THE EFFECTS OF LEAD-ZINC MINING ON SOILS IN AMEKA AREA AND ITS ENVIRONS SOUTH EASTERN NIGERIA ABAKILIKI SHEET 303 NORTH EAST

BY

INIEKUNG, Glory Ita
MTech/SPS/2018/8130

DEPARTMENT OF GEOLOGY
FEDERAL UNIVERSITY OF TECHNOLOGY MINNA

JUNE, 2023

THE EFFECTS OF LEAD-ZINC MINING ON SOILS IN AMEKA AREA AND ITS ENVIRONS SOUTH EASTERN NIGERIA ABAKILIKI SHEET 303 NORTH EAST

BY

INIEKUNG, Glory Ita
MTech/SPS/2018/8130

DEPARTMENT OF GEOLOGYFEDERAL UNIVERSITY OF TECHNOLOGY MINNA A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF TECHNOLOGY (MTECH) IN MINERAL EXPLORATION

JUNE, 2023

ABSTRACT

The aim of this work is to determine the impact of mining lead – zinc on soils in Ameka area and its Environs, Ebonyi State, Southeastern Nigeria. Heavy metal pollution in Nigeria environment is a major concern due to their toxicological effect on human and plants and the environment, greatly degrading soil and water quality and will ultimately harm to health of living organism by food chain. The study of the geology of the area was carried out using previous literature and traverse methods. The area is underlain by Abakaliki formation of the Lower Benue trough. Based on the lithological characteristics observed in the field, the shale unit may be divided into two lithofacies: dark grey shale lithofacies and light grey highly fissile shale. A total of thirty-nine samples were collected using systematic random sampling method and analyzed using atomic absorption spectroscopy and ultra violet / visible spectroscopy. The collected soils/ stream sediments were analyzed for heavy metals Zn, Pb, and Cu. to define the concentration levels of these metals in the stream bed sediments and soils within the study area, especially within farmlands where a high concentration of heavy metal could be absorbed by plants and within water reservoirs where surface runoff could contaminate the water system. The analysis reveals the presence of Lead within the study area. Lead has a concentration range of 0.225 mg/kg to 66.973 mg/kg, mean concentration of 24.861 mg/kg and a standard deviation of 24.843 mg/kg. The

geochemical background value suggested that Lead sources in surface water or sediment include deposits of lead-containing dust from the mining pile and wastewater from industries/mining. The analysis also shows that Zinc has a maximum concentration of 96.093 mg/kg within the study area. The result is variable distribution of Zn element concentration within the study area; However, 100% of samples show concentrations below the ERL and ERM; thus, indicating less risk to Zn toxicity to the area's inhabitants. The potential health risk associated with accumulation of toxic heavy metals in the body could lead to the damage of internal organs, degrading mental health and central nervous function. Prolonged exposure can result in slowly progressing physical, muscular, and neurological degenerative processes that mimic Alzheimer's disease, Parkinson's' disease, muscular dystrophy, and multiple Sclerosis.Generally, the study reveals that the soil in this area is contaminated and water sources in the study area is unsuitable for consumption. To minimize these effects, specific precautionary measures must be taken by both the government and the mining companies in order to curb the effects of these heavy metals.

TABLE OF CONTENTS

CHAPTER FOUR

CHAPTER FIVE

LIST OF TABLE

LIST OF FIGURE

Figure **Page**

LIST OF PLATE

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Mining is the extraction of valuable minerals or other geological materials from the Earth, usually from an ore body, lode, vein, seam, reef, or placer deposit. These deposits form a mineralized commodity that is of economic interest to the miner. (Gosar, 2004; Xiao *et.al*; 2017).

Ores recovered by mining include metals, coal, oilshale, gemstones, limestone, chalk, dimension-stone, rock salt, potash, gravel, and clay. In a wider sense, mining includes extraction of any non-renewable resource such as petroleum, natural gas, or even water.

Modern mining processes involve prospecting for ore bodies, analysis of the profit potential of a proposed mine, extraction of the desired materials, and final reclamation of the land after the mine is closed (Gosar, 2004; Xiao *et.al;* 2017).

Mining operations usually create a negative environmental impact, both during the mining activity and after the mine has closed. Hence, most of the world's nations have passed regulations to decrease the impact. Work safety has long been a concern as well, and modern practices have significantly improved safety in mines.

There are four main mining methods:

Underground Mining: Underground mines are more expensive and are often used to reach deeper deposits. Tunnel digging and sink shafts are done once the ore or mineral deposit is below the surface, Hand tools like chisels, hammers and wedges are also used to break up waste rock. The domain also needs to be blasted to remove rock so that the miners can easily separate the gold from the separately mined waste rocks.

Surface Mining: surface mines are typically used for more shallow and less valuable deposits. Workers Start by removing the overburden that lies above the surface, which are rock, soil and ecosystem.

Placer Mining: This is used to sift out valuable metals from sediments in river channels, beach sands, or other environments.

In-situ Mining: This is primarily used in mining uranium and involves dissolving the mineral resource on the spot then processing it at the surface without moving rock from the ground. (Xiao *et.al;* 2017).

The mining method used depends on the type of mineral resource that is mined, its location at or beneath the surface, and whether the resource is worth the cost to justify extracting it. Each mining method also has varying degrees of impact on the surrounding landscape and environment. (Uzoekwe and Aigberua, 2019).

Heavy metal pollution in Nigeria environment is a major concern due to their toxicological effect on human and plants. Heavy metals are natural constituents of earth crust and through natural processes such as erosion, volcanic eruption, they are transported and deposited in the environment. Significant amount of wastewater, generated from anthropogenic activities such as mining and smelting, fertilizer production, battery manufacturing, electroplating, wood preservation and agricultural activities pose a high risk to the environment, ecosystem and human health (Gosar, 2004; Xiao *et.al;* 2017). There is evident of mining activities being responsible for heavy metal contamination of both land and water (Johnston, 2004; Foulds *et al;* 2014).

Floods occurring at mining sites are considered to be serious contaminant dispersion agent (Mayes, *et.al*, 2013). Crude oil extraction has shown to contribute lead (Pb) and cadmium (Cd) contaminant to an industrial area (Uzoekwe and Aigberua, 2019).

In Nigeria, solid mineral exploitation is underdeveloped giving rise to artisanal and small-scale mining (ASM) with attendant pollution problems. Artisanal mining is illegal in many cases, and thus degrade the environment (ILO, 1999). ASM has experienced explosive growth in recent years due to the rising value of mineral prices and increasing difficulty of earning a living from agricultural and other rural activities. In 2017, an estimated population of 40.5 million people worldwide were directly engaged in ASM, up from 30 million in 2014, 13 million in 1999 and 6 million in 1993 (IGF, 2017).

In 2010, widespread and acute lead poisoning in Zamfara state, northern Nigeria killed at least 400 children (Medecins Sans Frontieres, 2012). It is considered as the worst outbreak of lead poisoning in modern history; more than 3,500 affected children require urgent, lifesaving treatment. In adults there are high rates of infertility and miscarriage (WHO, 2012). World Health Organization (WHO) in its Bi-Monthly Newsletter dated March to April 2012, tied the heavy metal contamination to artisanal gold mining in Pb-rich ore within the area. Gold and associated Pb-Zn-Cu sulfide ore is mined artisanally and processed manually in residential areas. During processing, mercury is added to the mineral ore to amalgamate the gold, hence, introduced into the ecosystem within the area. There have been other reports on heavy metal pollution arising from artisanal mining in the study area (Azubike, 2011, Babajide, 2011, UNICEF 2010-2011 and Uriah *et al*; 2013).

Heavy metal contamination in soil is a major concern in our today society; soil composition is an important aspect of nutrient management. While soil minerals and organic matter hold and store nutrients, soil water is what readily provides nutrients for plant uptake. Soil air, too, plays an integral role since many of the microorganisms that live in the soil need air to undergo the biological processes that release additional nutrients into the soil.

The basic components of soil are minerals, organic matter, water and air. The typical soil consists of approximately 45% mineral, 5% organic matter, 20-30% water, and 20-30% air Schnitzer (1983). These percentages are only generalizations at best. In reality, the soil is very complex and dynamic. The composition of the soil can fluctuate on a daily basis, depending on numerous factors such as water supply, cultivation practices, and/or soil type. (Pett-Ridge, 2005).

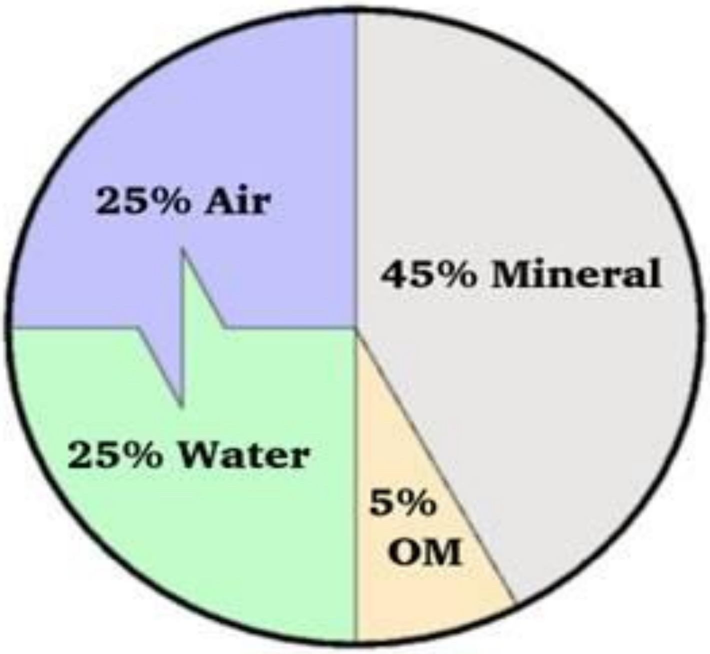

Figure 1.1: Approximate composition of soil
(Source: http://courses.soil.ncsu.edu/resources/physics/composition/compo3b.png)

The solid phase of soil, which includes minerals and organic matter, are generally stable in nature. Yet, if organic matter is not properly managed, it may be depleted from the soil. The liquid and gas phases of the soil, which are water and air respectively, are the most dynamic properties of the soil. The relative amounts of water and air in the soil are constantly changing as the soil wets or dries.

Heavy metals cannot be degraded; therefore, they are continuously being deposited and incorporated in water, thus causing heavy metal pollution in water bodies. These heavy metals may adversely affect soil ecology, agricultural production or product quality, and ground water quality, and will ultimately harm to the health of living organism by food chain. Sardar, *et al*., 2013

1.2 Study Area Description

1.2.1 Location, Extent and Accessibility of the Study Area

The study area lies between longitudes 8° 06' 30"E and 8° 08' 30"E and latitudes 6° 09' 30"N and 6° 11' 15" N (Fig 1.1). It extends from Amanchara in the north to Ameka in the south and Izzi and Amorie communities in the east and west respectively covering a total area of about 20.1 Km^2. The only major town within the area is Ameka, others being rural communities where mining activities have been going on. These communities include Ameri and Amanchara (in Izzi Local Government Area), and Amorie all in Ebonyi state, Southeastern Nigeria.

1.2.2 Accessibility

The area is accessible through a network of well-developed Major roads; these include the Ameka - Abakaliki road and Abakaliki - Amachara road. These roads are major express roads that lead to the area at various points. Minor roads in the area include:Ameka – Ameri - Eyingba road, Amorie – Ameka road and Ameka – Amechara road. Footpaths were also available to access some villages, thereby accelerating the transverse of the area (Fig1 2).

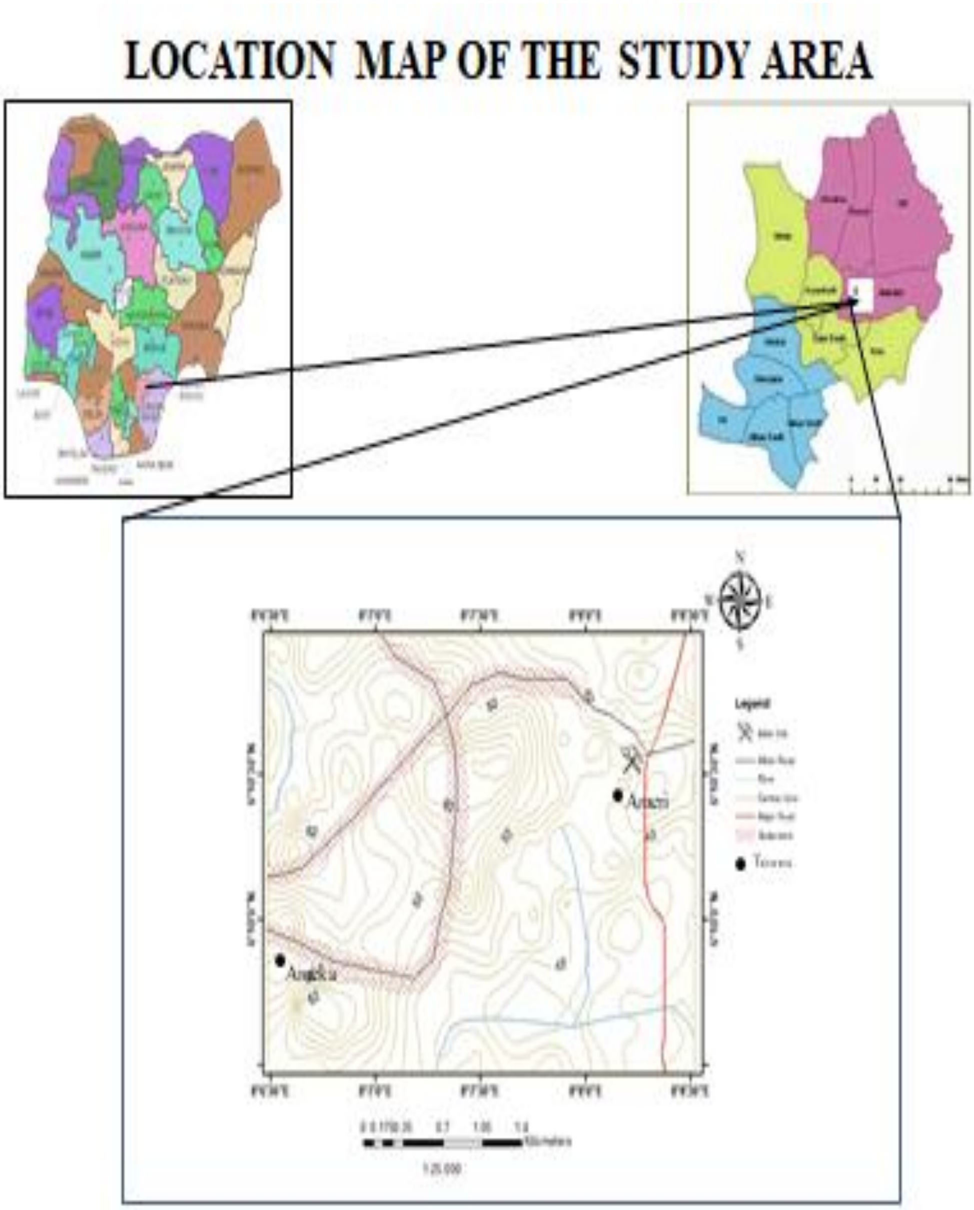

Figure 1.2: Location Map of the Study Area.

1.3 Geomorphology and Drainage

1.3.1 Geomorphology

The geomorphology of the study area is controlled by the prevalent structural, lithologic and physico-chemical factors. The topography could be described as comprising irregular ridges and gentle sloping hills. The elevation of the highlands ranges from 42m to 62m above mean sea level, while the lowlands rise to an average of about 30m

(Fig.1.3) (Aghamelu, 2011). The area is characterized by a uniform sloping drainage slightly tilted eastward. This is due to the Basement complex rocks of the oban massif, Obudu hills and Mamfe Embayment, which bound the area to the east (Obasi, *et al*., 2014). These topographic features are controlled by the bedrock geology.

The Abakaliki area is underlain by sedimentary rocks with pronounced intrusions of pyroclastic rocks in many places. The lithology consists mainly of well-indurated shales, argillaceous sandstones, siltstones and mudstones. The well indurated sandstones and siltstones are exposed at the hills and ridges while the shales and mudstones occupy the lowlands. The geomorphology controls the movement of the hydrochemical attributes in water. (Obasi, *et al*., 2014).

1.3.2 Drainage

Surface drainage in the study area is controlled by the Ebonyi River (Fig.1.3). This river traverses the entire study area with its eminent tributaries and distributaries transporting its hydro chemical attributes from one point to another. It flows predominantly North - South. Other major rivers in the area include Rivers Abe, Iyiokwu, Ololo, Achi and Atang while some minor ones include River Akpara, Ohamini, Ewe, Ogbogbo, Awumini and Oyirigbo. These rivers and streams vary in sizes, colour, taste, flowpath and chemistry. Some are seasonal and therefore, dry up during the dry season and increase in volume during the rainy season.

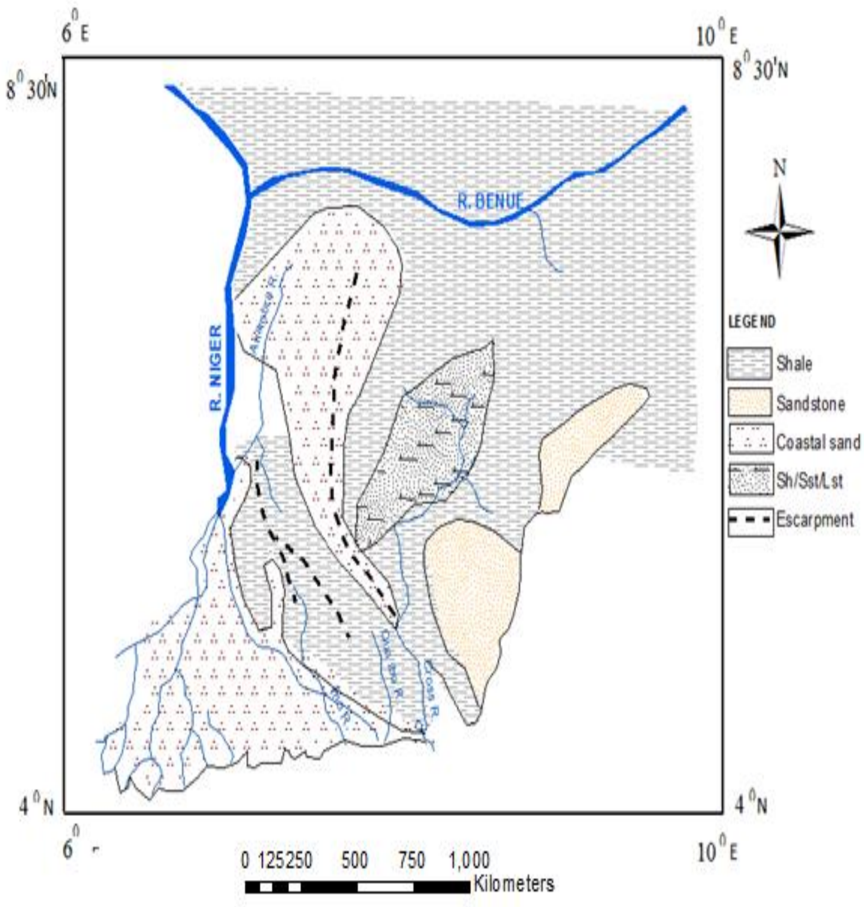

Figure 1.3: Map of South-Eastern Nigeria gross physiography, and geology (Egboka 1988).

The origin of most of these rivers and streams has been linked to the fractured shale and impervious contact between the shale and sandstone lenses, which characterize the lithology of the area (Okagbue and Ukpai, 2013). Due to the poor economic situation in these areas, these surface water resources have not been developed optimally. However, the Ezillo water Scheme, and more recently, the Oferekpe and Ukawu water Schemes are among the governmental efforts to extend the availability of pipe-borne water to rural areas, including this study area.

1.4 Climate and Vegetation

1.4.1 Climate

The study area (Fig.1. 4) is part of the tropical hinterland climate (Illoeje, 1979). The average monthly rainfall is about 222mm, with mean annual temperature of about 29^{0}C (FARM Unit, EBSU, 2009). It has a relatively longer rainy season (March-October) and a shorter dry season (November to February). These two climatic regimes are caused by two prevailing air masses that blow across Nigeria at different periods of the year. The tropical maritime air mass originates from the Southern high-pressure belt, which crosses the equator, and picks up moisture from the Atlantic Ocean and enters Nigeria from the south. This air mass (wet) is responsible for the wet season. The tropical continental air mass (essentially dry) originates from Eurasia-Arabia high-pressure belt (Ajayi, 2003). Its effect predominates in Nigeria from October to February, resulting in dry periods. The dry season is also characterized by the northeasterly wind (the hamattan wind) which causes extreme dryness.

Climatological analysis of rainfall and temperature of the study area shows that between 1999 and 2008, May and June received the highest amount of rainfall, while January and February have the least. February has the highest mean annual temperature, with August as the lowest, (Obasi, 2009). The result of this analysis is supported by Inyang (1975) who reported that the area falls within the fourth climatic region with four dry months. The driest month has annual rainfall less than 2.9mm, with the mean annual rainfall ranging from 2000-2500mm.

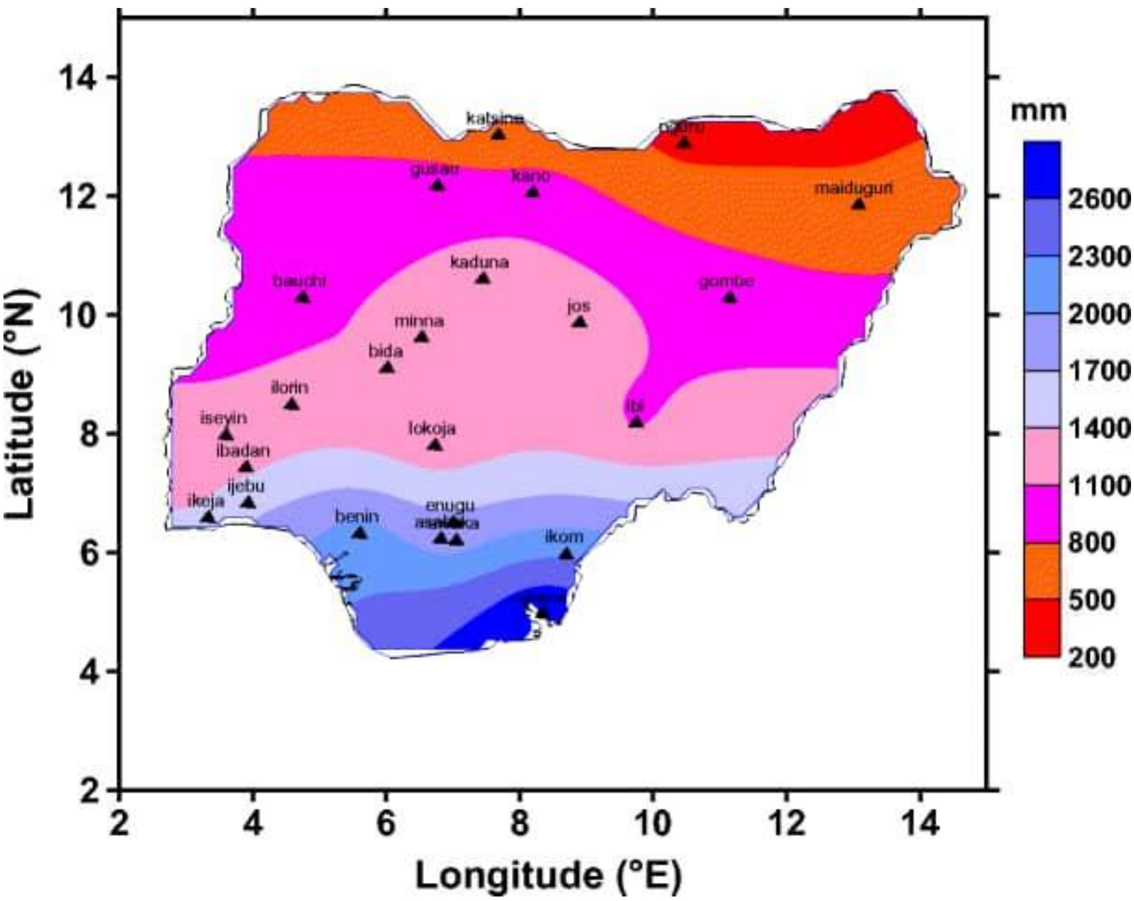

Figure 1.4: Mean annual rainfall distribution in Nigeria (Akintomide and kehinde, 2014).

1.5 Vegetation

The study area is part of the rain forest region of southeastern Nigeria (Fig.1.5). It has a humid climate and evergreen vegetation. The vegetation cover is composed of very dense trees and undergrowth of creepers. These trees are mostly tall, with buttress roots. However, consistent farming in the area has left some parts of the land bare, cultivated or fallowed.

The vegetation is controlled by many factors, including the drainage, topography, lithology and rainfall. The area has been described as part of the lowland rainforest region (Nnabo et al, 2011). The forest is rich in loamy and humus soils, which support the farming activities of the inhabitants of the area.

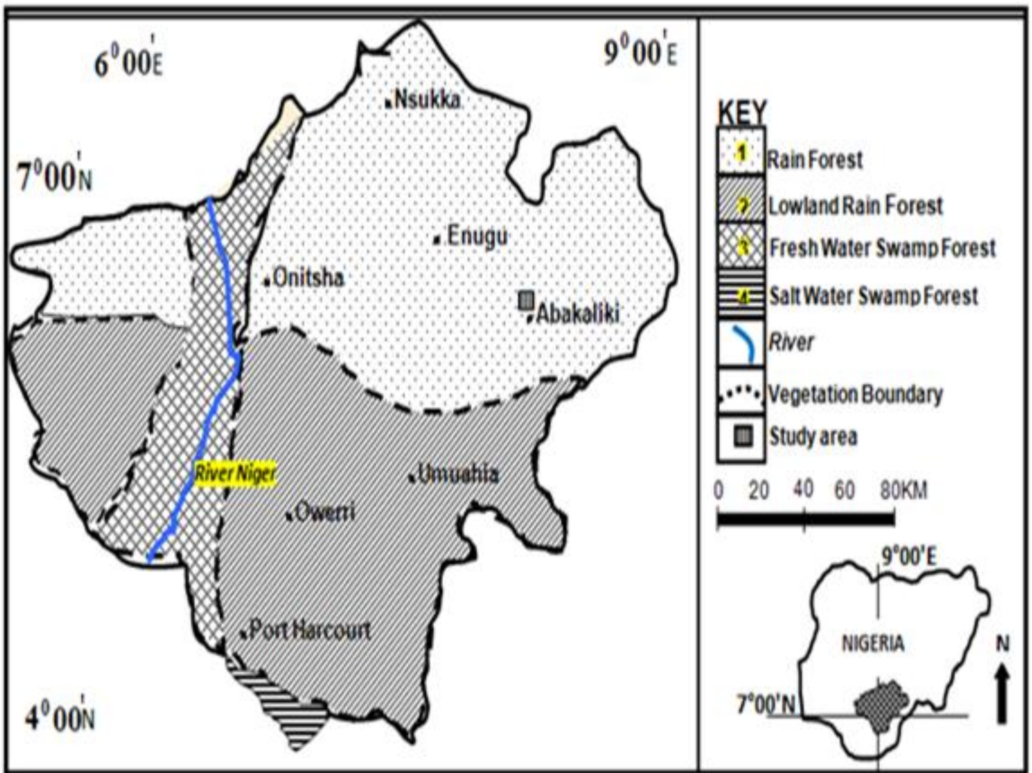

Fig. 6: Map showing vegetative zones* of Southeastern Nigeria (Modified after Murat 1972).

[*Zone's characteristics; 1 has 4 dry months with average rainfall of less than 4.9 cm a month. Zone 2 has 4 dry months with driest month being less than 2.9 cm of rainfall, and zone 3 has 3 dry months with less than 6 cm rainfall a month, while zone 4 has 1 to 2 dry months of less than 6 cm of rainfall a month.]

Figure 1.5: Vegetative zones of Southeastern Nigeria (Modified after Murat, 1972).

1.6 Statement of the Research Problem

In 2010, widespread and acute lead poisoning in Zamfara state, northern Nigeria killed at least 400 children World Health Organization (WHO) in its Bi-Monthly Newsletter dated March to April 2012, tied the heavy metal contamination to artisanal gold mining in Pb-rich ore within the area. Since the discovery and mining of mineral deposits in the

Abakaliki area in the early 1990s, not much data exists on the geochemical attributes of mining activities in the environment. Heavy metal weathering of the mineral deposits may have adverse consequences on soil quality due to soil – water interaction. Apart from the challenges to sustainable water quality, pollutants and contaminants from mining sources constitute a major threat to human health, aquatic lives, land use and agriculture and other aspects of ecosystem imbalance. Soil/ land degradation problem is evident within the mining axis. Mine wastes and tailings are directly discharged into farmlands and river channels. Rural dwellers in various communities commonly depend on water from the abandoned mines and drainage channels for their domestic activities. Numerous health challenges such as miscarriages, selenosis in infant, decline in fertility, physiological and mental in balance are commonly encountered in various communities. They mostly refer these health cases to evil forces and evil men and probably as penal measures for inadequate sacrifices to their gods.

Although several authors including Ezeh and Nnabo (2006), Ezeh *et al*., (2007), Nnabo *et al.,* (2009), Nnabo *et al*., (2011), Okagbue and Ukpai (2013), Obarezi and Nwosu, (2013), Oti and Nwabue (2013), Obasi and Akudinobi (2015), Obasi *et al*., (2015) Obiora *et al*., (2015) have done some work in parts of the study area, with minimal emphasis on soil. There has not been any major assessment across the mining fields and local farmlands which, World Health Organization (WHO,1991) stated that it was the major source for heavy metals pollutant in Zamfara. Also, geohydrological studies to determine the principal water flow direction of the hydrochemical attribute has not been done.

It is based on this background that an assessment of the quality of the environment (especially in the area of land use safety) in the mining axis of Ebonyi State, Nigeria should be carried out. The soil will be investigated, since the affected communities are predominantly farmers and water assessment will be carried out around polluted areas. Emphasis shall be placed on qualitative assessment of the various soils in the area and various input sources of hydrochemical significance shall be assessed. Therefore, making valuable information in this regard may likely alleviate the numerous health problems in the area and constitute a vital planning tool to healthcare providers, environmental management and regulatory authorities. There is need to investigate the movement of groundwater in the area, since the possible contaminants in the host rocks can migrate and be carried along in solution from one point to another. This will assist in the delineation of safe and unsafe areas with respect to contaminant transportation and waste management, and will also be used to determine recharge and discharge areas, which constitutes a vital tool in groundwater prospecting and management.

1.7 Justification for the Research Work

Mining of lead-zinc in Ebonyi State has been ongoing for more than 75 years and has been unregulated. Artisanal miners and indeed every member of the communities where we have these mining sites are exposed to contamination due to the ignorance of the miners to employ protective and safe measures of mining. These miners that have little to zero knowledge about proper mining practices excavate lands and leave large pits and, in some areas, obsolete tunnels which are unstable. These mine workers work without protective gears and among these mine workers are women and sadly children. Water used to wash the extracted lead are disposed at the earth surface, stock pile are affected by surface runoff which carries the lead into nearby streams and rivers, farmlands, and some seep into wells, Water collected in the pits also gradually seeps into underground water. This causes the contamination of streams, rivers, Wells, soils and as such the plants growing within those areas. This scenario is a ticking time bomb.

I. The research shall provide a data bank on the geochemical characteristics of soils, stream sediments and water sources of the areas.

II. This data constitutes the basic planning tool for economic development especially in the areas of urban planning, water resources development, mineral resources development and waste management.

III. This study will provide the adverse consequences of mineralization and mining activities in the study area.

IV. This study will provide information on the groundwater conditions.

V. Hence determining the sustainability of the water for consumption.

1.8 Aim and Objectives

The aim of this work is to determine the effects of mining lead – zinc on soils in Ameka area and its Environs, Ebonyi State, Southeastern Nigeria. Within this broad aim, the specific objectives are to:

i. Establish the geology of the area.

ii. Assess the mining techniques and processing methods in the area.

iii. Establish the physical and chemical composition of the medium.

iv. Establish the effects of Lead-Zinc mining on soils.

1.10 Scope and Limitation of the Work

1.9.1 Scope of Work

The scope of work is limited to Ameka and its environs which includes:

i. Establishing the geology of the area

ii. Assessment of mining methods and processes

iii. Taking soil and water samples

iv. Analyzing the samples in a laboratory using appropriate analytical methods.

1.9.2 Limitations

Challenges imposed on the work includes:

i. Unavailability of a suitable exposure (ditches, cleaves) for geological studies which led to reliance on existing literature to establish the geology of the area.

ii. Also, laboratory restrictions which did not allow total compliance to exact procedures required for sample analysis.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Geology of Nigeria

The stratigraphy of Nigeria Sedimentary basins has been subdivided into the pre-Cretaceous, Cretaceous, Tertiary and the Quaternary (Murat 1972). The Southern sedimentary basin of Nigeria belongs to the Benue Trough. The Trough was formed by the break-up of the South- American and African continents in the Early Cretaceous (Murat, 1972; Burke, 1976). Various cases of geomorphologic, structural, stratigraphic and Paleontologic evidence have been presented to support a rift model (Reyment, 1969; Benkhelil, 1989; Guiraud and Bellion, 1995).

Three sedimentary phases/cycles have been described in the regional stratigraphic history of southeastern Nigeria (Short and Stauble, 1967; Murat, 1972). These three phases include the Abakaliki-Benue phase/the first sedimentary cycle (Aptian-Santonian); the Anambra-Benin phases/second sedimentary cycle (Campanian – Mid Eocene); and the Niger Delta phase/third sedimentary cycle (late Eocene-Pliocene) (Oboh-Ikuenobe *et al.*, 2005). Each of these sedimentary phases is bounded by sequence boundaries with unconformity surfaces. Table 2.1 shows the regional stratigraphic sequence of southeastern Nigeria.

Table 2.1: Regional Stratigraphic Sequence of South Eastern Nigeria.

Quatenary	Pleistocene Pliocene Miocene	Benin	
		Ogwashi-asaba	
	Oligocene		3rd sedimentary cycle/phase
Tertiary			
	Eocene	Ameki	Niger delta. (developed during the upper eocene)
	Paleocene	Imo shale	
Upper cretaceous	maastrichtian	Nsukka Ajali sandstone	2nd sedimentary cycle/phase
		Mamu	Anambra basin/
			Afikpo basin
	Campanian	Nkporo Shale	
	Santonian	Diastem (uncomfomity)	1st sedimentary
	Coniacian	Awgu shale	Cycle/phase
	Turonian	Ezeaku group	The abakaliki –
	Cenomanian Albian	Odukpani Asu	Benue basin
		River group	
Lower Cretaceous	Aptian	Unnamed Units	
	Barremian	Precambrian Basement Complex	
	Hauterivian		

(adapted from Reyment, 1965, Murat, 1972 and Hoque, 1977)

The first cycle was initiated by the Mid-Albian transgression. The product of this transgression is the Asu River Group. The first regressive phase deposited the Odukpani Formation (Cenomanian). This was followed by the Turonian global transgression that deposited the Ezeaku Group and then, a regression that followed deposited the Coniacian Awgu Shale (Petters, 1978). This sedimentary cycle was terminated by the Santonian tectonic episode, which resulted in the folding of the earlier deposited sediments (Hoque and Nwajide, 1985; Murat, 1972).

The second sedimentary phase resulted from the Santonian folding and uplift of the Abakaliki region and dislocation of the depocenter into the Anambra Platform and Afikpo Region (Oboh-Ikuenobe *et al.,* 2005). The third marine transgression occurred in this sedimentary phase and deposited the Nkporo Group unconformably over the folded pre-Santonian sediments (Murat, 1972). Regressive phases which occurred during the Campanian to early Maastrichtian deposited the Mamu Formation, Ajali Sandstone and Nsukka Formation respectively (Oboh-Ikuenobe *et al.,* 2005) See Figure 2.1.

The third sedimentary phase, linked to the formation of the proliferous Niger Delta commenced in the late Eocene as a result of a major earth movement that structurally inverted the Abakaliki region and displaced the depositional axis further to the south of the Anambra Basin (Hoque, 1977). The wide spread marine transgression that began in the Paleocene led to the deposition of sediments that developed the proto-Niger Delta (Short and Stauble, 1967; Murat, 1972; Kogbe, 1976).

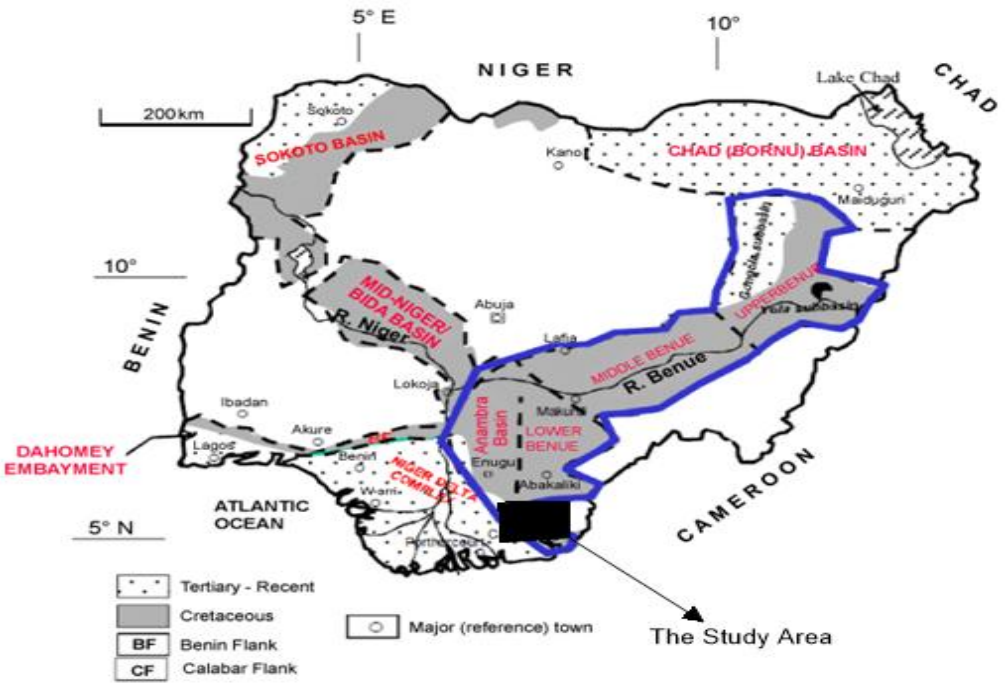

Figure 2.1: Map of Nigeria Showing Sedimentary Basins (after Abdulfatai *et al*., 2014)

2.2 Geology of the Benue Trough

The Stratigraphic History of South-Eastern Nigeria started with the deposition of marine shales, with subordinate sandstones and limestones ranging in age from middle – upper Albian. These rocks consist of non-fossiliferous, arkosic, poorly sorted, commonly cross-bedded sandstones and grey to dark fossiliferous shales.

The rocks are exposed around Ogoja and Abakaliki areas (Reyment, 1965). Uzuakpunwa (1974) however dated the Ogoja sandstone as Aptian. Nwabufo-Ene (1976) noted that the Abakaliki Shales of the Asu River Group is middle Albian, while the sediments at Ishiagu and Ndeaboh are early Albian. However, the Albian stage is the first transgressive phase of the Benue Trough. The regressive phase to this transgression occurred in the Cenomanian and deposited the Odukpani Formation in the Calabar Flank. These rocks consist of alternations of sandstones, shale, sandy shale and fossiliferous limestone.

In the Turonian, a further global transgression occurred and deposited the Ezeaku Group. It consists of grey shales, limestone lenses, siltstones and sandstones with shallow marine fauna such as ammonites, gastropods, pelacypods and foraminiferas (Fayose and Klast, 1976). The formation grades laterally into the Amasiri Sandstone and Awgu Shale. The regressive phase deposited the Coniacian Awgu Shales (Reyment, 1965).

The Santonian is a period of non-deposition (Oboh-Ikuenobe *et al.,* 2005). It resulted in the uplift, folding and widespread erosion of the pre-Santonian sediments (Short and Stauble, 1967). The Santonian events signified the end of the Aptian-Santonian sedimentary phase and also led to the uplifting of the Abakaliki Anticlinorium (Kogbe, 1976).

Subsidence occurring after the folding initiated renewed marine transgression and hence the deposition of the Nkporo Shales and its lateral equivalent, the Enugu Shale and OweiliSandstone (Kogbe, 1976; Short and Stauble, 1967). Minor regressions within this transgression deposited the Mamu Formation, Ajali Sandstone and Nsukka Formation comformably over the Nkporo Shales. The Nkporo is Campanian while others are. Maastrichtian in age (Kogbe, 1976).

Marine transgression was widespread in the Tertiary period. A major transgression in the Paleocene deposited the Imo Shale. At the end of the Paleocene, renewed regression initiated the period of deposition of the Tertiary Niger Delta. This regression deposited the Ameki Formation. The ages of this formation have been considered to range from Early to Middle Eocene (Reyment, 1965, Adegoke, 1969). This consideration is due to the ostracod and foraminiferal assemblages of this formation.

The Eocene progradation continued into the Oligocene and deposited the Ogwashi-Asaba Formation (Kogbe, 1976). Reyment (1965) suggested an Oligocene-Miocene age for the Formation. This stratigraphic unit is represented by the Benin Formation (Oboh-Ikuenobe *et al*, 2005). Figure.2.2

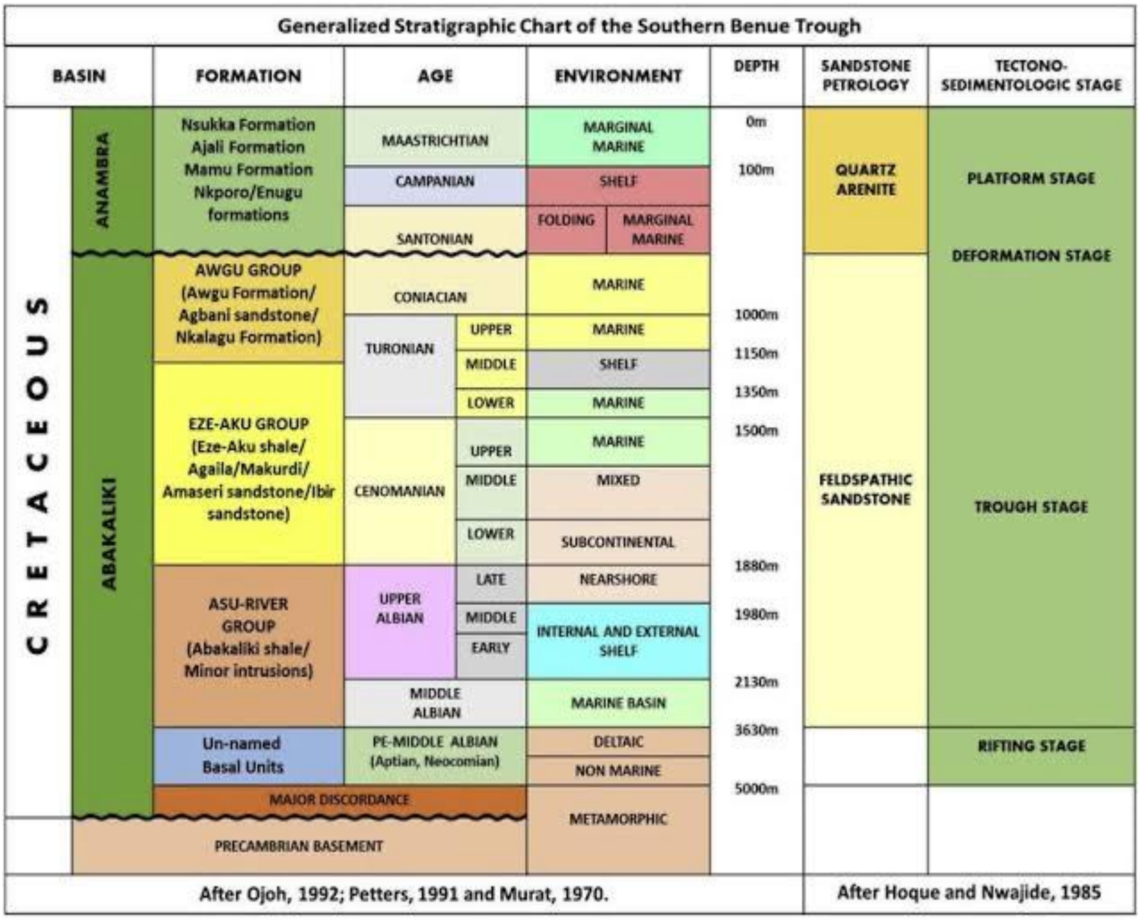

Figure 2.2: Stratigraphic Chart of the Southern Benue Trough (Kelechi, 2017)

2.3 Mining Processes and Techniques

The mining method used for the exploitation of the lead-zinc deposit is the open cast method. This method involved the opening of over-burdens (indurated Shale) by blasting and removing boulders by machines and man-made methods. The indurated nature of the Shale makes blasting a recommended method (according to the head of mines at Royal Salt). The lead-zinc deposit is generally associated with gauge minerals such as quartz, pyrite, and chalcopyrite; after the local miners mine the mineral deposit, it is separated from the gange manually. Then, it is bagged for shipping or sales. Big mining companies like Royal Salt have a processing plant for their mining operations; it is located in Ameri, where the deposit is fed to a smelting plant. The deposit is extracted to produce a pure lead deposit bagged and shipped out of the country.

2.4 Effects of Pb Zn Mining

Most research work in the study area has been incorporated into regional investigation. Ealier investigation in the area include those by Reyment (1965), Orajaka (1965), Murat (1972), Nwachukwu (1972), Uzuakpunwa (1974), Kogbe (1976), Olade (1976), Peters, (1978), Offodile (1980), and Benkelil (1989). Most of these works were based on the regional geology of the area. However, the discovery of lead – zinc in the Abakaliki area has attracted more interest in the detailed geological study of the area. Many workers including Ezeh and Nnabo (2006), Ezeh *et a*l;(2007), Nnabo *et a*l., (2009), Nnabo *et al*., (2011), Okagbue and Ukpai, (2013), Obarezi and Nwosu, (2013), Oti and Nwabue, (2013), Obasi and Akudinobi, (2015), Obasi *et al*, (2015) Obiora *et al*, (2015) have done some work in parts of the study area.

Detailed geological work in the Abakaliki area was first carried out by the field surveyors of the British Government of the ministry of overseas (Directorate of over-seas surveys), under the special Commonwealth African Assistance Plan, published by the Federal surveys of Nigeria in 1966. Orajaka (1965), Offodile (1980) and Nwachukwu (1975) studied the origin of the Benue Trough and established that the study area lies within the Southeastern limb of an asymmetrical axis whose axis trend NE-SW. Orajaka (1972) investigated and established the economic importance of the brine deposits in the Cretaceous sediments of Southeastern Nigeria. Recent workers like Ezeh and Nnabo (2006), enumerated the areas which are endowed with lead – zinc deposits in Ebonyi state. Ezeh *et al.*, (2009); Nnabo *et al.*, (2009), Nnabo *et al.*, (2011) have carried out preliminary investigations on the assessment and distribution of heavy metals in soils and stream sediments of Enyigba areas. Ezeh *et al.*, (2009) established high concentration of cadmium, lead and arsenic while Nnabo *et al.*, (2009 and 2011) reported moderate pollution status for soils and stream sediments of the Eka Awoke and Enyigba areas respectively. Okogbue and Ukpai (2013) investigated the concentrations of hydrochemical attributes of water resources of Abakaliki and observed high concentrations of nitrate, sulphates and some heavy metals. All these heavy metals emanate from toxic wastes. Obarezi and Nwosu (2013) studied the structural controls of mineralization in the Enyigba and Ameka area and showed NW-SE and N-S directions and dips of SW-NE direction. Obasi and Akudinobi (2015) studied the geochemical assessment and pollution status of soils of Ameka and observed moderate and extreme contamination for arsenic and cadmium respectively. Obasi *et al*; (2015) carried out hydrogeochemical investigation of water resources of Mkpuma Ekwaoku and environs and reported high concentration of heavy metals like cadmium, zinc, chromium and arsenic. Obiora et al; (2015) carried out an assessment of heavy metals in soils of the Enyigba areas and observed high risk for arable crop products. Oti and Nwabue, 2013 investigated the concentration of heavy elements in some vegetable species, and observed high concentrations in the area. In all cases, none of these workers have assessed the soil – water interaction at a particular time or season which is necessary for the study of seasonal variation. Also, these researches have not assessed the entire mining fields in order to compare the concentration and degree of pollution or contamination of the hydrogeochemical attributes in the various mining fields, and the flow direction of these hydrochemical attributes have not been established.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Preliminary Studies and Fieldwork.

3.1.1 Preliminary Studies:

The present work began with **preliminary studies** of the area which included three stages

i. Desk study which involve reviewing all literature pertaining to the subject matter and the area of study.

ii. Compilation of maps and materials needed for field work which involves map production, seeking of permits to access restricted areas and letters of introduction from the university.

iii. Reconnaissance survey of the area which was done to note the accessibility and general geology of the area to enable efficient working plan.

3.1.2 Field Work

i. Equipment used in the field include: Global Positioning System (GPS), compass clinometer, sample bags, marker, water bottles, geologic hammer, measuring tapes, pen, field notebooks and camera were used.

ii. The field work is tied to objectives 1, 2 and parts of 3 of the work and was conducted as follows:

iii. Geological mapping which was done using the traverse method, employing the use of compass/clinometers, geological hammer and topographic base map.

iv. The topographic map was on the scale of 1:25,000 and extracted from Abakaliki Sheet 303 NE.

v. Colour changes on the surface that may be a reflection of the changes in geology were noted, ditches or eroded areas were observed with the aim of unraveling the geology of the area.

vi. Taking inventories of wells and boreholes in the area which involved the determination of well depths, static water level of the area.

3.2 Collection of Samples

Soil samples were collected from stream sediments at various locations from the major tributaries and distributaries of Ebonyi River (which controls the drainage of the area), mine sites, and agricultural (crop) lands to assess the distribution of ionic species in the ecosystem Pre–test systematic sample preparation was done for each soil sample analysed, including drying, screening, and digestion. The Soil and ground water sample point on Fig.3.1 while the coordinate and description of the samples are shown on table 3.1

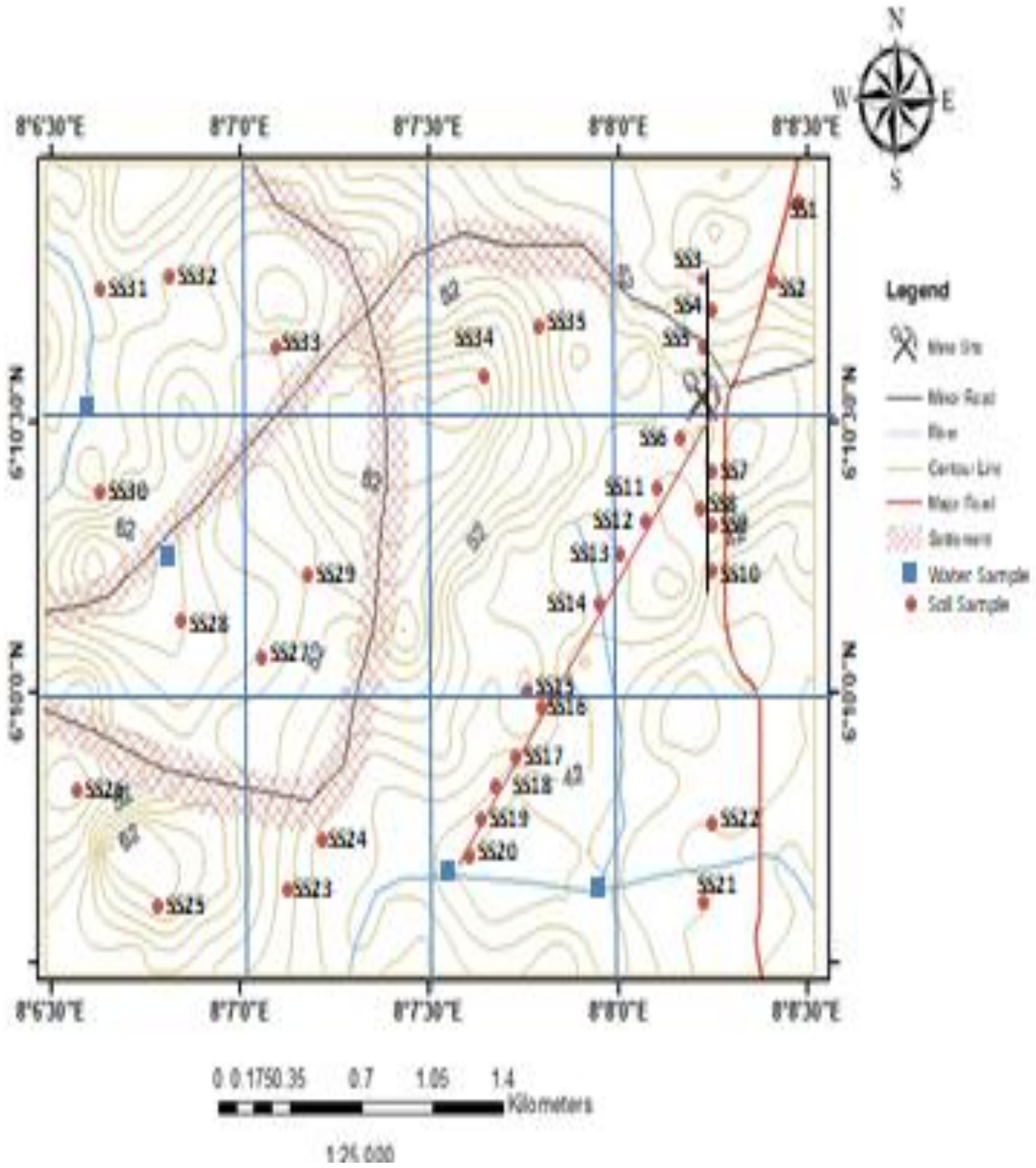

Figure 3.1: Soil and water sample locations

Table 3.1: the coordinate and description of the samples

Sample ID	Latitude	Longitude	Sample Type	Description
SS1	6° 10' 55"	8° 08' 28"	Soil	Soil from farmland
SS2	6° 10' 46"	8° 08' 25"	Soil	Soil from farmland
SS3	6° 10' 45"	8° 08' 14"	Soil	Soil from farmland
SS4	6° 10' 42"	8° 08' 15"	Soil	Soil from farmland
SS5	6° 10' 40"	8° 08' 13"	Soil	Soil from mine pit
SS6	6° 10' 28"	8° 08' 12"	Soil	Soil from mine pit
SS7	6° 10' 26"	8° 08' 15"	Soil	Soil from mine pit
SS8	6° 10' 17"	8° 08' 15"	Soil	Soil from mine pit
SS9	6° 10' 15"	8° 08' 15"	Soil	Soil from mine pit
SS10	6° 10' 13"	8° 08' 15"	Soil	Soil from mine pit
SS11	6° 10' 25"	8° 08' 06"	Soil	Soil from mine pit
SS12	6° 10' 21"	8° 08' 04"	Soil	Soil from mine pit
SS13	6° 10' 16"	8° 08' 00"	Soil	Soil from mine pit
SS14	6° 10' 12"	8° 07' 58"	Soil	Soil from mine pit
SS15	6° 09' 58"	8° 07' 46"	Soil	Soil from mine pit
SS16	6° 09' 52"	8° 07' 45"	Soil	Soil from mine pit
SS17	6° 09' 50"	8° 07' 43"	Soil	Soil from mine pit
SS18	6° 09' 48"	8° 07' 40"	Soil	Soil from farmland
SS19	6° 09' 47"	8° 07' 35"	Soil	Stream sediments
SS20	6° 09' 43"	8° 07' 33"	Soil	Stream sediments
SS21	6° 09' 45"	8° 08' 15"	Soil	Stream sediments
SS22	6° 09' 33"	8° 08' 13"	Soil	Soil from farmland

SS23	6° 09' 45"	8° 07' 13"	Soil	Soil from farmland
SS24	6° 09' 34"	8° 07' 06"	Soil	Soil from farmland
SS25	6° 09' 34"	8° 06' 47"	Soil	Soil from farmland
SS26	6° 09' 48"	8° 06' 34"	Soil	Soil from farmland
SS27	6° 10' 02"	8° 07' 02"	Soil	Soil from farmland
SS28	6° 10' 12"	8° 06' 50"	Soil	Soil from farmland
SS29	6° 10' 15"	8° 07' 12"	Soil	Soil from farmland
SS30	6° 10' 17"	8° 06" 35"	Soil	Stream sediments
SS31	6° 10' 45"	8° 06' 44"	Soil	Stream sediments
SS32	6° 10' 47"	8° 06' 47"	Soil	Soil from farmland
SS33	6° 10' 40"	8° 07' 05"	Soil	Soil from farmland
SS34	6° 10' 32"	8° 07' 40"	Soil	Soil from farmland
SS35	6° 10' 35"	8° 07' 48"	Soil	Soil from farmland
SS36	6° 09' 36"	8° 07' 58"	Water	Water from upstream source
SS37	6° 09' 40"	8° 07' 32"	Water	Water from river close to Royal Salt dump
SS38	6° 10' 15"	8° 06' 50"	Water	Water from borehole
SS39	6° 10' 31"	8° 06' 35"	Water	Water from downstream source

3.3 Sample Preparation

The soil samples were dried and disaggregated prior to sieving. The samples were laid out in pre-numbered evaporating dishes and sun-dried for three days. Each sample was disaggregated and homogenized by the use of agate pestle and mortar. (Mendoza *et al*, 2000).

About 2 grams of the dried samples were weighed into a digestion flask and 20mL of the acid mixture (650mL conc. HNO_3; 80mL per hydrochloric acid; 20mL conc.H_2SO_4) was added following 10mL of aqua regia using syringe and stirred. The resulting mixture would be heated on a Bunsen burner to a volume of 2.5mL, then 10mL of de-ionized water then added and again heated gently to a volume of 5mL, it was then be removed and allowed to cool. After this, it's then filtered into measuring cylinder with the help of filter paper and de-ionized water and added to an appreciable level of about 25mL. This is called aliquot. This aliquot was put in a container with a tight lid and used for analysis of Zn, Pb, Cd, Hg and As.

3.4 Laboratory Analysis:

Soil and stream sediments samples were carefully sun dried in a clean area for two days, disaggregated prior to transport to the laboratory. Water samples were analysed by Atomic Absorption Spectroscopy (AAS) at Muhammadu Buhari TETFund Centre of Excellence laboratory, Federal University of Lafia, Nasarawa State. Rocks, soil and stream sediments samples were analysed by X-Ray Florescence (XRF) at Central instrumentation laboratory, Centre for Dry land Agriculture, Bayero University, Kano. Four water samples were analyzed with the aim of evaluating the contamination level of the water system within the study area. Sample were taken from the upstream and downstream part of surface water (rivers), borehole within Ameka community and the nearest river to the Royal Salt pit and processing plant.

3.4.1 X-Ray Florescence (XRF) Analysis

The samples were first ground to fine powder with the aid of agate motar and pistol. Then it was sieved through a <60µm nylon mesh and the oversize is ground again until no grain larger than 60µm is left. 2g of each of the samples were weighed, poured into a sample holder (made of propylene, a thermoplastic) and covered with cotton wool to prevent spraying. The sample holders containing the samples were run in a vacuum for 10 minutes and then inserted into an S-2 Ranger (Bruker, UK) XRF Spectrometer for elemental analysis. They were allowed to run in the EDXRF spectrometer for 10 minutes each after which the results were obtained.

3.4.2 Atomic Absorption Spectroscopy (AAS) analysis

In the laboratory, all glass wares to be used were rinsed with concentrated nitric acid in a sub-boiling system then with deionized water before use to avoid contamination. Digestion was done by transferring 20ml of each water samples into a clean, dried 250ml beaker containing aqua-regia (HCl and HNO_3) in the ratio 3:1; that is, 15ml of HCl and 5ml of HNO_3.

3.5 Geochemical Assessment

3.5.1 Effect Range Low (ERL) and Effect Range Median (ERM)

The metal concentration of stream sediments/soils was compared with the Effect Range Low (ERL) and Effect Range Median (ERM) values used by United State Environmental protection Agency (USEPA), Mid Atlantic Integrated Assessment (MAIA) for estuaries (1997-98 summary report). This was in line with the sediment quality guideline established by Levinson (1974). ERL is the lowest concentration of metals in stream sediments that produced adverse effects in 10% of organisms reviewed in MAIA project. The ERM shows the 50% of the organism's studied and reported to have harmful effects. Based on ERL and ERM values, metal concentrations below the ERL values are not expected to pose any adverse effects, while levels above the ERM values are likely to be very toxic. Table3.2, shows the ERL and ERM limits for metal concentrations by USEPA, MAIA project (1997- 1998).

Table 3.2: ERL and ERM Limits For Metals US- EPA - MAIA, (1998).

Metals	ERL values in mg/Kg	ERM values in mg/Kg
Zinc (Zn)	150	410
Copper (Cu)	34	270
Lead (Pb)	47	220
Cadmium (Cd)	1.2	9.6
Chromium (Cr)	81	370
Mercury (Hg)	0.15	0.71
Silver (Ag)	1	3.7
Arsenic (As)	8.2	70

3.5.2 Pollution Index (€)

Pollution index (€) as proposed by Powell (1992) is the ratio of individual metal concentration in soils to the ERM value for that particular metal. It expresses how many times the concentration of the individual metal is higher than the ERM for that metal in soil samples.

$$\text{Mathematically; pollution index (€)} = \frac{C}{ERM} \tag{3.1}$$

Where C is the concentration of the individual metal in bed sediments (in mg/Kg), ERM is the effect Range Median (in mg/Kg).

€ > 1 Significant Contamination

€ < 1 Insignificant Contamination

3.5.4 Geoaccumulation Index (Igeo)

Geoaccumulation index (Igeo) is the measures of the geologic accumulation of pollutants and contamination in sediments (Obasi and Akudinobi, 2015). The constant 1.5 allows for natural fluctuations in content of a given substance in the environment and very small anthropogenic influences. The geoacculation index class is shown in table 3.3 below. Geoaccumulation index (Igeo) is defined by the formula;

$$\text{Igeo} = log_2 Cn/1.5Bn \qquad (3.2)$$

Where Cn is the measured concentration of metals in sediment fraction and Bn is the geochemical background value for the metal.

Table 3.3: Classes of Geoaccumulation Index (Igeo).

Class	Value	Soil/ sediment quality
0	Igeo ≤ 0	uncontaminated (UC)
1	0 <Igeo< 1	Uncontaminated (UC) to moderately contaminated (MC)
2	1<Igeo< 2	Moderately contaminated
3	2 <Igeo< 3	Moderately contaminated (MC) to heavily contaminated (HC)
4	3 <Igeo< 4	Heavily contaminated (HC)
5	4 <Igeo< 5	Heavily contaminated (HC) to extremely contaminated (EC)
6	5 <Igeo< 6	Extremely contaminated (EC)

3.5.4 Contamination Factor

Determination of pollution status of heavy metals in the stream bed sediment/ soils was also assessed using the contamination factor.

Mathematically, contamination factor is expressed as:

$$CF = \frac{C_{n-1}^{F}}{C_{n}^{F}} - \quad (3.3)$$

Where C_{n-1}^{F} is the mean content of the metal from sampling locations'

C_{n}^{F} is the concentration of the heavy metals in the Earth's crust as a reference value.

3.6 Geostatistical Analysis

To evaluate the pollution level of the soils within the study area that covers the Ameka mining district of Ebonyi State, a statistical analysis of the sampled elements were carried out using four evaluation parameters.

These include;

1. Effect Range Low (ERL) and Effect Range Median (ERM),
2. Pollution index,
3. Geoaccumulation index,
4. Contamination factor.

3.7 Data Interpretation

Bargraphs and two dimensional diagram was used for classifications of dominant anions and cations of chemical facies and geochemical attributes. Software used for accurate interpretation includes Geosoft Oasis Montaj for contouring, and Golden Software Grapher will be used to plot graphs and create tables.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Geology

4.1.1 Lithologic Description of Stratigraphic Units of the Study Area

The study area falls within the Asu River Group of the Southern Benue Trough. The Shale was deposited during the middle Albian Age, making it the oldest sedimentary unit in Southern Benue Trough. The shale unit is also the host rock of the lead and zinc veins within the study area, and they have been emplaced during the Santonian (Nwajide, 2009). The Asu River Group shale has numerous exposures around the mining pits, drainage, and road cuts.

The study area geological studies show that the shale lithology underlying the environment is characterized into two units; unit B comprises highly indurated shale units observed within and around mining sites (Plate 4.1). Unit A is a brownish shale and mudstone unit (Table 4.1).

Table 4.1: Lithological Succession of Rocks in the Study area defined from Geologic Mapping

Age	Group	Formation	Lithostratigraphic Unit	Lithofacies
Middle Albian	Asu River Group	Abakaliki Shale	Unit B: Light Gray Fissile Shale	Brownish shales and mudstone
			Unit A: Dark Grey Shale	Very hard and massive Shale and mudstone

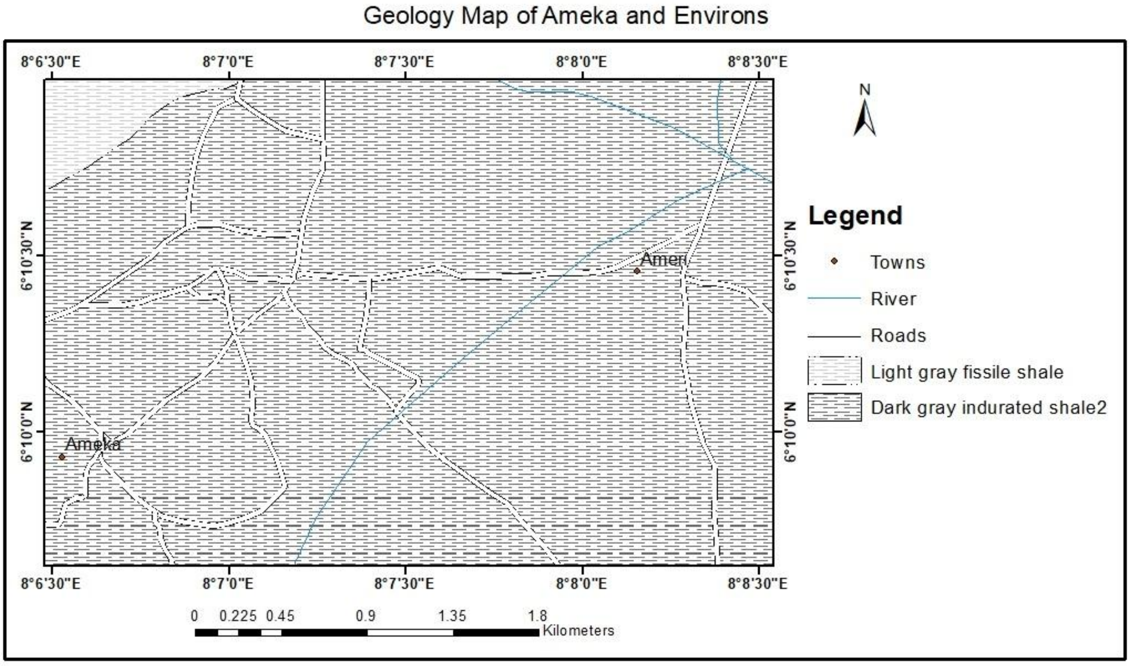

Figure 4.1: Lithologic Geologic Map of the Study area.

4.1.2 Unit B: dark grey indurated shale

Induration of a geologic formation refers to the hardening of rocks by thermal action. This unit comprises dark grey, highly indurated shales (plates 4.1) that are massive. The dark grey to black Shale occupies all the mining pits within the study area. The properties (hardness and massive nature) of the shale lithology are interpreted to have resulted from the thermo-tectonic event of the Santonian. The event was accompanied by hydrothermal fluids that deposited the lead-zinc deposit of the study area. Based on their hardness, the Shale rocks are used by locals for construction. The lithology has a NE-SW strike and an S-E dip direction. The dip amount of the formation ranges from 10°- 45° with higher figures observed around and within mining pits. The lead-zinc deposits within the Shale have a dominant N-S, NW-SE with a minor NE-SW trend. This lithologic unit is observed at the Mining Pits within Ameka and Enyigba, banks of river Otata, and road cuts.

Plate I: Indurated Dark Grey shales observed at drainage in Ameka

Plate II: Indurated Dark Grey Shales observed in a Lead-zinc Pit at Royal Salt Mining Pit

4.1.3 Unit C: light gray fissile shale

These shales are light grey and fissile (plate 4.3). Fissility refers to splitting rocks along their planes of weakness, forming thin sheets of the rock unit. The fissile nature of this rock unit resulted from the alignment of platy phyllosilicate Minerals as a result of compaction, deformation, and aliment of minerals caused by moderate thermal (temperature) effect. The light grey shale lithologic unit overly the indurated Shale within the study area. The shale unit is highly weather in some locations resulting in reddish-brown colouration, and it is also fractured, which is evident by the occurrence of micro faults and joints within the unit. The unit has a NE-SW strike and dips in the southeast direction. The faults and joints have a major NW-SE and N-S trend. The lithologic unit is observed around Amachara community in the northwestern part of the study area.

Plate III: Light grey fissile shale, observed at Amachara.

Plate IV: Soil sample collection at a Farm

Plate V:Farmland close to Royal Salt dump

4.2 Mining Technique / Processes

The mining method used for the exploitation of the lead-zinc deposit is the open cast method. This method involved the opening of over-burdens (indurated Shale) by blasting and removing boulders by machines and manual methods. The indurated nature of the Shale makes blasting a recommended method (according to the head of mines at Royal Salt). The lead-zinc deposit is generally associated with gangue minerals such as quartz, pyrite, and chalcopyrite; after the local miners have mined the mineral deposit, it is separated from the gangue manually. Then, it is bagged for shipping or sales. Big mining companies like Royal Salt have a processing plant for their mining operations; it is located in Ameri, where the deposit is fed to a smelting plant. The deposit is extracted to produce a pure lead deposit bagged and shipped out of the country. (plate 401 and plate 4.2)

Plate VI: Harvested lead-zinc material

Plate VII: Processed Lead waiting for packaging in Royal Salt Company in Ameri

Table 4.2: sample locations and concentration of the analytical elements

SAMPLE ID	LATITUDE	LONGITUDE	SAMPLE TYPE	DESCRIPTION	Latitude	Longitude	Cu	Pb	Zn
SS1	6° 10' 55"	8° 08' 28"	Soil	Soil from farmland	6.181944	8.141111	6.41828	2.628757	21.28315
SS2	6° 10' 46"	8° 08' 25"	Soil	Soil from farmland	6.179444	8.140278	8.86193	3.531421	22.73786
SS3	6° 10' 45"	8° 08' 14"	Soil	Soil from farmland	6.176389	8.137222	12.12274	21.2913	36.06143
SS4	6° 10' 42"	8° 08' 15"	Soil	Soil from farmland	6.178333	8.1375	39.86193	33.09332	44.89213
SS5	6° 10' 40"	8° 08' 13"	Soil	Soil from mine pit	6.177778	8.136944	31.1593	54.18801	95.27768
SS6	6° 10' 28"	8° 08' 12"	Soil	Soil from mine pit	6.174444	8.136667	52.76497	66.00173	96.06143
SS7	6° 10' 26"	8° 08' 15"	Soil	Soil from mine pit	6.173889	8.1375	32.4678	66.97315	94.89213
SS8	6° 10' 17"	8° 08' 15"	Soil	Soil from mine pit	6.171389	8.1375	30.20867	46.27315	95.27768
SS9	6° 10' 15"	8° 08' 15"	Soil	Soil from mine pit	6.170833	8.1375	30.82197	45.11153	85.83836
SS10	6° 10' 13"	8° 08' 15"	Soil	Soil from mine pit	6.170278	8.1375	29.39207	40.25315	82.97388
SS11	6° 10' 25"	8° 08' 06"	Soil	Soil from mine pit	6.173611	8.135	50.56191	66.97315	96.09332
SS12	6° 10' 21"	8° 08' 04"	Soil	Soil from mine pit	6.1725	8.134444	46.74271	63.35213	94.1841
SS13	6° 10' 16"	8° 08' 00"	Soil	Soil from mine pit	6.171111	8.133333	43.83191	62.51469	83.19979
SS14	6° 10' 12"	8° 07' 58"	Soil	Soil from mine pit	6.17	8.132778	41.08169	57.76509	81.76941

SS15	6° 09' 58"	8° 07' 46"	Soil	Soil from mine pit	6.166111	8.129444	38.81099	49.60365	53.64456
SS16	6° 09' 52"	8° 07' 45"	Soil	Soil from mine pit	6.164444	8.129167	21.52823	47.67216	52.71869
SS17	6° 09' 50"	8° 07' 43"	Soil	Soil from mine pit	6.163889	8.128611	18.80299	27.34216	45.62369
SS18	6° 09' 48"	8° 07' 40"	Soil	Soil from farmland	6.163333	8.127778	8.86193	29.52336	45.35281
SS19	6° 09' 47"	8° 07' 35"	Soil	Stream sediments	6.163056	8.126389	6.75193	25.21966	41.33135
SS20	6° 09' 43"	8° 07' 33"	Soil	Stream sediments	6.161944	8.125833	5.88193	24.11336	38.01977
SS21	6° 09' 45"	8° 08' 15"	Soil	Stream sediments	6.1625	8.1375	4.26843	4.198556	29.14731
SS22	6° 09' 33"	8° 08' 13"	Soil	Soil from farmland	6.159167	8.136944	4.124601	3.545313	19.69763
SS23	6° 09' 45"	8° 07' 13"	Soil	Soil from farmland	6.1625	8.120278	2.534601	2.675313	12.8018
SS24	6° 09' 34"	8° 07' 06"	Soil	Soil from farmland	6.159444	8.118333	2.704601	1.625313	16.37261
SS25	6° 09' 34"	8° 06' 47"	Soil	Soil from farmland	6.159444	8.113056	1.114601	0.225313	8.884183
SS26	6° 09' 48"	8° 06' 34"	Soil	Soil from farmland	6.163333	8.109444	1.100601	0.825313	7.545259
SS27	6° 10' 02"	8° 07' 02"	Soil	Soil from farmland	6.167222	8.117222	2.374607	0.925313	15.60992
SS28	6° 10' 12"	8° 06' 50"	Soil	Soil from farmland	6.17	8.113889	2.834601	0.995313	15.69346
SS29	6° 10' 15"	8° 07' 12"	Soil	Soil from farmland	6.170833	8.12	2.454606	1.995313	45.3406

SS30	6° 10' 17"	8° 06" 35"	Soil	Stream sediments	6.171389	8.109722	0.124608	0.895313	17.71756
SS31	6° 10' 45"	8° 06' 44"	Soil	Stream sediments	6.179167	8.112222	0.684327	1.703904	12.04726
SS32	6° 10' 47"	8° 06' 47"	Soil	Soil from farmland	6.179722	8.113056	0.124601	1.399466	10.39947
SS33	6° 10' 40"	8° 07' 05"	Soil	Soil from farmland	6.177778	8.118056	2.973982	1.096422	31.33008
SS34	6° 10' 32"	8° 07' 40"	Soil	Soil from farmland	6.175556	8.127778	11.43826	6.798202	61.78228
SS35	6° 10' 35"	8° 07' 48"	Soil	Soil from farmland	6.159722	8.13	12.5289	7.798202	12.7982
SS36	6° 09' 36"	8° 07' 58"	Water	Water from upstream source	6.16	8.132778	6.41828	2.628757	21.28315
SS37	6° 09' 40"	8° 07' 32"	Water	Water from river close to Royal Salt dump	6.161111	8.125556	8.86193	3.531421	22.73786
SS38	6° 10' 15"	8° 06' 50"	Water	Water from borehole	6.170833	8.113889	12.12274	21.2913	36.06143
SS39	6° 10' 31"	8° 06' 35"	Water	Water from downstream source	6.175278	8.109722	39.86193	33.09332	44.89213

4.3 Result of the Geochemical Analysis

The collected soils/ stream sediments were analyzed for heavy metals Zn, Pb, and Cu. The aim is to determine the concentration levels of these metals in the stream bed sediments and soils within the study area, especially within farmlands where a high concentration of heavy metal could be absorbed by plants and within water reservoirs where surface runoff could contaminate the water system. Table 4.2 shows the resulting concentration of chemical elements from the geochemical analysis of soil/stream sediment. Some of these elements naturally occur within shales (the primary rock type within the study area), and their natural levels are presented in table 4.3.

Table 4.3: Average abundance of selected heavy metals in the earth's crust and Shale (Levinson, 1974)

Element	Earth's Crust	Shale
Zn	70	90
Cu	55	50
Pb	12.5	20

(Levinson, 1974)

The results from the analysis were plotted on a histogram plot and bar charts for better data analysis of the results (Fig. 4.2 to 4.8) respectively and also on a two-dimensional plot (Fig. 4.9 to 4.11) to have a lateral view of the contamination levels .of heavy metals within the soils in the study area. Two statistical methods were carried out;

1. Descriptive statistics (1st quantile, 3rd quantile, median, mean and standard deviation)

2. Geostatistical analysis (ERM and ERL, Pollution index, geoaccumulation, and contamination factor)

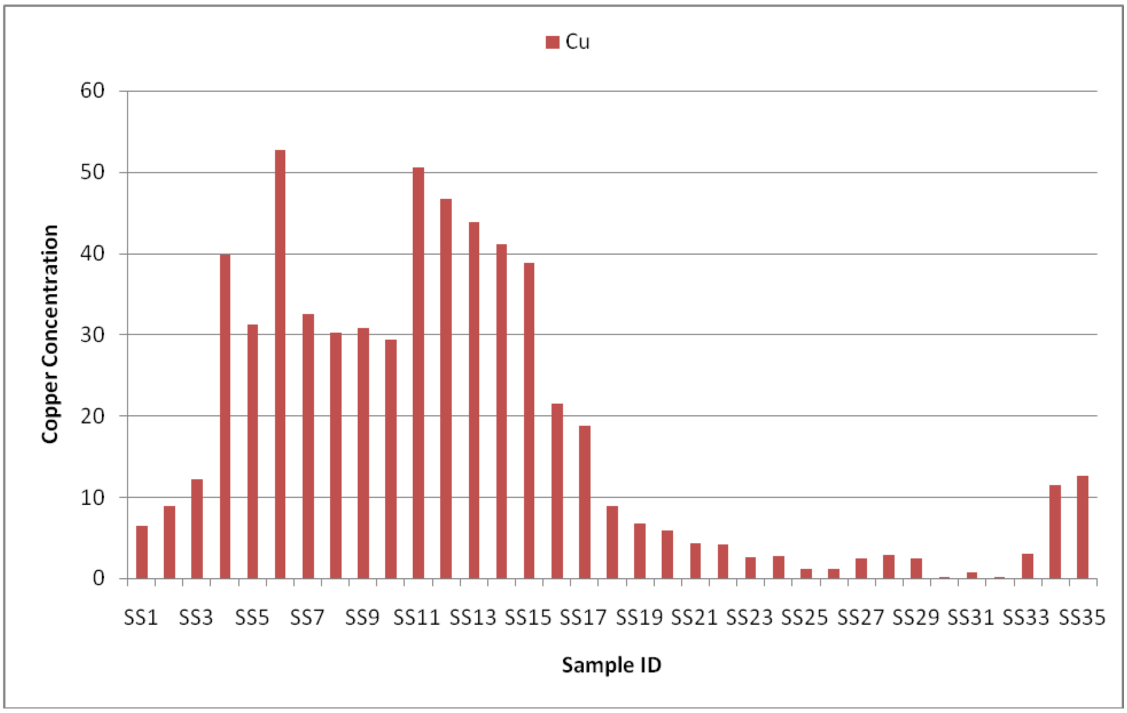

Figure 4.2: Copper (Cu) concentration in Soil in the study area

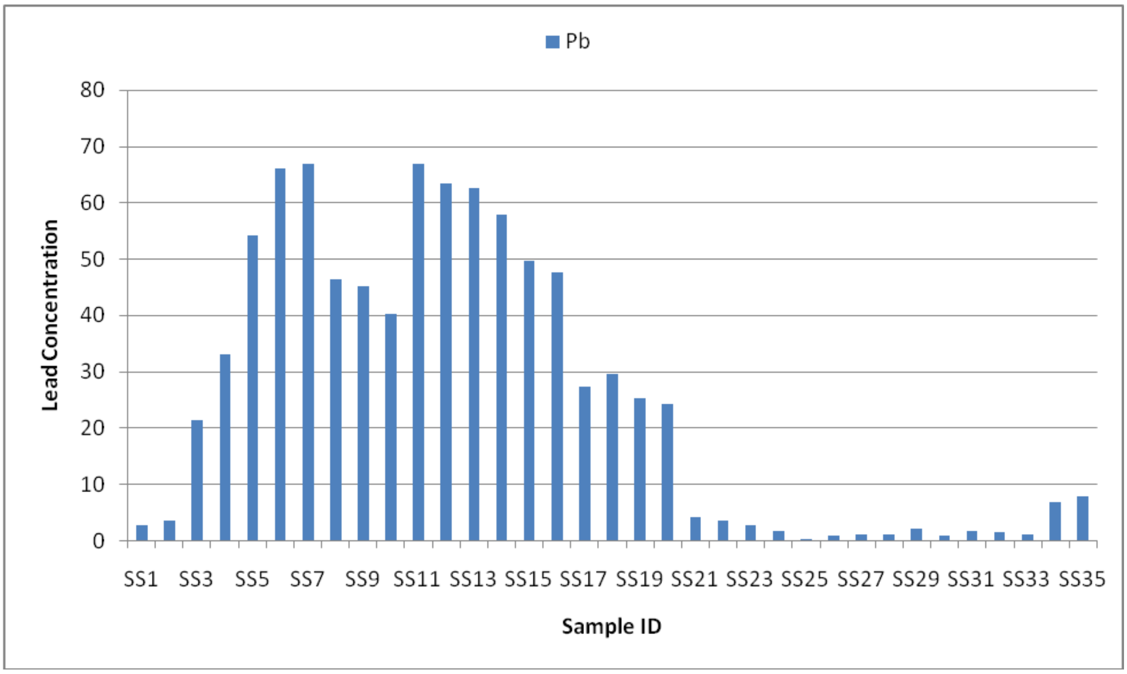

Figure 4.3: Lead (Pb) concentration in the Soils in the study area

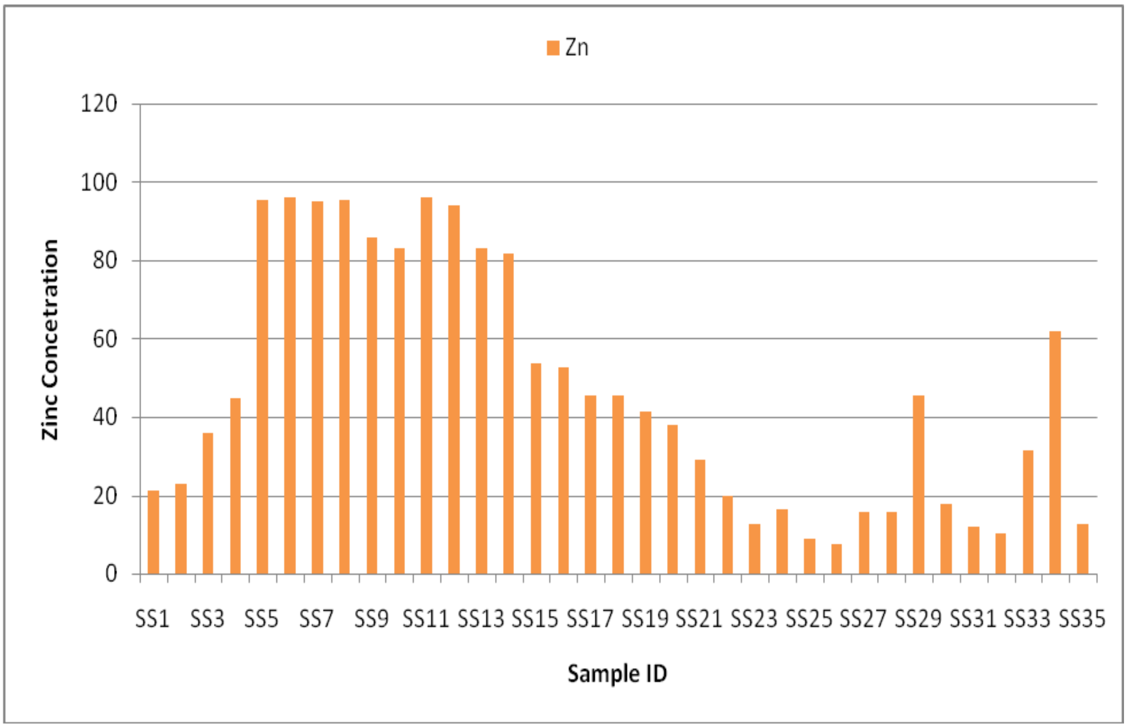

Figure 4.4: Zinc (Zn) concentration in soils for the study area

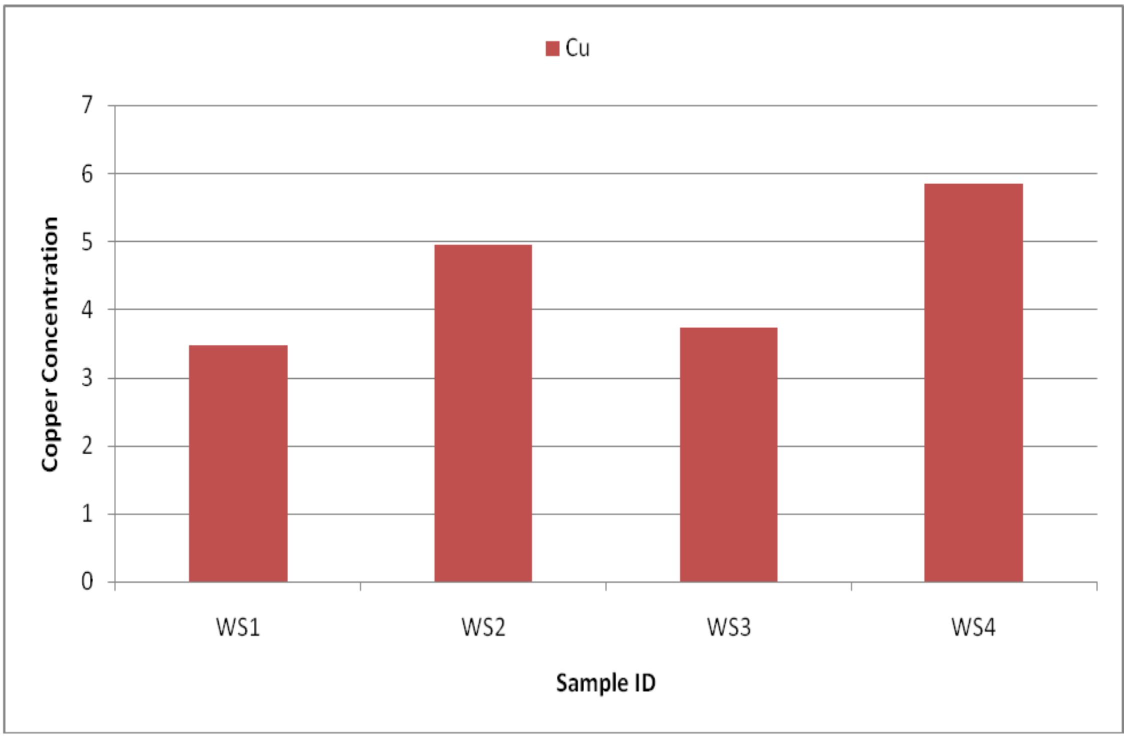

Figure 4.5: Copper (Cu) concentration in water samples in the study area

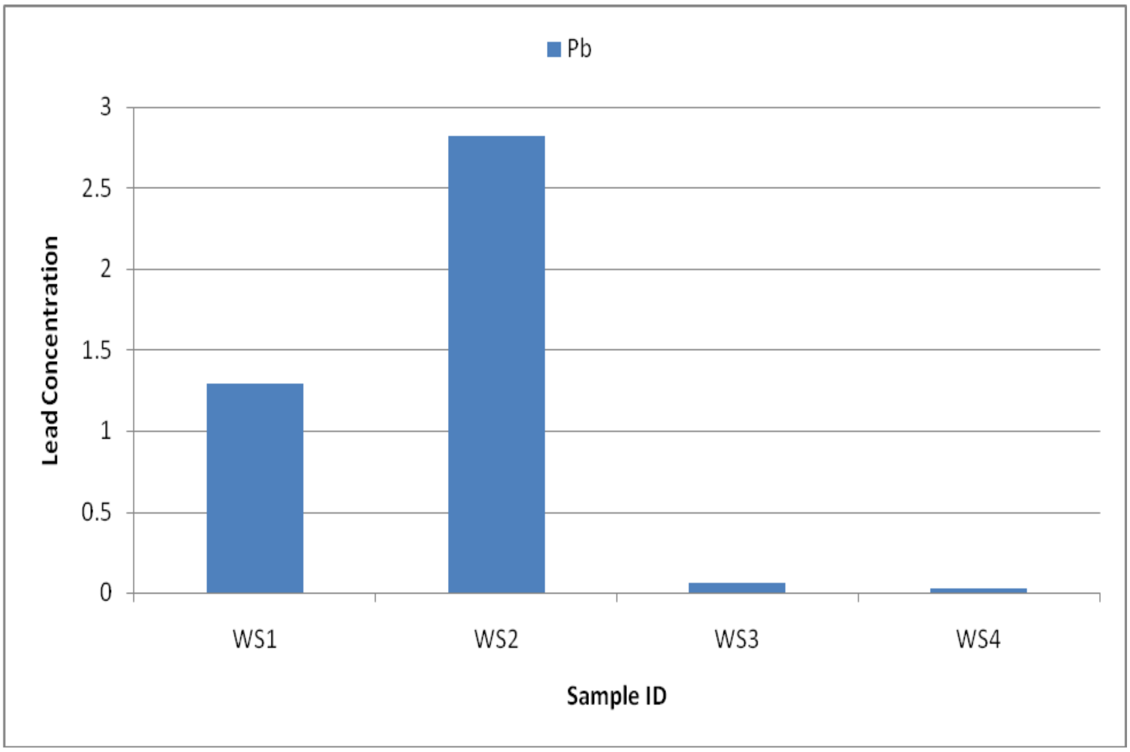

Figure 4.6: Lead (Pb) concentration in water samples in the study areas

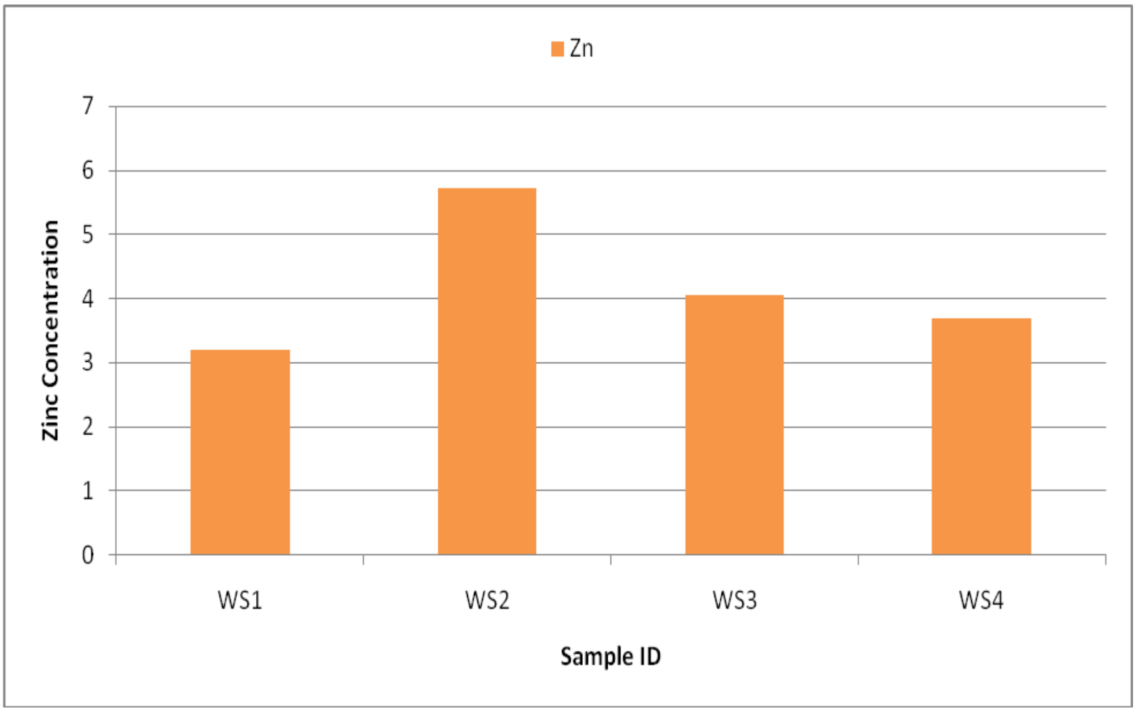

Figure 4.7: Zinc (Zn) concentration in water samples

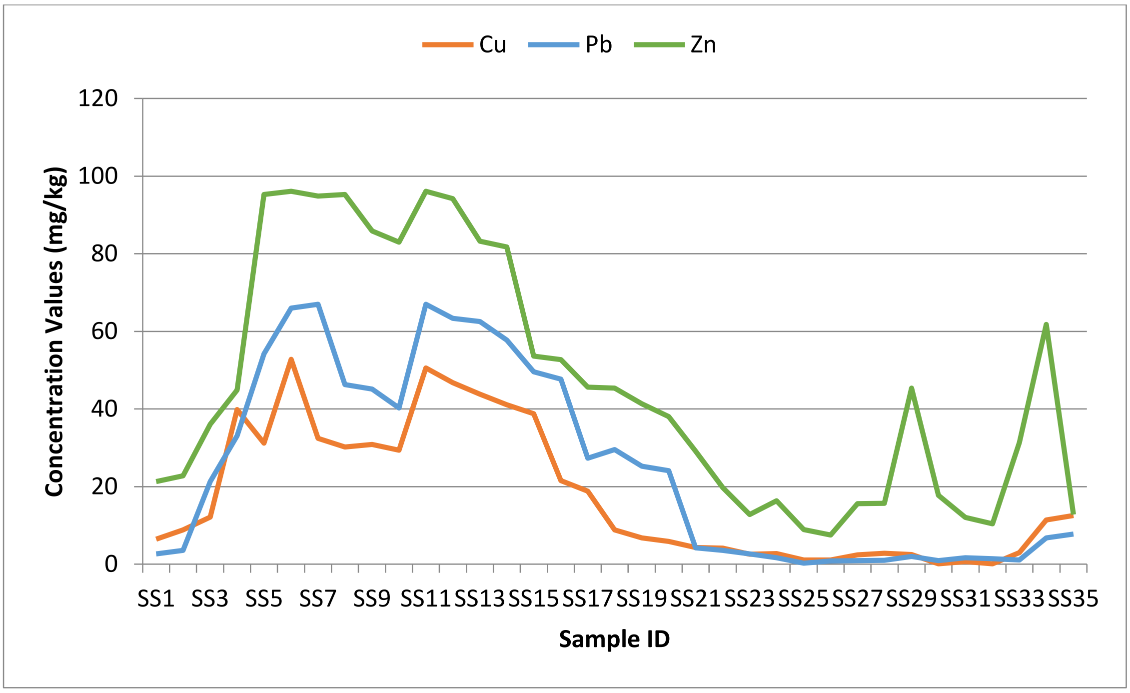

Figure 4.8: Copper, Lead and Zinc Concentrations in Soils in the study area

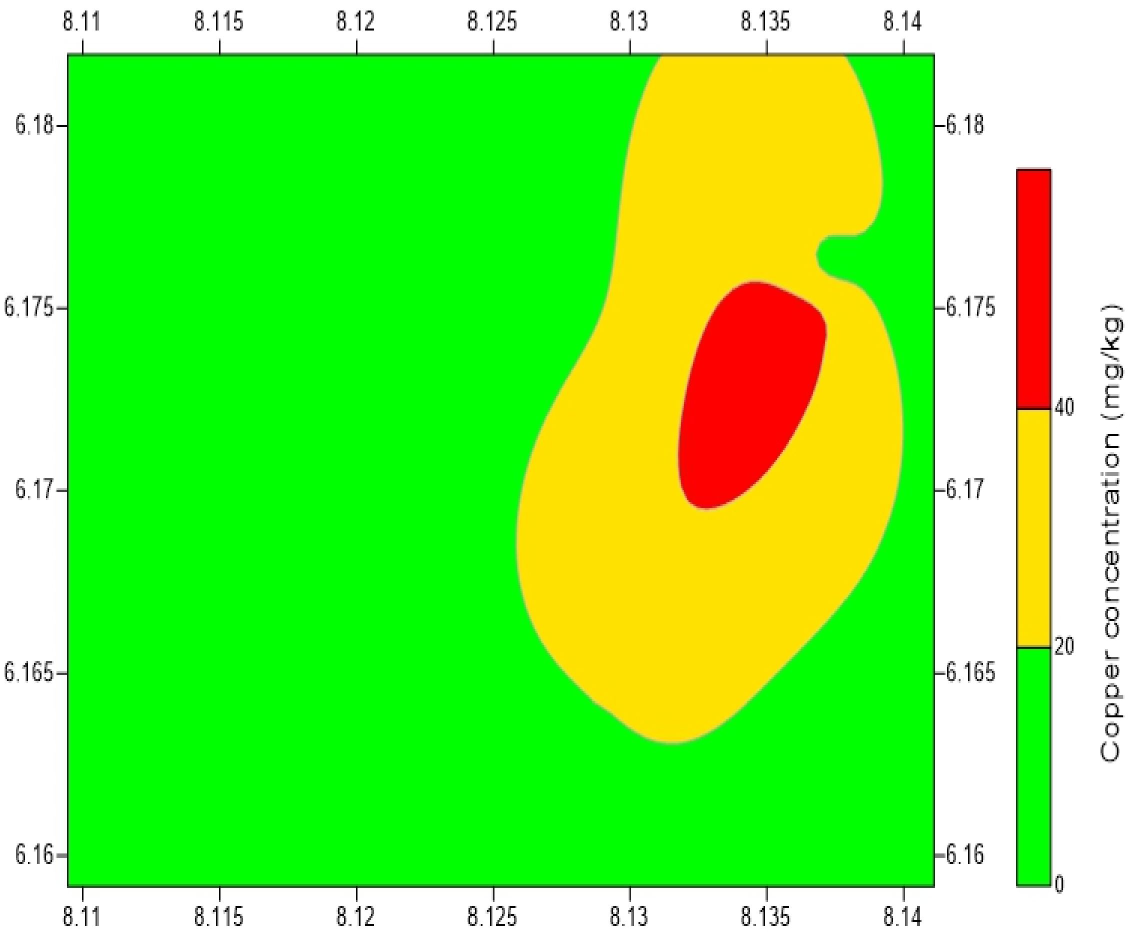

Figure 4.9: Two-dimensional contour map of Copper concentration

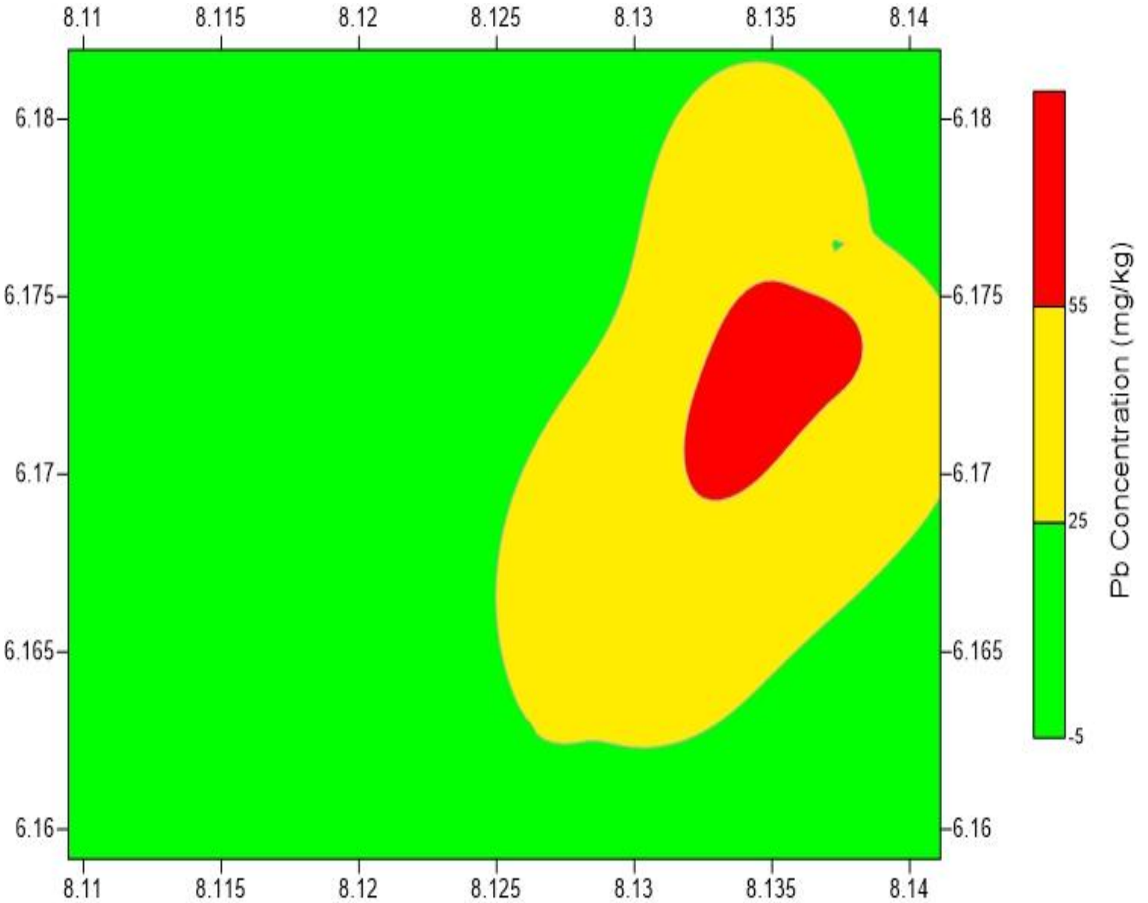

Figure 4.10: Two-dimensional contour map of Lead concentration

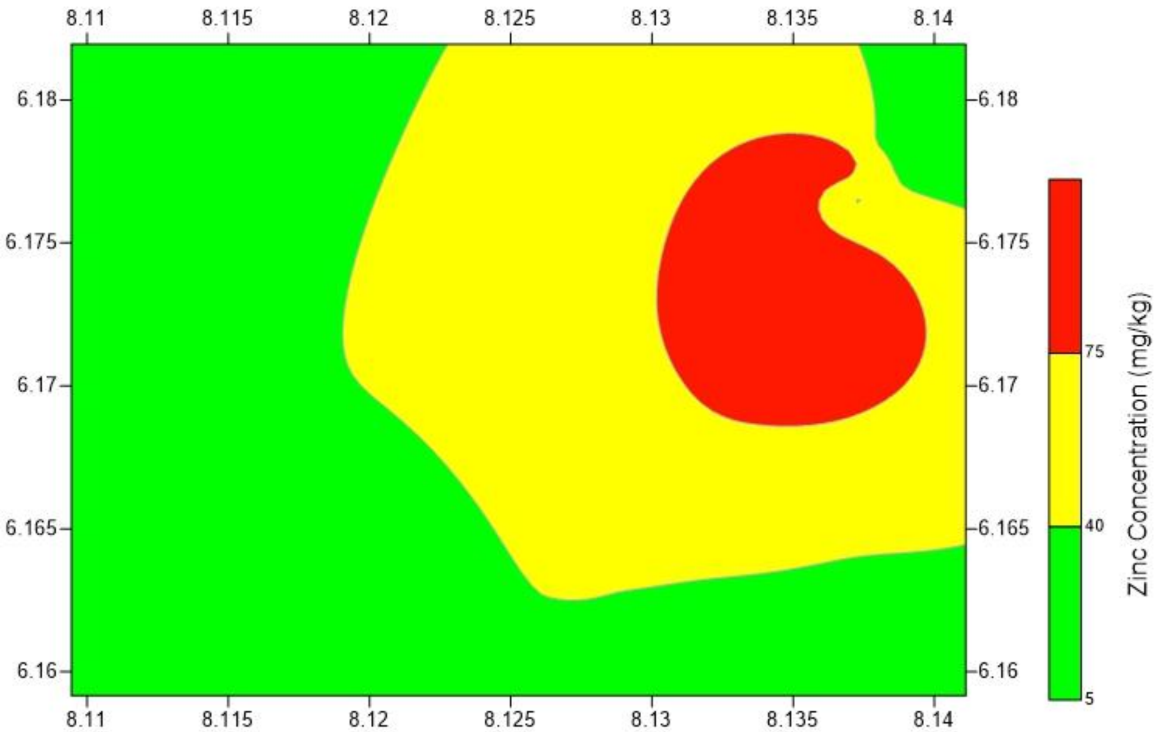

Figure 4.11: Two-dimensional contour map of Zinc concentration

Table 4.4: is a summary of descriptive statistical analysis for soils in the study area

Statistic	Cu	Pb	Zn
Number Of Observations	35	35	35
Mean	17.381	24.861	46.411
Standard Error	2.902	4.199	5.351
Median	8.862	21.291	41.331
Mode	8.862	66.973	95.278
Standard Deviation	17.166	24.843	31.659
Sample Variance	294.675	617.190	1002.314
Kurtosis	-0.956	-1.369	-1.310
Skewness	0.731	0.500	0.460
Range	52.640	66.748	88.548
Minimum	0.125	0.225	7.545
Maximum	52.765	66.973	96.093
Sum	608.322	870.128	1624.401
Count	35	35	35
Confidence Level(95.0%)	5.896758	8.533975	10.87537

Table 4.5 is the ERL and ERM of metals while table4.6 is the pollution index of the studied soils of the dry season

Table 4.5:The ERL and ERM limits for metals (US –EPA – MAIA 1998)

Metals	ERL values in mg/kg	ERM values in mg/kg
Zinc (Zn)	150	**410**
Copper (Cu)	34	**270**
Lead (Pb)	47	**220**

Table 4.6: Pollution Index (€) for Soil/ stream sediments in the study area of dry season samples.

S\n	Sample Location	Sample ID	Cu	Pb	Zn
1	MrEkechi Farm	SSSA1	0.023771	0.011949	0.05191
2	Ameka Abandoned Pit	SSSA2	0.032822	0.016052	0.055458
3	Ameka Active Pit 1	SSSA3	0.044899	0.096779	0.087955
4	Stream Sediment	SSSA4	0.147637	0.150424	0.109493
5	Farm close to Royal Salt Dump	SSSA5	0.115405	0.246309	0.232385
6	MaziOkezie Farm/ stream sediment	SSSA6	0.195426	0.300008	0.234296
7	Stream Sediment Amachara	SSSA7	0.120251	0.304423	0.231444
8	Royal Salt Pb - Zn mine	SSSA8	0.111884	0.210333	0.232385
9	Active Pb - Zn mine Ameri	SSSA9	0.114155	0.205052	0.209362
10	Small Pb - Zn mine Ameka	SSSA10	0.10886	0.182969	0.202375

11	Stream Sediment, Amorie	SSSA11	0.187266	0.304423	0.234374
12	Stream Sediment 2 Amorie	SSSA12	0.173121	0.287964	0.229717
13	Ameka Community	SSSA13	0.16234	0.284158	0.202926
14	North of Ameka	SSSA14	0.152154	0.262569	0.199438
15	Stream Sediment Ameri	SSSA15	0.143744	0.225471	0.13084
16	South of Ameka	SSSA16	0.079734	0.216692	0.128582
17	Ameka Active Pit 2	SSSA17	0.069641	0.124283	0.111277
18	Ameka Active Pit 3	SSSA18	0.032822	0.134197	0.110617
19	Ameka Active Pit 4	SSSA19	0.025007	0.114635	0.100808
20	Ameka Community 2	SSSA20	0.021785	0.109606	0.092731
21	Ameka Community 3	SSSA21	0.015809	0.019084	0.071091
22	South of Ameka 2	SSSA22	0.015276	0.016115	0.048043
23	MrEkechi Farm 2	SSSA23	0.009387	0.012161	0.031224
24	MrEkechi Farm 3	SSSA24	0.010017	0.007388	0.039933
25	Farm close to Royal Salt Dump	SSSA25	0.004128	0.001024	0.021669
26	Royal Salt Pb - Zn mine 2	SSSA26	0.004076	0.003751	0.018403
27	Stream Sediment Amachara	SSSA27	0.008795	0.004206	0.038073
28	Royal Salt Pb - Zn mine 3	SSSA28	0.010499	0.004524	0.038277
29	MaziOkezie Farm 2	SSSA29	0.009091	0.00907	0.110587
30	Active Pb - Zn mine Ameri 2	SSSA30	0.000462	0.00407	0.043214
31	North of Ameka	SSSA31	0.002535	0.007745	0.029384
32	Stream Sediment, Amorie	SSSA32	0.000461	0.006361	0.025365
33	Stream Sediment, Amorie 2	SSSA33	0.011015	0.004984	0.076415

34	Stream Sediment, Amorie 3	SSSA34	0.042364	0.030901	0.150688
35	Stream Sediment Amachara	SSSA35	0.046403	0.035446	0.031215

Table 4.7 shows the geoaccumulation index of stream sediments of soils in the study area

Table 4.7: Geoaccumulation index value for Stream Sediments/ Soil Sample Analyzed

S\N	SAMPLE LOCATION	Sample ID	Zn	Cu	Pb
1	MrEkechi Farm	SSSA1	0.035762	0.046479	0.032679
2	Ameka Abandoned Pit	SSSA2	0.041968	0.060675	0.033385
3	Ameka Active Pit 1	SSSA3	0.047995	0.147073	0.038314
4	Stream Sediment	SSSA4	0.070893	0.168282	0.040655
5	Farm close to Royal Salt Dump	SSSA5	0.066155	0.191997	0.048697
6	MaziOkezie Farm/ stream sediment	SSSA6	0.076287	0.201481	0.048784
7	Stream Sediment Amachara	SSSA7	0.066946	0.202184	0.048653
8	Royal Salt Pb - Zn mine	SSSA8	0.065559	0.184403	0.048697
9	Active Pb - Zn mine Ameri	SSSA9	0.065945	0.183181	0.047582
10	Small Pb - Zn mine Ameka	SSSA10	0.065031	0.177701	0.047219
11	Stream Sediment, Amorie	SSSA11	0.075466	0.202184	0.048788
12	Stream Sediment 2 Amorie	SSSA12	0.073956	0.199511	0.048573
13	Ameka Community	SSSA13	0.072719	0.198871	0.047248
14	North of Ameka	SSSA14	0.071472	0.195071	0.047063

15	Stream Sediment Ameri	SSSA15	0.070379	0.187746	0.042558
16	South of Ameka	SSSA16	0.059042	0.185836	0.042372
17	Ameka Active Pit 2	SSSA17	0.056439	0.159102	0.040827
18	Ameka Active Pit 3	SSSA18	0.041968	0.162793	0.040764
19	Ameka Active Pit 4	SSSA19	0.036737	0.155216	0.039772
20	Ameka Community 2	SSSA20	0.034084	0.153059	0.038879
21	Ameka Community 3	SSSA21	0.027916	0.068996	0.036039
22	South of Ameka 2	SSSA22	0.027257	0.060864	0.031851
23	MrEkechi Farm 2	SSSA23	0.01789	0.047324	0.027246
24	MrEkechi Farm 3	SSSA24	0.019139	0.023357	0.029876
25	Farm close to Royal Salt Dump	SSSA25	0.002087	-0.07167	0.023343
26	Royal Salt Pb - Zn mine 2	SSSA26	0.001844	-0.00923	0.021597
27	Stream Sediment Amachara	SSSA27	0.016636	-0.00373	0.029366
28	Royal Salt Pb - Zn mine 3	SSSA28	0.020042	-0.00023	0.029423
29	MaziOkezie Farm 2	SSSA29	0.017273	0.033221	0.040761
30	Active Pb - Zn mine Ameri 2	SSSA30	-0.04006	-0.00532	0.030719
31	North of Ameka	SSSA31	-0.0073	0.025628	0.026597
32	Stream Sediment, Amorie	SSSA32	-0.04006	0.016163	0.025025
33	Stream Sediment, Amorie 2	SSSA33	0.020965	0.004427	0.036811
34	Stream Sediment, Amorie 3	SSSA34	0.046877	0.092172	0.044068
35	Stream Sediment Amachara	SSSA35	0.048629	0.098771	0.027243

Table 4.8: Categories of Contamination Factor (CF) after Hakanson, 1980

CF < 1	**Low contamination factor indicating low contamination**
1 < CF < 3	Moderate contamination factor
3 < CF < 6	Considerable contamination factor
6 < CF	Very high contamination factor

4.4 Discussion of Result

4.4.1 Descriptive statistic

The result from the geochemical analysis of Zinc reveals an even distribution of the element within the study area. The concentration level ranges from 7.545 mg/kg to 96.093 mg/kg with a mean concentration level of 46.411 mg/kg and a standard deviation of 31.659 mg/kg. Zinc has a background value in the earth crust and shale rocks as 70 mg/kg and 90 mg/kg, respectively (Table 4.2 and Figure 4.6). ATSDR, 2005, EPA 1979 stated that absorption is the dominant reaction that results in zinc enrichment in suspended and bedded sediments. The natural increase in Zinc concentration could result from Zinc-rich ore deposits or anthropogenic sources (waste disposal, mining operation, and fertilizer). Toxic zinc levels in humans may occur when its concentration approaches 400mg/kg in water. These toxic levels are characterized by irritability, muscular stiffness, pain, loss of appetite, and nausea.

Figure 4.11 shows the zinc distribution and concentration in the study area. High Zinc concentration in soils and stream sediment is observed around the active mining region of active and abandoned mine pits at the southwestern and northeastern parts of the study area. Towns within the mining areas are at high risk of contamination. High concentrations of Zinc in stream sediments and soil are observed around small-scale mines in Ameka, active mine pit at Ameka, Royal salt mine pits, areas around Ameri mine pit, communities around Royal Salt dumpsite, Mr. Ekechi's Farm, Ameka community. Lower concentrations are observed around stream sediments at the Amorie and Amachara. The areas with a high concentration of Zinc have both passive and active zinc ore and its mining; therefore, this could be the primary source of the element into the environment. Skin irritation was observed on the skin of Mr. Ekechi and his son.

Analysis of the element copper reveals a concentration range of 0.125 mg/kg to 52.765 mg/kg; it has a mean concentration of 17.381 mg/kg and a standard deviation of 17.381 mg/kg. The background concentration of copper in the earth's crust is set at 55mg/kg in Earth's Crust and 50mg/kg in Shale (Table 4.2 and Figure 4.1). Tyler and McBride (1982) observed that most copper deposited in soil from the atmosphere, agricultural use, and solid waste and sludge disposal would be strongly adsorbed and remain in the upper centimeters of soil. In general, copper is adsorbed to organic matter, carbonate minerals, clay minerals, hydrous iron, and manganese oxides (Callahan et al. 1979; Fuhrer, 1986). The concentration of copper (Figure 4.7) is high around the mining areas in the northeastern and southwestern parts of the study area. The high concentration is attributed to the association and mining of lead ore within the study area, as chalcopyrite (copper ore) is an associate mineral to the deposit. An intermediate copper concentration is observed around Amorie stream sediments, lower copper concentration is observed around the Amachara stream sediments, and the Ameka community recorded high levels of Cu concentration. Generally, the farmland within the mining areas recorded high levels of Cu concentration. Anomalous levels of Cu are observed within the Royal Salt mine.

The major source of lead in an environment is lead ore. The analysis reveals the presence of Lead within the study area. Lead has a concentration range of 0.225 mg/kg to 66.973 mg/kg, mean concentration of 24.861 mg/kg and a standard deviation of 24.843 mg/kg (table 4.2 and 4.5). The geochemical background value is 12.5 mg/kg in the earth crust and 20 mg/kg in Shale. Finster *et al.* (2004) suggested that Lead sources in surface water or sediment include deposits of lead-containing dust from the mining pile and wastewater from industries/mining sites that handle Lead. Figure 4.13 is the lead concentration and distribution map of the study area. Above-average lead concentration is recorded around the active mining communities within the mining environment and their host communities. The high-end natural concentration of Lead in Shale (20 mg/kg) is observed around Ameri stream sediments, Royal Salt, Ameka community, and farmlands within this area.

A low concentration of Lead characterizes the northwestern part of the study area (Fig.13) this is interpreted as a result of no occurrence of lead deposit or no mining operations within the Amachara environment.

4.5 Interpretation of Effect Range Low (ERL) and Effect Range Median (ERM)

4.5.1 Effect range low (ERL) and effect range median (ERM)

The metal concentration of soils and stream sediments was compared with the Effect Range Low (ERL) and Effect Range Median (ERM) values used by the United States Environmental Protection Agency (USEPA), Mid Atlantic Integrated Assessment (MAIA) for estuaries (1997-98 Summary Report). The report is in line with the sediment quality guideline established by Levinson (1974). ERL is the lowest concentration of metals in stream sediments that produced adverse effects in 10% of organisms reviewed in the MAIA project. The ERM shows the 50% of the organism's studied and reported to have harmful effects. Based on ERL and ERM values, metal concentrations below the ERL values are not expected to pose any adverse effects, while levels above the ERM values are likely to be very toxic. Table 4.5 shows the ERL and ERM limits for metal concentrations by USEPA, MAIA project (1997- 1998). Regarding that, three (3) assessment categories of stream sediments/ soil were observed. They include;

1. Good, when the metal concentration values are below the ERL value.
2. Intermediate, when the metal values are above ERL but below the ERM values
3. Poor when the metal values are above the ERM values.

a. Zinc (Zn)

The results of ERL and ERM of the metals analyzed are presented in Table 4.7. From Table 4.9, the ERL value of Zn is 150 mg/kg, and the ERM value is 410 mg/kg. The analysis shows that Zinc has a maximum concentration of 96.093 mg/kg within the study area. The result is variable distribution of Zn element concentration within the study area; However, 100% of samples show concentrations below the ERL and ERM; thus, indicating less risk to Zn toxicity to the area's inhabitants. Though Zn was evenly distributed in all the study area soils, the ERL and ERM suggest poor contamination status in the study area.

b. Copper (Cu)

The highest concentration of copper from the result of the analysis is 52.765 mg/kg. The ERL value is 34mg/kg while the ERM value is 270mg/kg. Copper is above the ERL level in 20% of the sample; the areas with above ERL levels are the farmland behind

Royal Salt, Royal Salt Mine Site, and stream sediments at Amorie. The high concentration at Amorie area is due to the surface flow of water from active mining area. The copper concentration is below the ERM values. Therefore, the contamination status of copper is both Good and intermediate in the study area.

c. Lead (Pb)

For Pb, a level as high as 66.973 mg/kg was recorded within the study area. The ERL of Pb is 47mg/kg, while its ERM value is 220mg/kg. 25.71 % of the samples showed Pb concentration above the ERL value while 74.29% samples are below the ERL, and 0% are above the ERM value. The result indicates poor to intermediate contamination, with contaminated areas around Ameka abandoned pit (now water pond), Ameka active pit area, the farm close to Royal Salt Mine, Royal Salt mine environment, Active mining pit at Ameri and within Ameka community. The quality of the sediment is presented in table 4.8.

Table 4.9: Quality of sediments/soils in the study area using ERL and ERM (US-MAIA, 1998)

Metal	Below ERL (%)	Above ERL (%)	Above ERM (%)	Remark
Zn	100	0	-	Poor Contamination
Cu	80	20	-	Intermediate Contamination
Pb	74.27	25.71	-	Good - Intermediate Contamination

4.5.2 Pollution Index (€)

The pollution index (€) is the ratio of individual metal concentration in soils to the ERM value for that particular metal (Powell, 1992). It expresses how many times the concentration of the individual metal is higher than the ERM for that metal in soil samples. Tables 4.6 and 4.9 show the calculated pollution index.For pollution index, when € ≥ 1 = Significant Contamination (SC), when € ≤ 1 = Insignificant Contamination (IC)

The ERM value of Zinc is 410mg/kg, the concentration of Zinc in all of the sample's locations is below ERL, and the ERM value in many locations, its pollution index ranges 0.018€. To 0.23€. The result indicates low contamination. Its pollution index is below the toxic level and indicates insignificant contamination.

The ERM value for copper is 270mg/kg. Copper is below ERL value in most parts of the study area and below a ERM value in all the sample's locations, and its pollution index is below the toxic level 0.004€. To 0.18€; this indicates insignificant contamination. (Table 4.7)

The ERM value for Lead is 220mg/kg. The concentration of Lead is below the ERM value in all samples analyzed. Its values range from 0.001€ to 0.30€, indicating that the Pollution index status of insignificant contamination.(Table 4.7)

The analysis of the pollution index is summarised in table 4.6. The occurrences of heavy metals in the soil within the study area may have resulted from surface runoff of water from the mining sites to various Rivers, streams, and soil. It could also be a result of siting processing locations in communities away from mining area observed within Ameka community.

Table 4.10: Quality of soils/ sediments within the study area using pollution index (after Powell, 1992)

Metal	Index Range	Remark
Zn	0.018€. to 0.23€.	IC
Cu	0.0004€. to 0.18€.	IC
Pb	0.001€ to 0.30€	IC

4.5.3 Geoaccumulation Index (Igeo)

Geoaccumulation index (Igeo) measures the geologic accumulation of pollutants and contamination in sediments (Obasi and Akudinobi, 2015). The constant 1.5 allows for natural fluctuations in the content of a given substance in the environment and minimal anthropogenic influences. The geoaccumulation index class is shown in table 4.6.

Table 4.11: Geoaccumulation index value for Stream Sediments/ Soil Sample Analyzed.

Metal	% UC	%UC - MC	%MC	%MC -HC	%HC	%HC - EC	%EC	Remark
Zn	-	100	-	-	-	-	-	No Contamination
Cu	8.57	91.43	-	-	-	-	-	No Contamination
Pb	14.28	85.72	-	-	-	-	-	No Contamination

Following the geoaccummulation index values from table 4.6, it can be deduced that Zinc, Copper, and Lead satisfy class 0 (practically uncontaminated) and class 1 (uncontaminated to moderately contaminated).

4.5.4 Contamination Factor

The pollution status of heavy metals in the stream bed sediment/ soils in the Pb/Zn mining fields of Ameka and its environs were also assessed using the contamination factor. According to Hakanson, 1980, the contamination factor (Equation 4) expresses the mean concentration with reference to the metal concentration in the earth's crust. Table 4.7 shows categories of contamination factors, while calculated values are represented in table 4.11.

Table 4.12: Contamination Factor for soils / stream sediments of dry season in the study area

Element	Mean content	Background value (Average shale)	Contamination factor	Remarks
Zn	46.411	90	0.52	Low factor
Cu	17.281	50	0.35	Low factor
Pb	24.861	20	1.24	Moderate Contamination factor

From table 4.8a and b, analysis of contamination factor of acquired samples shows that the contamination factor (CF) of Zn and Cu is less than 1 (CF < 1), which implies a low contamination factor of the metals. Pb has a moderate contamination factor (1< CF < 3) within the study area.

4.6 Trace/Minor Constituents

Trace constituents are inorganic elements that a less than 0.1mg/l in water and between 0.01-10.0mg/l in concentration in water as minor constituents (Freeze and Cherry, 1979). The minor. Trace constituents studied include Zinc, Copper, and Lead. Two surface and two groundwater samples were analyzed (Table 4.11) for these constituents.

4.6.1 Geochemical analysis of water sample

The lead concentration ranges from 2.629mg/l to 33.093mg/l, it has a mean concentration of 15.136 mg/l and standard deviation of 14.736 mg/l(table 4.7 to 4.9). Higher concentration of lead is recorded at water bodies (river) close to Royal Salt mining pit and processing plant. This is regarded as a major entry point of heavy metal (Pb) into the environment as the area also recorded high concentration of heavy metal in soil. Downstream surface water recorded Pb concentration of 21.29 mg/l while the upstream surface water recorded Pb concentration of 3.53mg/l. the major borehole serving Ameka community recorded Pb concentration of 0.05 mg/l. WHO (1984) proposed a health guideline value of 0.05 mg/l, and it reviews its guideline in 1993 given a value of 0.01mg/l. This review was necessary because lead is a cumulative poison. There should be no accumulation of Lead in the human body. From the analysis, lead concentrations can be described as toxic within the downstream water way and surface water close to mining sites. Based on the fact these areas also recorded high Pb concentration in soil, it can be concluded that the poor mining technique employed by miners within the study area is the source of Pb in the study area.

4.7 Health Hazards

Some heavy metals at minimal quantities aid life, these are referred to as trace elements, but a high concentration of the same metal could become toxic. It could lead to the damage of internal organs, degrading mental health and central nervous function. Prolonged exposure can result in slowly progressing physical, muscular, and neurological degenerative processes that mimic Alzheimer's disease, Parkinson's' disease, muscular dystrophy, and multiple Sclerosis (Gerhat and Blomquist, 1992).

Gerhat and Blomquist (1992) stated that stream sediments are mobilised and transported downstream during flooding, resulting in the redeposition of contaminants downstream. Through this process, contaminants are introduced into new areas/communities by the stream ecosystem, thereby becoming available for ingestion by more significant numbers of aquatic organisms. This generally would lead to pollution of stream sediments which has several consequences for stream ecosystem and humans.

The waterway draining the study area passes through most mining areas. The accumulated water in the pits also drains into the waterway transferring contamination in soils and stream sediments. Organisms living within sediments ingest the contaminants and accumulate them in their tissue (Montgomery *et al.*, 2008; long *et al.*, 1995). These possible accumulated concentrations in these organisms can be passed on to higher organisms in the food chain; the higher organisms ingest contaminated organisms that live in the sediments (Gerhat and Blomquist, 1992 and Montgomery *et al.*, 2008). According to FDA,1987; IOM, 2002 and EPA, 2003. effective impact of this metal can yield the following.

1. Brain damages.
2. Kidney diseases/complications.

3. Nervous system breakdown
4. Psychological disorders
5. Death.
6. Abdominal pain, vomiting, and other unpleasant symptoms.

The study shows there is low to moderate contamination of heavy metals in the soil. However, it should be noted that due to inadequate environmental monitoring of mining operations, an increase in the concentration and prolonged exposure could lead to the above-stated health issues.

4.8 Environmental Hazards

Environmental hazard is concerned with studying adverse geological conditions concerning how they can affect the human environment (such hazards mainly result from natural processes though often enhanced by human activities) (Obasi, 2018). Significant environmental hazards in the study area include erosion, land degradation resulting from mining, flooding, and pollution, resulting in the prevalence of water-borne diseases. (Obasi, 2018).

4.9 Damage of Vegetation

The vegetation damage is very intensive and vast during mine development and mining operations. Thick dust is discharged into the air mainly from the mining processes, which generally affects both the feeding of plants and also contaminates the plants. The overall effect of this is that the photosynthetic and fruiting ability of the crop is impaired with a consequent decrease in crop production.

4.10 Geological Hazards

Mining operations disturb the equilibrium of the geological environment, which may trigger specific geological hazards such as landslides, subsidence, flooding, erosion, and tremors and their secondary effects (Obasi, 2018). Ajakaiye (1985) noted that minor earth tremors are generated due to the blasting of rocks in various quarries. Villages and settlements in the neighborhood of the quarries have experienced unpleasant earth movements when the rocks are blasted. Some buildings have been damaged due to minor tremors occasioned by the incessant blasting of the rocks. Ajakaiye (1985).

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

A geochemical assessment of the Lead-zinc mining district of Ameka, Ebonyi State, Southeastern Nigeria, was carried out to evaluate the pollution levels of soil and water bodies. These areas include Ameka, Amorie, Amanchara, and Ameri communities, where active and abandoned mines are located.

Thirteen soil/stream sediments were collected within the study area, and they were subjected to geochemical analysis and pedologic safety analytical tools, which includes Effect Range Low (ERL), Effect Range Median (ERM), Pollution Index (€), Geoaccumulation Index (Igeo) and Contamination Factor (Cf). Four water samples were analyzed using Atomic Absorption Spectrophotometric and Ultra Violet / Visible Spectroscopy. This study has led to the following findings:

Geologically, the area is underlain by shales and mudstone. The rocks that have been affected by tilting and fracturing are genetically linked to the Santonian Orogeny. This fracturing has induced secondary porosity on the shales, forming the semi-confined aquifer associated with the study area. This fractured system controls groundwater movement, and the structural placement controls the drainage of the study area.

Geochemical investigation of stream sediments and soils revealed Intermediate Contamination (IC) to Poor Contamination (PC) of Pb and Cu using the Effect Range Low (ERL) and Effect Range Median (ERM) analytical method. Cu, Pb, and Zn show Insignificant Contamination (SC) using the Pollution Index (€). Cu, Pb, and Zn show low to moderate Contamination (MC) using the Geoaccumulation Index (Igeo). Pb shows moderate Contamination factor (MC), and Cu and Zn show low Contamination factor (LC) using the Contamination Factor (Cf). The assessment of contamination degree shows a moderate degree of contamination in Ameka areas. The area is prone to chronic health and environmental hazards.

5.2 Recommendation

Based on the findings on the geochemical investigation of the Ameka mining district of Ebonyi State, Nigeria, the following recommendations have been made:

5.2.1 Mining laws and Policies

To minimize the environmental effects of mining operations, specific precautionary measures must be taken by both the government and the mining companies. The government's role is to provide the legislation required to make it mandatory for the companies to practice all necessary precautions to prevent or minimize environmental damage.

There is a need to strengthen the new law with the following inputs.

1. Government should enact laws to control and incorporate the activities of illegal miners in this area, as they form an integral part of the mining sector.

2. Government should make a policy that mandates the mining companies to segregate and dump their wastes at appropriate dumping sites properly.

3. Government should equally ensure that mining companies restore each operational site to its original state after mining, following the Environmental Impact Assessment (EIA) plan.

4. Some of these abandoned mining pits should be used as tourist sites, recreational sites, and fish ponds. This can enhance the economic life of the area.

5. Processing companies must install appropriate equipment, where necessary, for preventing or minimizing pollution;

5.3 Contribution to Knowledge

i. The collected soils/ stream sediments from the study area were analyzed for heavy metals Zn, Pb, and Cu. The aim is to determine the concentration levels of these metals in the stream bed sediments and soils within the study area.

ii. Geochemical investigation of stream sediments and soils revealed Intermediate Contamination (IC) to Poor Contamination (PC) of Pb and Cu using the Effect Range Low (ERL) and Effect Range Median (ERM) analytical method. Cu, Pb, and Zn show Insignificant Contamination (SC) using the Pollution Index (€). Cu, Pb, and Zn show low to moderate Contamination (MC) using the Geoaccumulation Index (Igeo). Pb shows moderate Contamination factor (MC), and Cu and Zn show low Contamination factor (LC) using the Contamination Factor (Cf). The assessment of contamination degree shows a moderate degree of contamination in Ameka areas. The area is prone to chronic health and environmental hazards.

iii. The geochemical background value reveals that Lead sources in surface water or sediment include deposits of lead-containing dust from the mining pile and wastewater from industries/mining. The natural increase in Zinc concentration could result from Zinc-rich ore deposits or anthropogenic sources (waste disposal, mining operation, and fertilizer). The high concentration Copper in some location is attributed to the association and mining of lead ore within the study area, as chalcopyrite (copper ore) is an associate mineral to the deposit.

iv. The study reveals that the soil in the study area is contaminated and water sources in the study area is unsuitable for consumption.

REFERENCES

Abdulfatai, I. A., Okunlola, A. I., Akande, W. G., Momoh, L. O., & Ibrahim, K. O. (2014). Review of gully erosion in Nigeria: causes, impacts and possible solutions.

Adegoke, O.S. (1969) Eocene Stratigraphy of Southern Nigeria. Collogue sur Eocene Vol, III Bur. Rech. Geol. Min. Mem., No 69,23-48.

Aghamelu, O. P., Amah, J. I., Omonona, O. V., & Onwe, I. M. (2020). A study of the dynamics of soil erosion using Rusle2 modelling and geospatial tool in Edda-Afikpo Mesas, South Eastern Nigeria. *Pakistan Journal of Geology (PJG)*, *4*(2).

Ajakaiye, D. E., Hall, D. H., & Millar, T. W. (1985). Interpretation of aeromagnetic data across the central crystalline shield area of Nigeria. *Geophysical Journal International*, *83*(2), 503-517.

Ajayi, O. O. & Adebayo, A.O. (2003). Dissolution of chalcopyrite with hydrogen peroxide in sulphuric acid medium. *Chemical and biochemical engineering quarterly 17 (3),* 213-218.

Akintomide, A. A. and Kehinde O.O (2014). Analysis of rainfall and temperature variability over Nigeria. *Global journal of human-social science Geography, Geo-sciences, Environmental Disaster management* 14 (13), 1-17, 2014.

Azubike, O.C. (2011). Update on the lead poisoning incident in Zamfara State, Nigeria. Paper presented at the regional multi-stakeholder workshop, Anglophone West Africa, sub-Regional action planning on mercury use in Artisanal and small-scale gold mining.

Babajide, A.F.A.S. (2011). Issues of lead poisoning and developing countries, unpublished paper presented at the University of Lagos, Akoka, Lagos Nigeria.

Benkhelil, J. (1989). Cretaceous Deformation, Magmatism and Metamorphism in the Lower Benue Trough. Nigeria in African Geology Reviews (Peter Bowden and Judith Kinnaird, ed). Geol. John Wiley and Sons Ltd. Benue Rift (Aulacogen): A re-interpretation. *Journal of Mining*. 20(10): 56-90.

Burke, K. (1976) The Chad Basin: An Active Intra-Continental Basin. Developments in Geotectonics, 12, 197-206.

Callahan-Levy, C. M., & Messe, L. A. (1979). Sex differences in the allocation of pay. *Journal of Personality and Social Psychology*, *37*(3), 433.

Egboka, B. C., Nwankwor, G. I., & Orajaka, I. P. (1988). Groundwater occurrence and flow pattern in the Enugu coal-mine area, Anambra State, Nigeria. *Hydrological sciences journal*, *33*(5), 465-482.

Environmental Protection Agency EPA's Report on the on the environment (2003 Draft). U.S. Environmental Protection Agency, Washinton, DC, 2003.

Ezeh, H. N., Anike, O. L. and Egboka, B. C. E., (2007) The Distribution of some Heavy Metals in Soil in areas around the Derelict Enyigba Mines and its Environmental Implication. Journ. Min. Geol. Vol. 2(2) pp. 99-106.

Ezeh, H.N & Anike O.L. (2009). The preliminary assessment of the pollution status of streams and artificial lakes created by mining in the mining district of Enyigba, south eastern Nigeria. *Global journal of Environmental sciences 8 (1).*

Ezeh, H.N. & Nnabo, P.N. (2006). Lead and Zinc deposits of Ebonyi State, Journal of Applied & Natural Sciences (JANS), 1 (1), 5z8 – 66.

Farm Unit, EBSU (2009). Perceptions of climate change and variability, impacts and adaptation strategies by farmers in South-eastern Nigeria; Research gate.

Fayose, E. A & de Klasz, I. (1976): Microfossils of the Ezeaku Formation (Turonian) at Nklalagu Quarry Eastern Nigeria, *Nigerian Journ, Min. Geol*., 13, p. 51 – 61

Finster, M. E., Gray, K. A., & Binns, H. J. (2004). Lead levels of edibles grown in contaminated residential soils: a field survey. *Science of the Total Environment*, *320*(2-3), 245-257.

Food and Drug Administration (FDA) regulation of product risk and its impact upon young biomedical. *Journal of Product Innovation Management* 4 (2), 138-148, 1987.

Foulds, S.A., Brewer, P.A., Mackling, M.G., Haresign, W., Betson, R.E., Rassner, S.M.E. (2014). Flood related contamination in catchments affected by historical metal mining: An Unexpected and merging hazards of climate change, Sci: *Total Environ* 476:165-180.

Fuhrer, J. (1986). Chemistry of fogwater and estimated rates of occult deposition in an agricultural area of Central Switzerland. *Agriculture, ecosystems & environment*, *17*(3-4), 153-164.

Gerhat, J. M., & Blomquist, J. D. (1992). Selected trace elements and organic contaminant in stream bed sediments of the Potomac River Basin. *US Geological Survey, Water Resources Investigation Report*, *95*(4267), 1-12.

Gosar, M. (2004). Impacts of mining and smelting activities on environment and landscape degradation. in Slovenia. *Geologija*, *63*(2), 221–250.

Guiraud, R., Bellion, Y; 1995. Late Carboniferous to Recentgeoldynamic evolution of the west Gondwanian, Cratonic, Tethyan margins. *The ocean Basins and Margins vol 8*. Pp 101- 124.

Hakanson, L. (1980). An ecological risk index for aquatic pollution control. A sedimentological approach. *Water research*, *14*(8), 975-1001.

Hoque, M. (1977). Petrographic differentiation of tectonically controlled Cretaceous sedimentary cycles, southeastern Nigeria. *Journal of Sedimentary Geology*, *vol.17*, pp 235 245.

Hoque, M., & Nwajide, C.S. (1985). Tectonic Sedimentological evolution of an elongate Intracratonic basin (aulacogen). The case of the Benue Trough of Nig. *Journal of Mining and Geology* 21, pp. 19-26.

Illoeje N.P. (1979). A new Geography of Nigeria. Longman, London. National Academy of sciences (NAS) (1979) Firewood Crops. Washington DC.

Institute of Medicine (IOM) 2002. Racial/ethnic disparity trends in children's mental health care access and expenditures. *Health services research* 48 (1) 129-149

Intergovernmental Forum on Mining, Minerals Metals and Sustainable Development (IGF) (2017). Global Trends in Artisanal and Small-Scale Mining (ASM): A review of key numbers and issues. Winnipeg, e.g., IIS

International labour Organisation (ILO) (1999). Strengthening artisanal mining research and policy through baseline census activities. *Natural Resources Forum 29 (2),* 144-153,2005.

Inyang, F. .and Monanu, S. "Climatic regimes." *Nigeria in Maps. Ethiope Publication House, Benin* (1975): 27-29.

Johnson, Dallas, and Beverley, Hale. "White birch (Betula papyrifera Marshall) foliar litter decomposition in relation to trace metal atmospheric inputs at metal-contaminated and uncontaminated sites near Sudbury, Ontario and Rouyn-Noranda, Quebec, Canada." *Environmental Pollution* 127.1 (2004): 65-72.

Kelechi, O. (2017). The Southern benue trough and Anambra basin, southern Nigeria: a stratigraphic review. *Journal of Geography, Environment and Earth Science international 12 (2*), 1-16, 2017.

Kogbe, C. A. (Ed.). (1976). *Geology of Nigeria* (pp. 237-252). Lagos: Elizabethan publishing company.

Levinson, A. A. (1974). Introduction to exploration geochemistry. Applied Publishing Co., Calgary.

Long, E. R., Macdonald, D. D., Smith, S. L., & Calder, F. D. (1995). Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environmental management*, *19*, 81-97.

Mayes, M. A., Sharma, P., & Tang, G. (2013). Role of soil organic carbon and colloids in sorption and transport of TNT, RDX and HMX in training range soils. *Chemosphere*, *92*(8), 993-1000.

Montgomery, J., Heneghan, L., Miller, S. P., Baer, S., Callaham Jr, M. A., Pavao- Zuckerman, M., ... & Richardson, S. (2008). Integrating soil ecological knowledge into restoration management. *Restoration ecology*, *16*(4), 608-617.

Murat, R.C. (1972). Stratigraphy and Paleogeography of the Cretaceous and Lower Tertiary in Southern Nig. African Geol. Ibadan, 251-268.

Nnabo, P.N., Ezeh, H.N. & Chima, K.I. (2009). The preliminary assessment of the level of some heavy metals in the stream sediments of Eka-Awoke watershed, SE of Abakaliki, SE Nigeria. *Journal of Applied & Natural Sciences* (JANS)4 (1), 70-78.

Nnabo, P.N., Orazulike, D.M. & Offor, O.C. (2011). The preliminary assessment of the level of heavy elements contaminations in streambed sediments of Enyigba and Environs, SE Nigeria. *Journal of Basic Physical Research* 2 (2), 43-52.

Nwabufo-Ene, K. E (1976), Cretaceous-Tertiary Fauna and facies from South Eastern Nigeria. Unpublished MSc thesis. Univ. of Wales UK

Nwachukwu, S.O. (1975). The temperature of formation of vein, minerals in the south portion of the Benue Trough, Nigeria. *Journal of Mining Geol.* 11 (1 and 2), 44-55.

Nwachukwu, S.O., (1972), The Tectonic Evolution of the Southern Portion of the Benue Trough, Nigeria. *Geol. Mag;* **109**(30): 411-419.

Nwajide, C.S. & Reijers, T.J.A. (2001). Geology of the Southern Anambra basin: *Sedimentary geology and Sequence Stratigraphy in Nigeria*,**45**(70): 33-197.

Nwajide, C.S. (2013) Geology of Nigeria's Sedimentary Basins, CSS Bookshops Limited, Lagos, Nigeria.

Obarezi, J.E. & Nwosu, J.I. (2013). structural controls of Pb-Zn mineralization of Enyigba district, abakaliki, southern Nigeria. *Journal of Geology and Mining Research 5 (11),* 250-261,2013.18, 2013.

Obasi, P. N. (2009). Hydrochemical Investigation of Okposi and Uburu Areas of Ohaozara and Environs of Ebonyi State, Nigeria. Unpublished MSc thesis. Nnamdi Azikiwe University, Awka.

Obasi, P. N.& Akudinobi, B. E. B., (2014). Hydrochemical Evaluation of Water Resources of the Ohaozara Areas of Ebonyi State, Southeastern Nigeria. *Journal of Natural Sciences Research.* 3 (3) 75 – 80.

Obasi, P. N., & Akudinobi, B. E. B. (2015). Geochemical Assessment of Heavy Metal Distribution and Pollution Status in Soil/Stream Sediment in the AmekaMinning Area of Ebonyi State, Nigeria. *African Journal of Geo-Science Research*, 2015, 3(4): 01-07.

Obasi, P. N., Akudinobi, B. E. B., Eyankware, M. O. & Nweke, O. M. (2015). Hydrochemical Investigation of Water Resources Around MkpumaEkwaoku Mining District, Ebonyi State Southeastern Nigeria. *African Journal Of Geo-Science Research*, 2015, 3(3): 01-07.

Obasi, P. N., Okolo, C. M., & Edene, E. N. (2018). Hydrochemistry and structural control of groundwater flow in the mining areas of Abakaliki, southeast Nigeria. *Sustainable Water Resources Management*, *9*(1), 32.

Obiorah, S. C; Chukwu, A., Toteu, S. F & Davies, T. C (2015). Assessment of Heavy metals Contamination in soils around Pb- Zn mining Areas in Enyigba, Southeastern Nigeria. Jour. Geol. Soc. India Vol 87 453- 462.

Oboh-Ikuenobe, F.C., Obi, G.C.& Jaramillo, C. A. (2005) Lithofacies, Palynofacies, and sequence stratigraphy of Paleogene strata in southeastern Nigeria. ."*Journal of African Earth Sciences* 41.1-2 (2005): 79-101.

Offodile, M. E., (1980). A mineral survey of the Cretaceous Benue Valley, Nigeria. *Cretaceous Research*, 1: 101-124.

Okagbue, C.O & Ukpai, S. N. (2013). Geochemical evaluation of groundwater quality in Abakalikiarea, Southern Nigeria. *Jordan Journal of Earth and Environmental Sciences.* Vol.5 No.1 p. 1-8.

Olade, M.A. Elueze, A.A. (1979). Petrochemistry of the Ilesha amphibolites and Precrambrian crustal evolution in the Pan-African domain of SW Nigeria. *Volume 8, issues 3-4 April 1979*, Pages 303-318.

Orajaka, S. (1965). The Geology of Enyigba. Ameri and Ameka lead-zinc lodes Abakaliki Eastern Nigeria.Arecon.*Journ. Min. Geol*. Vol 2. pp 65-69.

Orajaka, S. (1972). Saltwater resources of East Central State of Nigeria. *Journal Mining Geology*. Volume 7, Number 1 and 2, pp 35-40.

Oti, W, J. O.,& Nwabue, F. I. (2013). Heavy metals effect due to contamination of vegetables from Enyigba Lead Mine in Ebonyi State, Nigeria. *Environ. Pollut.*, *2*(1), 19-26.

Peters, S.W. (1978). Stratigraphic Evolution of the Benue Trough and its implications for Paleogeography of west Africa. *Journal of Geology Volume 86*, pp 311-322.

Pett-Ridge, J., & Firestone, M. K. (2005). Redox fluctuation structures microbial communities in a wet tropical soil. *Applied and environmental microbiology*, *71*(11), 6998-7007.

Powell, A. L. (1992). A First Course in Factor Analysis. 2nd Edition.Lawrence Erlbaum Associates. Hillsdale, New Jersey, USA. In: Shin, P. K. S. & Lam, W. K. C. 2001. Development of a Marine Sediment Pollution Index.Environmental Pollution. 113, 281-291.

Reyment, R. A. (1969). Aspects of the Geology of Nigeria, University of Ibadan Press, p 144.

Reyment, R.A., (1965). Review of Nigerian Crcetaceous-Cenozoic Stratigraphy. *Journal Mining* Geology. Volume 3, pp 61 –80.

Sardar, K., Ali, S., Hameed, S., Afzal, S., Fatima, S., Shakoor, M. B., ... & Tauqeer, H. M. (2013). Heavy metals contamination and what are the impacts on living organisms. *Greener Journal of Environmental management and public safety*, *2*(4), 172-179.

Schnitzer, M. (1983). Organic matter characterization. *Methods of soil analysis: Part 2 Chemical and microbiological properties*, *9*, 581-594.

Short. K. C. & Stauble, A. I. (1967). Outline of the Geology of Nigeria Delta.Hull AAPG**54:** 761-779. *Symposium, Newcastle upon Tyne*, UK, 20-25 September 2004.

Tyler, L. D., & McBRIDE, M. B. (1982). Mobility and extractability of cadmium, copper, nickel, and zinc in organic and mineral soil columns. *Soil Science*, *134*(3), 198-205.

UNICEF Programme Cooperation Agreement, Environmental Remediation-Lead Poisoning in Zamfara, Final Report, September 2010-2011.

United States Environmental Protection Agency – Mid Atlantic Integrated Assessment (US EPA MAIA (1988) project report.

Uriah U, Tsuwang K, Gusikit R, Mangs A (2013). Lead and Mercury Contamination Associated with Unabated Zamfara Lead Poisoning, *Journal of Earth Science and Engineering* 3: 764-775.

Uzoekwe SA, Aigberua AO (2019). Heavy Metal Distribution and Assessment of Ecological Risk in Surface Waters and Sediments within the Flow Station in Kolo Creek, *Nigeria.J. Chem Soc. Nigeria* 44**(**5)**:** 809-824.

Uzuakpunwa, A. B. (1974). Abakaliki Pyroclastics of Eastern Nigeria; New Age and Tectonic Implication. *Geol.Mag*.Vol.III, pp. 65-70.

World Health Organization (WHO), 1984. Guidelines for Drinking Water Quality and Health Risk Assessment of Disinfectants and Disinfection By-products.

World Health Organization (WHO), 1991. Guidelines for Drinking Water Quality, Geneva. Switzerland.

World Health Organization (WHO), 2012. Bi-Monthly Newsletter. March to April Edition

Xiao R, Wang SL, Wang JJ, Zhang Z (2017). Heavy metal contamination and health risks associated with artisanal and gold mining in Tongguan, Shaanxi, Ilina; *Ecotox. Environ.* Safe 141:17-2