recorded high mercury value of 0.018 which is positively correlated with the mean mercury concentration obtained from the soil in the

wet season. This value also corresponds with the mercury concentration of the sediments of the Manyera river in Niger state with 0.018 according but lower than the value derived from other locations and studies in different parts of the world. The mercury concentration range of 0.012-0.018 also revealed that the maximum value was derived at the point source where the anthropogenic discharge of mercury during gold processing was prevalent.

Overall, the results of the mercury concentration on the soils, tailings and sediment reflected some mercury concentration which can cause health concern to the community. The health risk assessment carried out in this work using the non carcinogenic and the hazard indexes revealed that the ingestion and inhalation pathways are at comfortable levels but the sporadic pollution caused by tailings and soil at area around the processing area are a thing of concern. Hence consistent gold processing in uke will lead to greater release of anthropogenic mercury which can biomagnifies and causes great harm to the health of the community.

The results of the stream/surface water is also a thing of concern with respect to the exposure risk assessment in the community. The mercury concentration ranges from 0.001 and 0.022 during the wet season and 0.001 -0.021 during the dry season. The majority of the samples are above the threshold limits set by WHO which is 0.002 mg/L. Communities such as Uke rely greatly on water from the river for domestic use and drinking, meaning, the people are vulnerable to mercury intoxication under exposure.

Fish according to many studies is vulnerable to mercury contamination especially the methyl mercury. Fish is a staple diet in Uke and the community is at risk of exposure if it is contaminated. The results from this work showed that the mean average concentration of the fish ranges from 0.0002 – 0.047. The order of mercury bioaccumulation in the organs is

gills>liver>intestine>muscle>bone. The WHO threshold limit for human consumption of Fish is 0.5kg/mg which confirms the fish are within safe limits. Comparative results from other research work locally showed that the mercury concentration of fish in Uke is higher than the fish from the Manyara river in Niger which is 0.008 kg/mg. Nevertheless, the value is lower to other global locations as listed in table.

This study also focused on the examination of the plants and vegetables within the vicinity of the gold processing center. The results shown confirmed that the mean concentration of mercury in the wet season ranges from 0.0012 – 0.104 and dry season ranges from 0.001-0.02mg/l. The allowable range is 0.03-0.01 mg/kg. Some plants or vegetables such as rice, sweet potatoes and pepper have high mercury values which are a source of concern for food safety.

A deeper probe into the vulnerability of the ecosystem to anthropogenic release of mercury through gold processing activities in the study area was corroborated with the adoption of geospatial techniques. The remote sensing techniques were adopted to ascertain whether the vegetation in the area has experienced stress due to possible heavy metal contamination in this case mercury. Specifically, the NDVI technique was applied to Landsat imagery to extract values which could be indicative of stress on the vegetation. Moreover, the mercury values were superimposed on the NDVI values while the Keffi sheet was selected as a control to compare with values derived from the Uke study site. The results of the low NDVI values correlated with the areas of high mercury values. The comparison of the NDVI in the control (Keffi) sheet and Uke also indicated that the values derived from the Uke study area showed stressed vegetation than Keffi. This could be as a result of the introduction of mercury through gold processing to the ecosystem.

This research also explored the possibility of designing a risk management and communication system capable of helping policy administrators to monitor mercury contamination. Consequently, a GIS-based mercury vulnerability system was developed to predict mercury hotspots. This system involved the integration of dataset such as flow direction, slope, distance to community, distance from gold processing center, elevation, land use/land cover, mercury value and NDVI. These data were modelled using the weighted overlay method to prepare a mercury predictability risk map for the uke study site.

The multidisciplinary approach to this work is complimented by the use of quantitative methodology to assess the perception of the artisanal miners and the community to the use of mercury in gold processing. The results from the corresponds are revealing as it confirmed that there is low perception by both parties to the dangers of using mercury in mining.

Overall, this research has been able to sensitize the community and policy makers about the risk posed to the ecosystem on the unregulated use of mercury in gold processing. The mercury vulnerability map has emerged as a monitoring tool which can be adopted to manage mitigation programs and for risk communication in mercury contamination management.

5.2 **Conclusion**

This study has revealed that the soil, tailings, stream water, some plants has been fairly contaminated by mercury and above WHO approved limits. Most of the Eco media contamination were seasonal contaminated mostly in the wet season when operational activities of the artisanal miners were at its peak. The major threat to the environment came from the mine waste(tailings) which had the high contamination factor (CF) and the geoaccumulation index was

high to confirm the high risk to the health of the Uke community. This assertion is further buttressed due to the fact that some of the community members used this material as the source of plastering their locally constructed building. This further increase the indoor mercury inhalation risk and a big hazard to inhabitants. In a similar development, the exposure assessment also confirmed the vulnerability of the vegetable and plants to mercury contamination especially Rice and Pepper. The high mercury value in rice should be further investigated since the general believe is fish is generally regarded as the major gateway for organic mercury into the food chain. Rice has been found in other related works to be vulnerable and could pose a health risk to food safety. Furthermore, the fish samples analyzed confirmed them to be within the human consumption limit but the persistent gold processing improve the risk of mercury bioaccumulation and leading to mercury access to the food web through fish. This study also reiterated the need for policy administrators to increase the enlightenment of the artisanal miners on the damage posed by mercury exposure since the interaction with them showed high level of ignorance on the matter. Moreover, the occupational hazard risk is exceedingly high due to lack of use of face mask and other protective guards.

Development of a GIS-based mercury migration vulnerability model in this work is highly novel and can be a valuable tool in risk management and communication strategy for policy administrators. The various risk maps are expected to be important in designing the mitigation measures for managing mercury contamination and exposure assessment.

5.3 Recommendations

There is no doubt that the effect of mercury on the environment is hazardous. This study has meticulous carried out the identification of the dangers of hazards involved in the anthropogenic

disposal of mercury during processing of gold at Uke. The results confirmed the silent negative effect of artisanal activities of gold processing in the area and the following recommendations will go a long way to abate the area from further delirious effect

- Immediately set up a monitoring mechanism to carry out a mercury balance campaign to directly document the mercury consumption in the area
- Adopt phytoremediation measures to clean mercury hotspots areas
- Upgrade mercury amalgam technology through provision of locally made retorts
- Encourage coexistence of mercury processors along with the miners to improve the quality of processing and adoption of cleaner technologies
- Promote the development of regulated cyanidation plants to improve mercury capture.

5.4 Contribution to Knowledge

This study is novel in many ways in the country especially with respect to mercury and ASMG

- It is the first multi transactional study locally, involving the use of analytical, geospatial and quantitative methodology

- The development of mercury migration and vulnerability model will provide policy administrators tools to monitor and develop mitigation strategies in mercury risk plan.

5.5 Suggested Areas For Further Research

- Carry out a more detailed Perception Studys on mercury effect on the miners and community.
- Carry out mercury speciation studies to identify different forms of mercury operational in the area through mercury isotopes study
- Carry out studies on mercury in ASM and effect on women and children
- Carry out the air quality analysis to determine particulate mercury
- Carry out further health and human risk analysis using biomarkers such as blood, urine and hair artisanal miners.

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Appendix 1

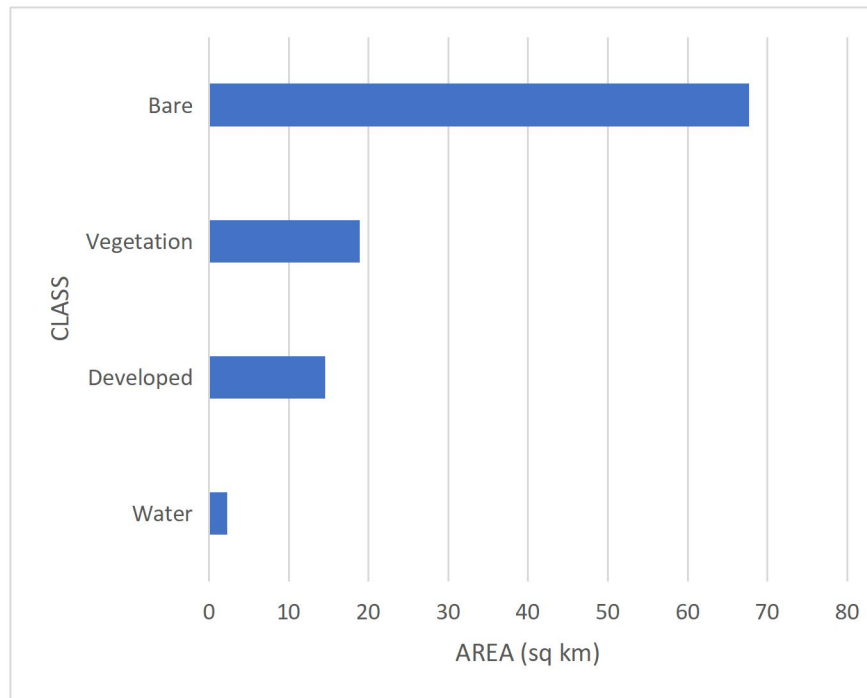
Statistical Comparison of Mercury Values in Fish, Boreholes and Surface Water

Media	Fish	Borehole water	Surface water
Minimum value	0.0002	0.001	0.001
Maximum	0.047	0.021	0.022
Average	0.009248	0.0041895	0.0092429
Median	0.00531	0.0014	0.011
Standard Deviation	0.009792563	0.0055931	0.0084481

Source: Author's Field Work ,2023

Appendix II

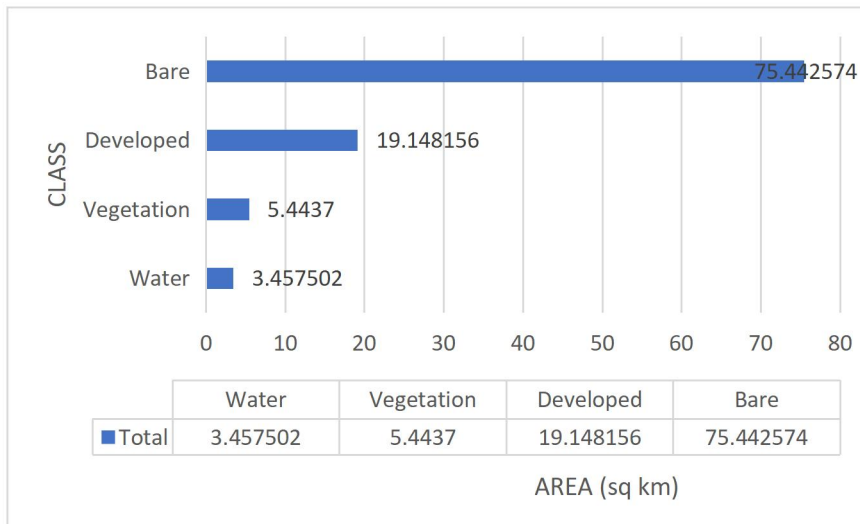
Time Series Land Use bar Chart from 2010



Source :Author's Field Work 2023

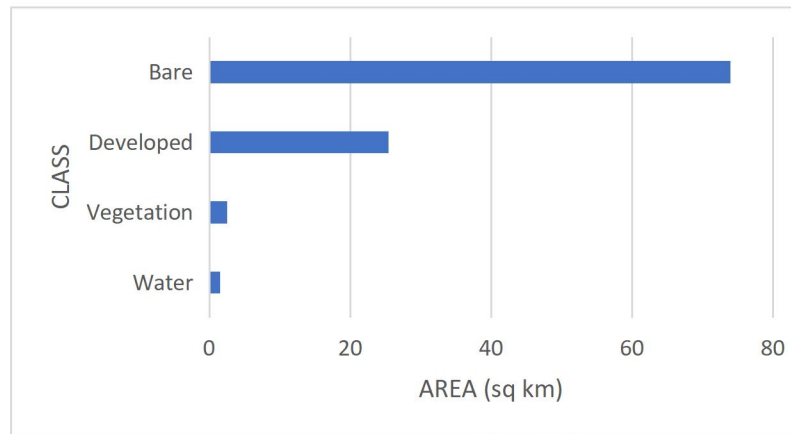
Appendix III

Time series Land Use bar Chart from 2017



Source: Author's Field Work, 2023

IV
Series



Nigeria

Appendix

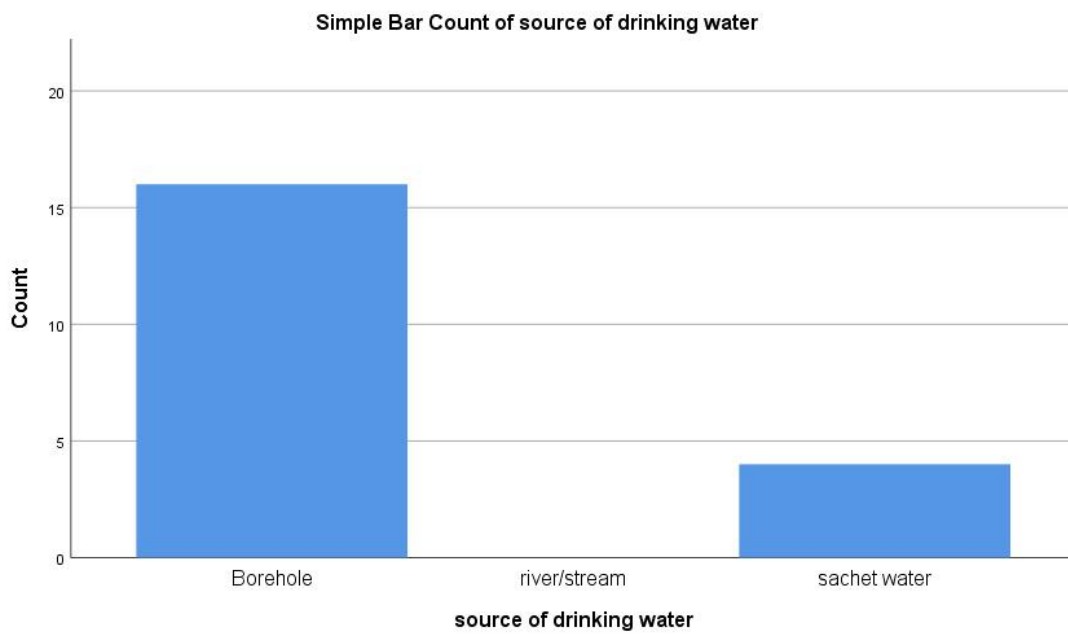
Time-
:Land Use Cover
Analysis 2022

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Source: Author's Field Work ,2023

Appendix V

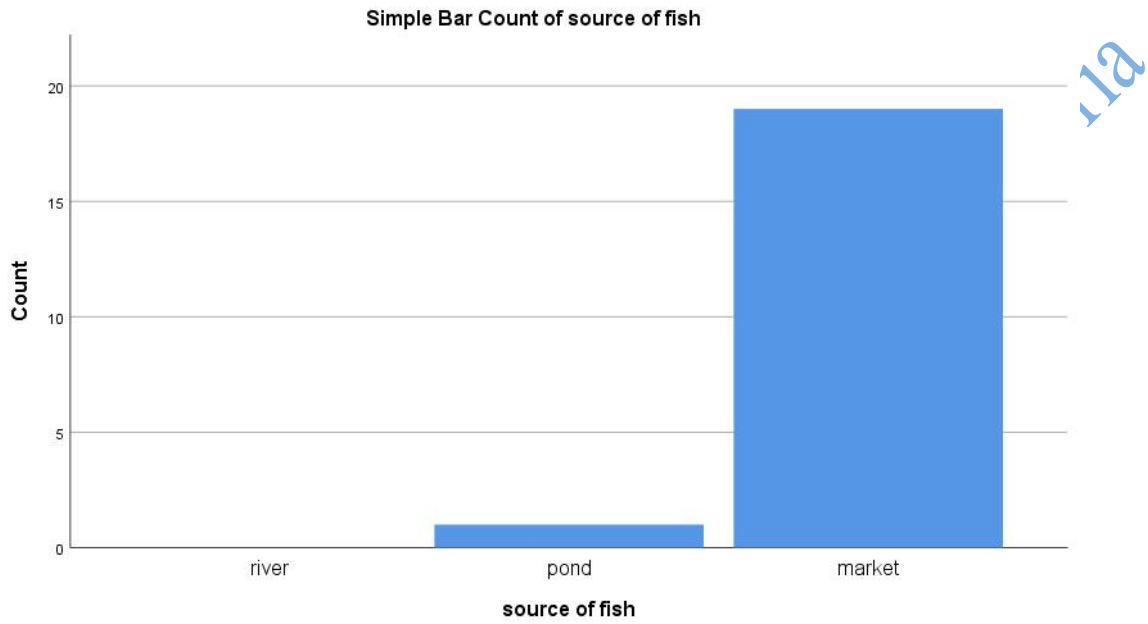
Bar chart Source of Drinking water



Source: Author's Field Work, 2023

Appendix VI

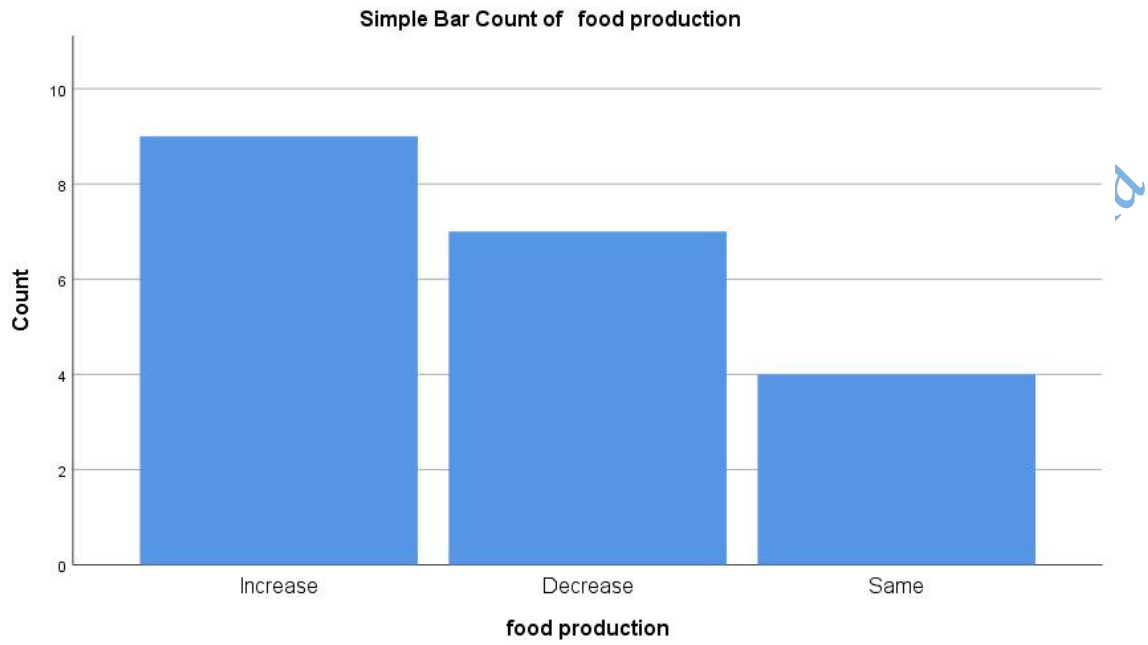
Graph Showing Sources of Fish



Source: Author's Field Work, 2023

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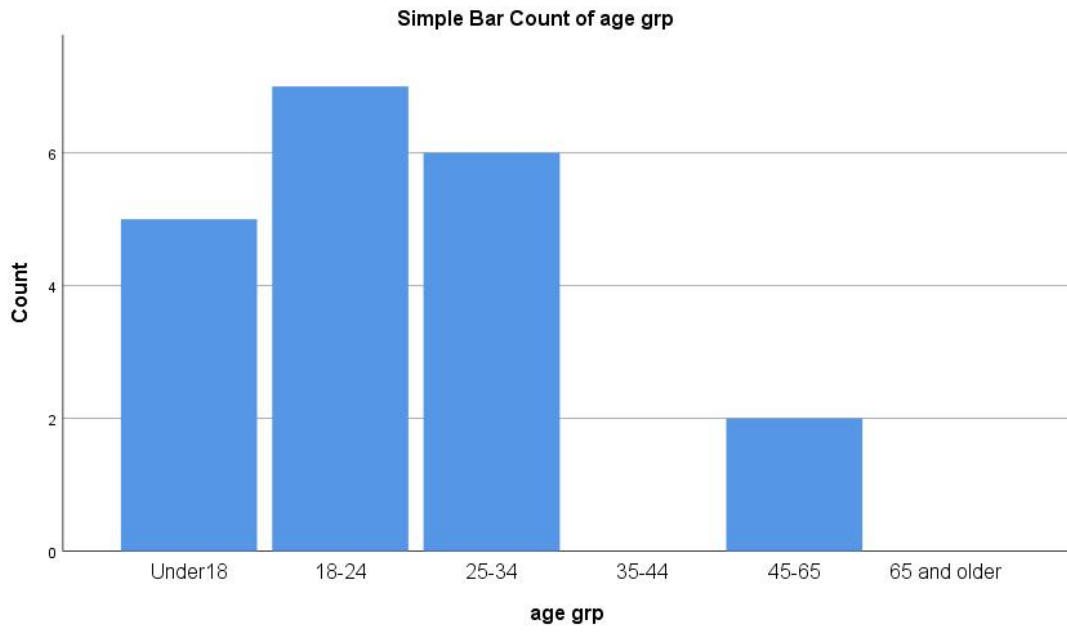
Appendix VII



Source: Author's Field Work, 2023

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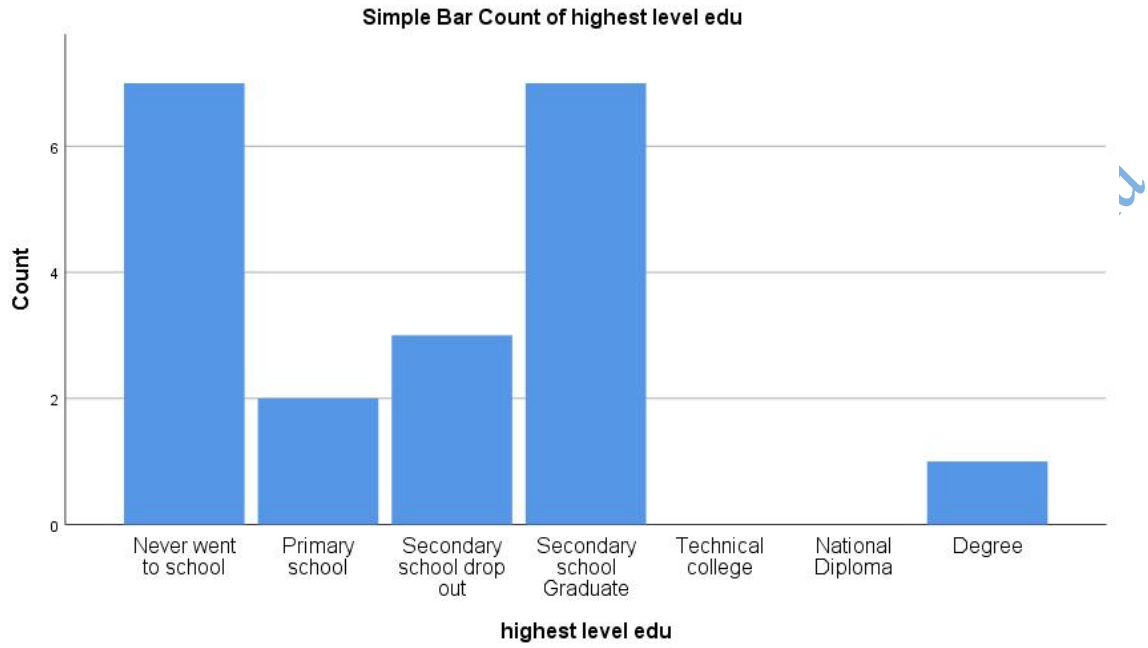
Appendix VIII



Source: Author's Field Work, 2023

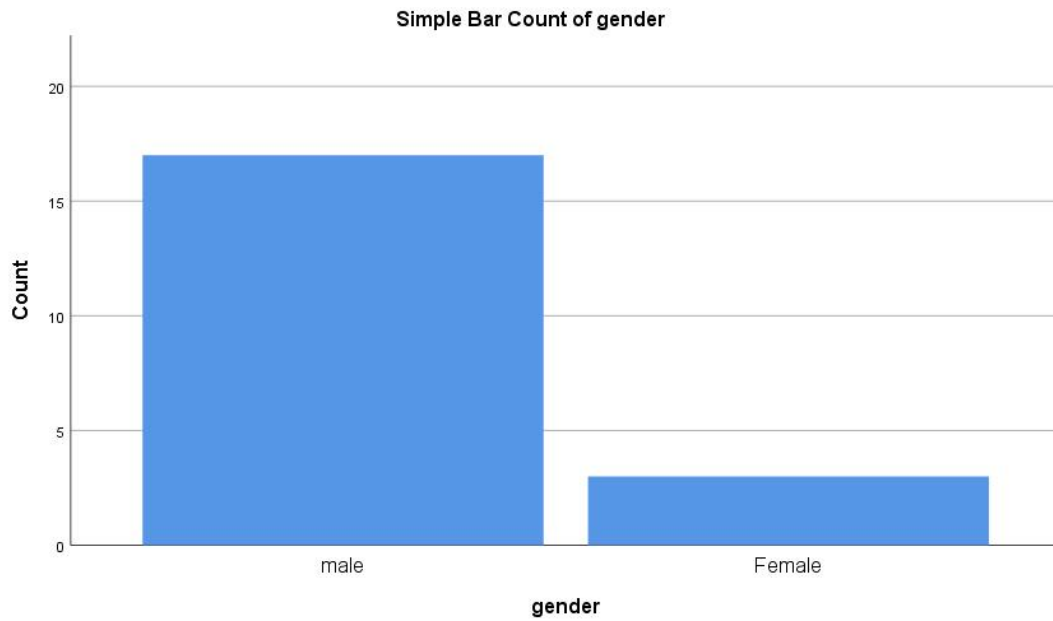
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Appendix IX



Source: Author's Field Work, 2023

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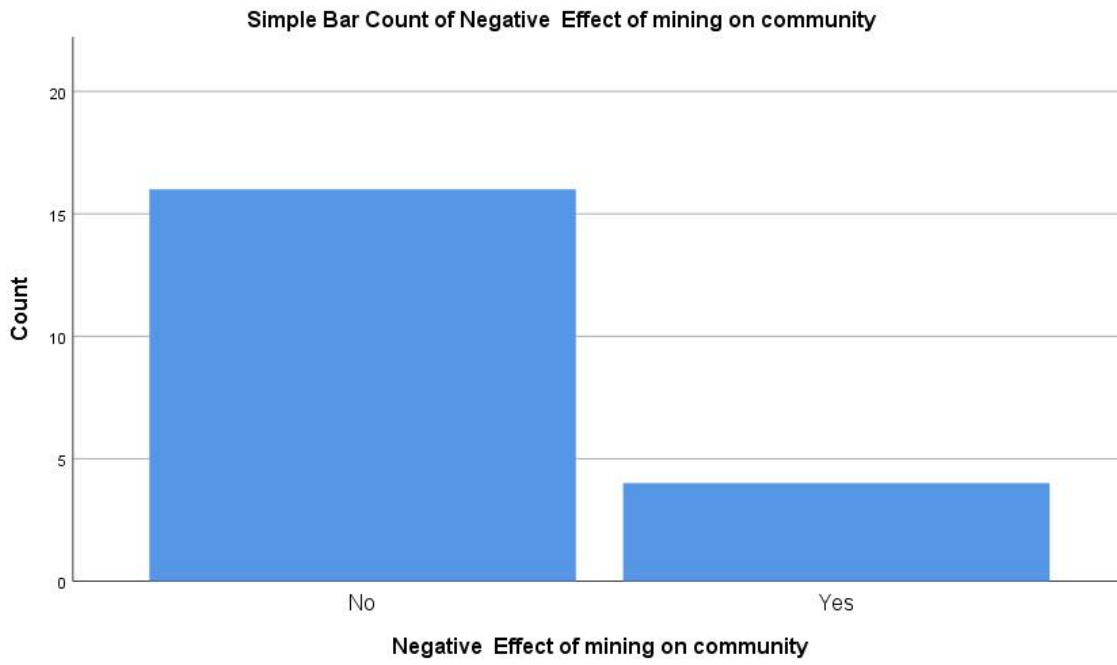


Source: Author's Field Work, 2023

Appendix X

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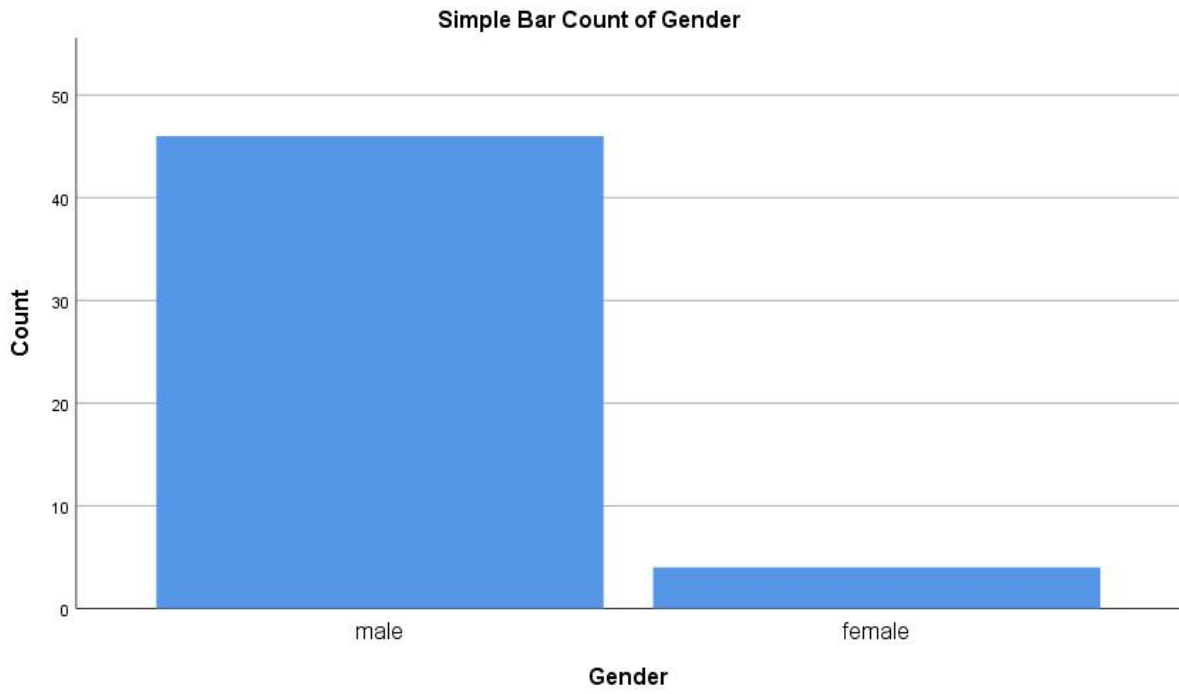
Appendix XI



Source:

Author's Field Work, 2023

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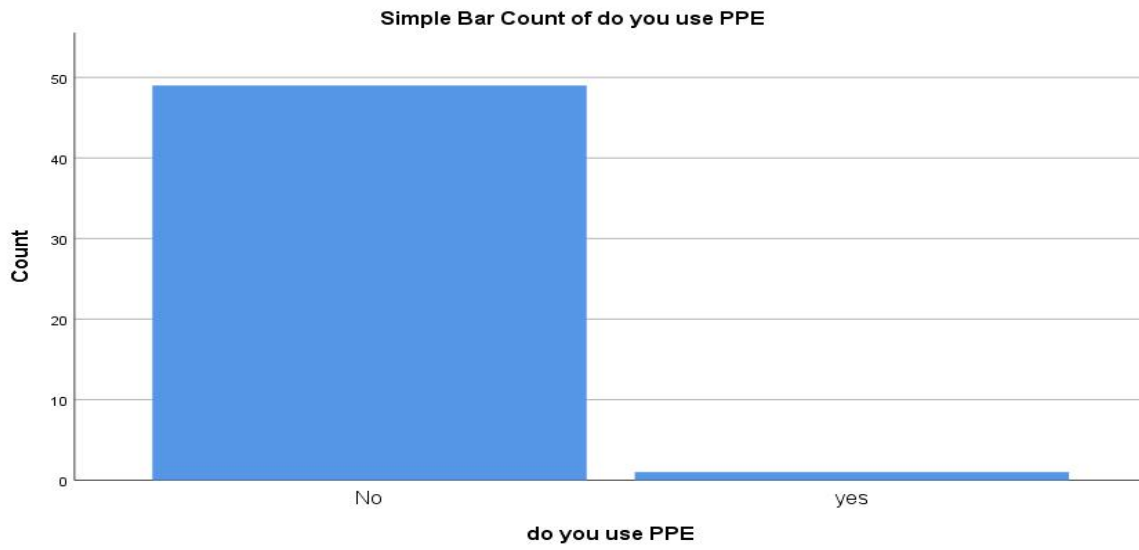


Source: Author's Field Work, 2023

Appendix XII

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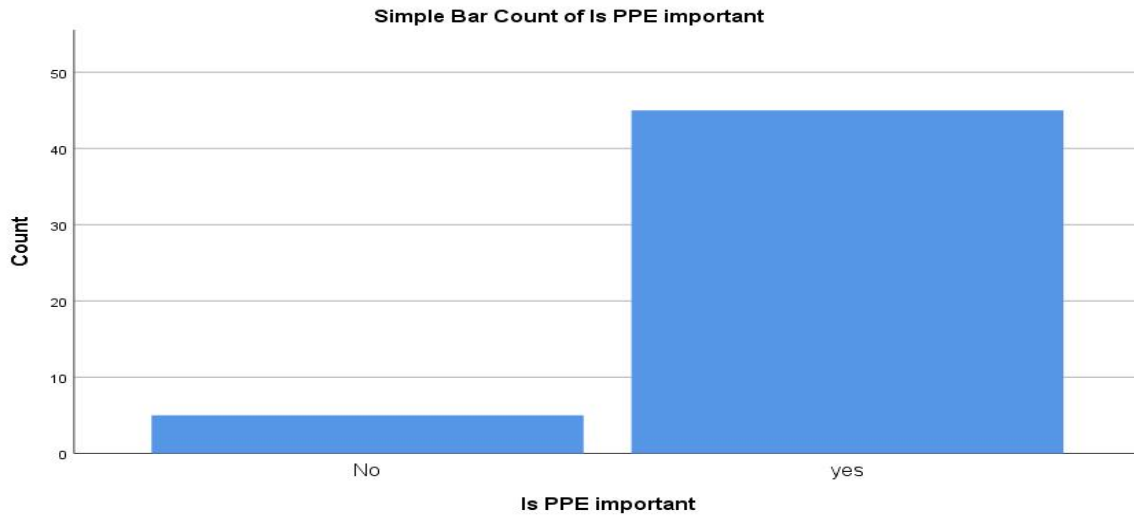
Appendix XIII



Source: Author's Field Work, 2023

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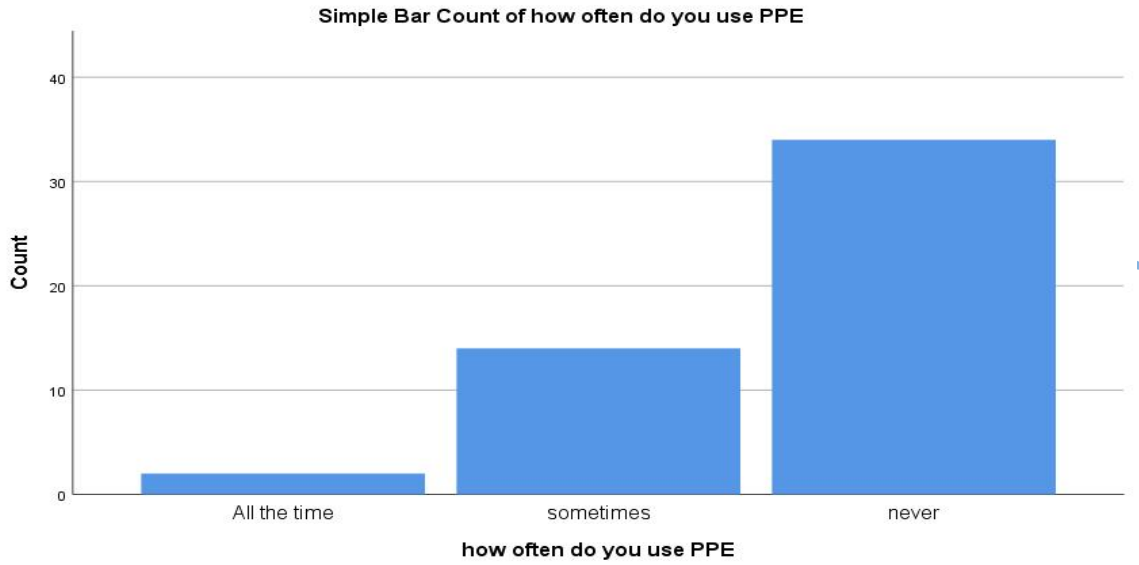
Appendix XIV



Source: Author's Field Work, 2023

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Appendix XV

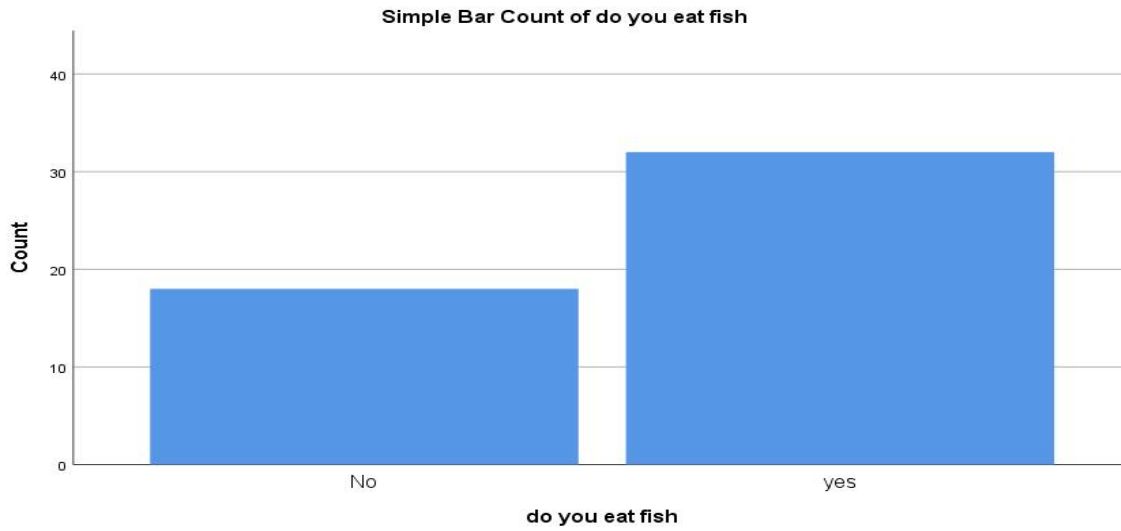


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Appendix XVI

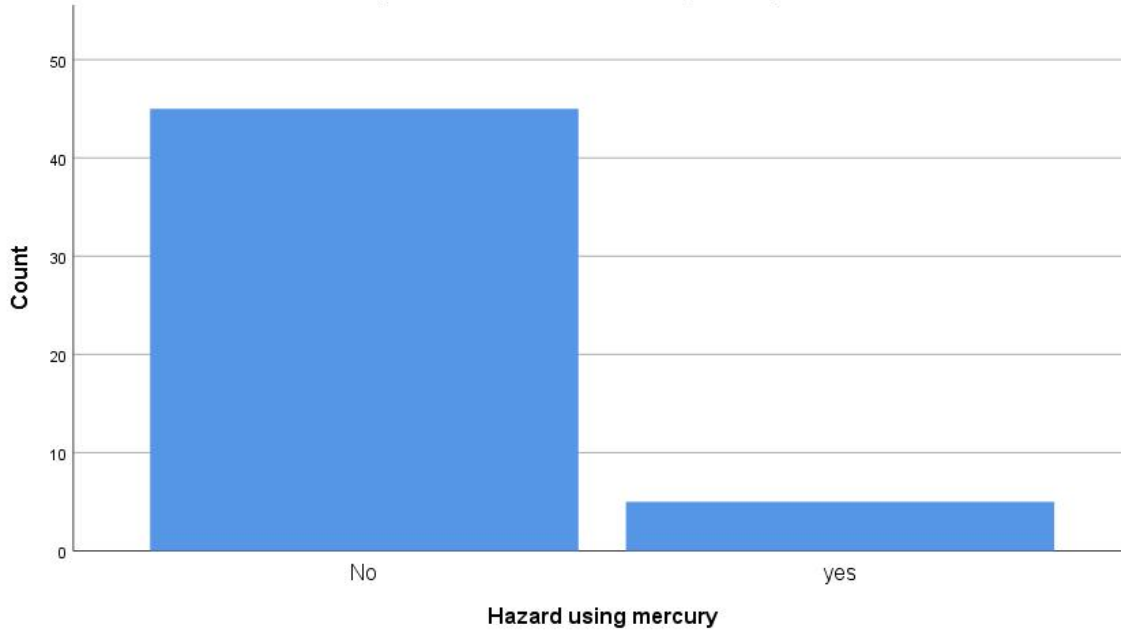


Source: Author's Field Work, 2023

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Appendix XVII

Simple Bar Count of Hazard using mercury

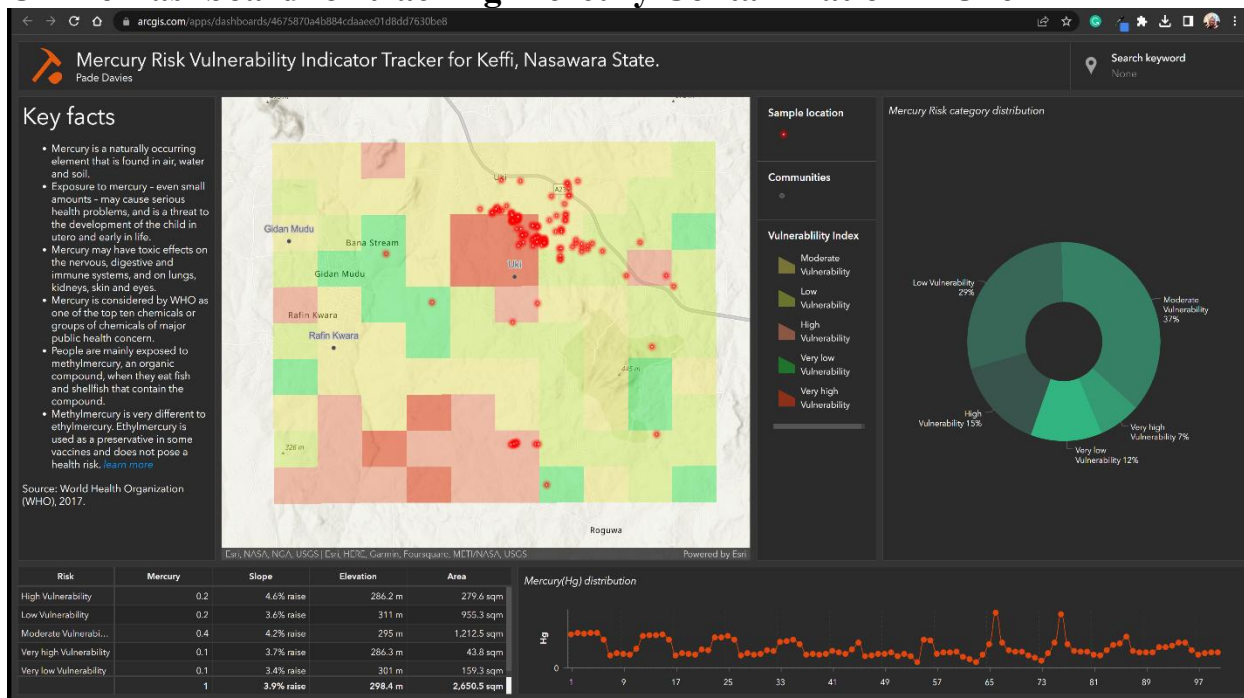


Source: Author's Field Work, 2023

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Appendix XVIII

Online Dashboard for tracking Mercury Contamination in Uke



Source : Author's Field Work, 2023

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Appendix XIX
Surface water Parameter Measurement



Source: Author's Field Work, 2023

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Appendix XX

Field Operations of Miners



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ce: Author's Field Work, 2023

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Appendix XXI



Soil Sampling with the Auger

Source : Author's Field Work, 2023

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Bio-data

A. Personal Data:

- 1. Full Name:** Davies Henry Olapade
11 Crescent, House 75, Kado Estate, Abuja.
padedavies@gmail.com
08036212155
- 2. Date and Place of Birth:** 12th July, 1966; Abeokuta
- 3. Nationality:** Nigerian
- 4. State of Origin:** Ogun State
- 5. Name and Address of Next of Kin:** Davies Olabisi
11 Crescent, House 75, Kado Estate, Abuja.

B. Educational Background:

Educational Institution Attended with Dates and Qualification:

School Attended	Dates	Qualifications
❖ Iwo Grammar School, Iwo	1976 - 1981	GCE
❖ Ahmadu Bello University, Zaria.	1982 - 1986	B.Sc Geology
❖ University of Nigeria, Enugu Campus	1992 - 1993	PGD Management
❖ University of Nigeria, Enugu Campus	1993 – 1995	MBA
❖ Enugu State University of Science & Tech.	1993 – 1996	M.Sc Envat'l Mgt.
❖ Lead City University, Ibadan	2020-2023	Phd in view

C. Working Experience with Dates:

- ❖ Bajok Farms, Ikare-Akoko (NYSC) 1986 – 1987
- ❖ Geological Survey Department (Ministry of Solid Minerals Development) 1987 – 2004
- ❖ Nigerian Geological Survey Agency 2004 - 2022

D. Publication

- ❖ Development of a Mineral Occurrences Database for National Development at NMGS Calabar Conference: 2007
- ❖ Development of A Geospatial Database for Sustainable Management of Nigerian Mineral Resources at Accra, Ghana, 2013
- ❖ Development of Nigerian Drill-Core Database as a Tool in Sedimentary Basin studies: International Conference on Sedimentology, Ibadan, 2014
- ❖ Development of Nigerian Drill-Core Web-based Database as a Tool in Sedimentary Basin Studies at NMGS Conference, 2015, Lagos
- ❖ The Development of A Nigerian Web-Based Portal for Accessing Geosciences information at Giraf Workshop , Maputo October, 2015
- ❖ Mercury Contamination from Gold Mining Activities on Surface and Groundwater of Uke: Possible implications on Community Health at 5th Conference on international Medical Geologists Association -Nigeria, August ,2022
- ❖ Integrated assessment of risk of Mercury Exposure from Artisanal Mining Activities at Uke, Nassarawa State Using GIS and Remote Sensing Methods. Leads City Faculty of Science Conference, November 2022

Signature

Date

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The University Compliance Certification

This is to certify that, this Thesis is written **Davies, Henry Olapade** with Matric number **LCU/PG/001668**, in the Department of Biological Science, Faculty of Natural and Applied Sciences, Lead City University, Ibadan is in full compliance with the approved University format and style.

Signature

Date

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