ENVIRONMENTAL ASPECTS OF SOLID MINERAL RESOURCES DEVELOPMENT IN NIGERIA: AN OVERVIEW

Ezenwa Young Obioha, Osita C. Okeke and Hope Israel

Department of Geology, School of Physical Sciences, Federal University of Technology (FUTO), Owerri, Nigeria.
Corresponding Author: obiohe@yahoo.com, obiohaey@futo.edu.ng
Phone: +234(0)8038774782

Abstract

Solid mineral resources are a nation's natural endowment. They include native metals, industrial minerals, ores and gemstones on which mankind depend for their food, shelter, security and economic livelihood. The exploration, exploitation and development of mineral resources upset natural ecosystem; generate tailings and wastes, which may be hazardous to mankind. Mining can be by surface and/or underground methods, often involving mass deforestation, drilling and blasting which generate noise, dust and particulate matter into the environment. The processing and development may generate wastes and other deleterious effects in the environment. Excavations and unreclaimed mined lands are capable of causing weathering, erosion, flooding and gulling which devastate the environment. In order to reduce hazards in mining, safe mining methods, which reduce wastes/tailings production, reclaim excavated/mined land and minimize pollution, are necessary. Laws and regulations can be enacted and enforced to protect our environment. Education can be used to enlighten the people about the need for environmental protection and safety. Remediation measures such as bioremediation and treatability can be applied to ameliorate polluted environment.

Keywords: Health hazards, Pollution, Remediation, Solid Mineral Resources.

1.0 Introduction

A resource is a man's or a county's natural endowment or possession that can serve as wealth, a means for economic revamping, comfort or help (Okeke, 2017). A solid mineral is a naturally occurring, inorganic matter, with a definite chemical composition and internal structure, found in the earth. For the purpose of economic administration, some exceptions are applied, for example, mercury (Hg) which is a liquid at standard temperature and pressure (STP) is included in the class of minerals (Bateman, 1959). The United State Department of Agriculture (1986) defines environment as encompassing the interaction of all living species, climate, weather and natural resources that affect human's survival and economic activity. The concept of the natural environment encompasses the biosphere, lithosphere, hydrosphere and atmosphere. The sum total/aggregates of all living and non-living things surrounding man in his habitat (biotic and abiotic), including water resources, land/soil, air, plants and animals (Nnabuihe et al., 2016) with which he interacts and reacts, and which affect him.

Though the mineral resources of the country had been studied (Ekwueme, 1993a, b; 1994; Ofor, 1997; Ofulume, 2011; Obioha, 2014; 2018) and many others, more work is still needed to be done to properly understand/ and classify the solid mineral resources of this country. The present study is aimed at contributing to unraveling these complexities.

2. 0 Solid Mineral Resources of Nigeria and Their Uses

Solid mineral resources can be classified into three main groups based on their application, namely: native elements, ore minerals and industrial minerals (Bateman, 1959: Wright, 1971; Winkler, 1979), or four when the radioactive mineral group is added.

2.1 Native Elements: such as Au, Ag, Pt, Hg, Fe, Cu, etc. can occur uncombined in nature, because of their non/low-reactive character, which makes them very stable and useful ornamental jewelries and articles of trade (Ofor, 1997; Ofulume, 2011). These elements, mainly Fe and Cu occur in the Benue Trough of Nigeria, Au and Ag occur in the Ring Complexes of Jos-Plateau and in the Schists belts of northern and southern Nigeria. Though gold and barite have recently been found to occur in the Oban (Ekpeke, 2008) and Obudu plateau (Obioha, 2018) of southeastern Nigeria.

2.2 Ore Mineral Resources: These are minerals from which metal(s) could be extracted economically. The ore minerals occur together with the gangue (i.e. the unwanted components which are usually discarded during processing) and the metal which is the desired economic element (Bateman, 1959; Akpeke, 2008). Some proofed ore mineral occurrences in Nigeria may be sub-classified as follows:

Iron Ores- Hematite (Fe_2O_3), magnetite (Fe_3O_4) and siderite (Fe_2CO_3) which are important ore sources of Fe for engineering and construction. These occur throughout the Cretaceous and Tertiary sedimentary basins in Nigeria (Fig. 1; Table 1). They are the main raw materials for steel companies such as Alaja and Ajaokuta Steel Rolling Mills and serve as the main minerals for industrial development.

Tin Ore (Figs. 1; Table 1) - Cassiterite (or tinstone-SnO_2), is the most important ore of tin (Sn). It occurs in hydrothermal vein deposits, in acid igneous rocks and as replacement deposits (Whitten and Brooks, 1978) such as the Younger Granite Ring Complexes of Jos Plateau areas northern Nigeria. They also occur in alluvial deposits and pegmatites. They are used mainly for the production of metal tin for food cans, alloys and soldering materials. Tin ore was the first metal ore of Nigeria before the civil war which negatively affected its production.

Zinc Ore- Sphalerite (or zinc blend- ZnS), is the main Zn ore found in metasomatic deposits with galena. It is used in the manufacture of roofing materials, alloys (e.g. brass 60% Cu : 40% Zn), tombak (90% Cu : 10% Zn) and German Silver (55% Cu : 27% Zn :18% Ni) (Bateman, 1959), coils and can (Offo, 1997). Sphalerite is found in Ishiagu–Abakaliki areas of Ebonyi State, Southern Nigeria. Characteristically, the sphalerite mineralized zones occur in an N-S and NE-SW trending fault zones of the Benue trough Nigeria, the Arufu-Akwarnga area of Kwarra State and Kwande Kogi areas in basaltic cones and vents of steep folds about 200 to 600 meters thickness in the Turonian shale beds of Nigeria (Tattam, 1934; McConnel, 1949).

Aluminum Ores: The main ore of Al is bauxite, a residual lateritic sediment formed under tropical environment. According to American Mineralogical Society (http://www.ams.org), Al is the most abundant metal element in the earth's crust (USAD). Al smelting companies in Nigeria include First Aluminum Co. Port Harcourt and Standard Aluminum Co. Onitsha and many others. Al is used for the manufacture of long span roofing sheets, coils and paint.

Gold ores: Gold sulphide (Au_2S) and the native elements are the most important sources of gold (Au). Au is an extremely malleable and ductile metal with a beautiful yellow luster. It is an excellent conductor of heat and electricity and has high melting point > 1000^oC (Ofor, 1997). It is very resistant to atmospheric corrosion and to acid attack. These properties make Au a precious metal for jewelry, dentistry and monetary value. Gold occurs in Kafanchan District of Kaduna State, the Ilesha gold-field of Oyo State, Minna area in Niger State as well as Sokoto and Bauchi states. Au is measured in carats quoted as 24 for pure Au. A 17 carat Au means 17 parts of gold to 7 parts of the alloying metal.

Copper Ores (Fig. 1 and 2; Table 1)- chalcopyrite ($CuFeS_2$), bornite (Cu_5FeS_4) and azurite- $2CuCO_3Cu(OH)_2$, are the most important sources of Cu. Cu is a cubic, twined, massive or dendritic mineral, with hardness of 3 and specific gravity of 8.8, malleable and ductile (Whitten and Brooks, 1978). The copper-red colored variety has metallic luster and streak, no cleavage, but shows dendritic fracture. These properties make Cu very useful for electrical wires, battery terminals, coils, and alloys. Cu occurs in hydrothermal and metasomatic deposits of the Cretaceous formations in Benue Trough, Nigeria.

Lead Ore: Galena (PbS) is the most important ore of lead (Pb), it is found in hydrothermal deposits and as replacement sulfide ore deposit association with Zn. It occurs in Abakaliki-Ishiagu areas of Imo, Abia, Ebonyi States of Nigeria (Ofor, 1997), Zurak District

and Wase areas of Plateau State. Pb is used in the production of gun powder, paint, and battery terminal (Tattam, 1934; McConnel, 1949; Table 1).

Barium Ore- Barite (barytes) a barium sulphate mineral ($BaSO_4$), is the principal ore for Ba, as well as an important industrial mineral for drilling mud formulation due to its high SG (4.0- 4.5; Bateman, 1959) and for high quality paint (Ofor, 1997). Barite is found in the Cretaceous formations in Calabar Flank and Oban Massif of Cross River State; Benue state Nigeria (Akpeke, 2008) and Obudu-Benue areas Southeastern Nigeria (Obioha, 2014).

2.3 Industrial Minerals: Include clay, bentonite, feldspars and barite, used in oil and gas drilling mud formulation, to prevent bow-out and enhance borehole stability in drilling operations; feldspar (plagioclase and orthoclase), silica sand and limestone used for the manufacture of tiles, and other decorative materials, salt (halite- an evaporite mineral used for food seasoning and drug manufacturing), and carbonate/limestone (such as calcite and aragonite-$CaCO_3$; dolomite- $CaMg(CO_3)_2$) used for cement manufacture and other various industrial purposes; phosphate, apatite and clay used for agricultural purposes (MSMD, 2015, Report of Vision 2020; Table 1; Figs. 1 and 2).

2.4 Radioactive Minerals: These include thorite (ThO_2) and uraninite (UO_2), which are the most important sources of radioactive metals thorium (Th) and uranium (U) respectively. They are often regarded as strategic minerals demanded for national armament and defense. Table 1 summarizes the Nigerian solid mineral resources demand by industries, while Figs (1) shows the mineral resources distribution in Nigeria.

3.0 Solid Mineral Resources Development In Nigeria

Mineral resource development can be discussed under the headings: exploration, mining and quarrying, drilling, processing and beneficiation, utilization and management of associated wastes. Exploration is the search for mineral resources deposits. This precedes mining and quarrying which aim at extracting the mineral from the earth. Solid mineral exploration involves a vast number of activities which include geophysical exploration using gravity methods for dense/heavy metals like Ba, Cu, Pb, Au, Pt; magnetic methods for magnetic minerals like magnetite (Fe_3O_4) and pyrite (FeS_2), seismic method used to define / delineate the structural setting, depth of occurrence and geometric orientation of the mineral deposits.

Table 1: Mineral Resources Distribution in Nigeria by Industry

	Industry	**Minerals Requirement**
1	Oil	Barite, bentonite, mica, gypsum, soda ash, calcium carbonate
2	Petrochemical	Micas, asbestos, Limestone, gypsum, clay, marble, dolomite,
3	Construction/ Building	Limestone, gypsum, clay, granite, marble, dolomite, sand/sandstone, gravel, laterite
4	Agriculture	Phosphate, Apatite, limestone, lime, kaolin, magnetite, gypsum, dolomite
5	Steel	Iron ore, limestone, coal, dolomite, manganese, bentonite, molybdenum, magnetite, kyanite, selenium, tungsten, and nickel
6	Manufacturing	Kaolin, talc, limestone, feldspar, quartz, dolomite, soda ash, barite, diatomite, tin, titanium dioxide, lead and zinc
7	Pharmaceutical	Petroleum, clay, limestone/carbonates, diatomite,
8	Electrical/Electronics	Micas, bauxite, silica, ores (Fe, Zn, Al, W, Cu, Pb).
9	Jewelries/ Ornamentation	Precious metals: gold, silver, platinum, beryl, tourmaline, agate, sapphire, azurite.

(Source: Modified after Ministry of Solid Minerals Development; NMGS DLP Lectures, 2015).

3.0 Mining

Mining is the extraction of mineral resources deposits from the earth. It involves mineral exploration, exploitation, processing and development. The exploration/search involves excavation (clearing for exposition of mineral deposits), drilling which is a specialized type of mining involving the use of bore holes, tunnels, and/or shafts for mineral resources extraction. Land caving, waste and tailings production are often associated with these operations. Transportation involves the movement and distribution of the mineral resources from their point of extraction to the plant for crushing, processing and distribution often using bulldozers, screens and conveyor belts. Processing and beneficiation refer to all the work done after the extraction of the mineral resources aimed at enhancing and upgrading its value and making it ready for distribution and consumption. Utilization is the ultimate application of the minerals by man and/or industry for betterment of life, industrial and national development. Fig. 1 summarizes the mineral resources of Nigeria by location. The stages in mining may be summarized as shown in table 2. Some steps necessary for mine development are illustrated below, while the major steps involved in mining are summarized in Table 2.

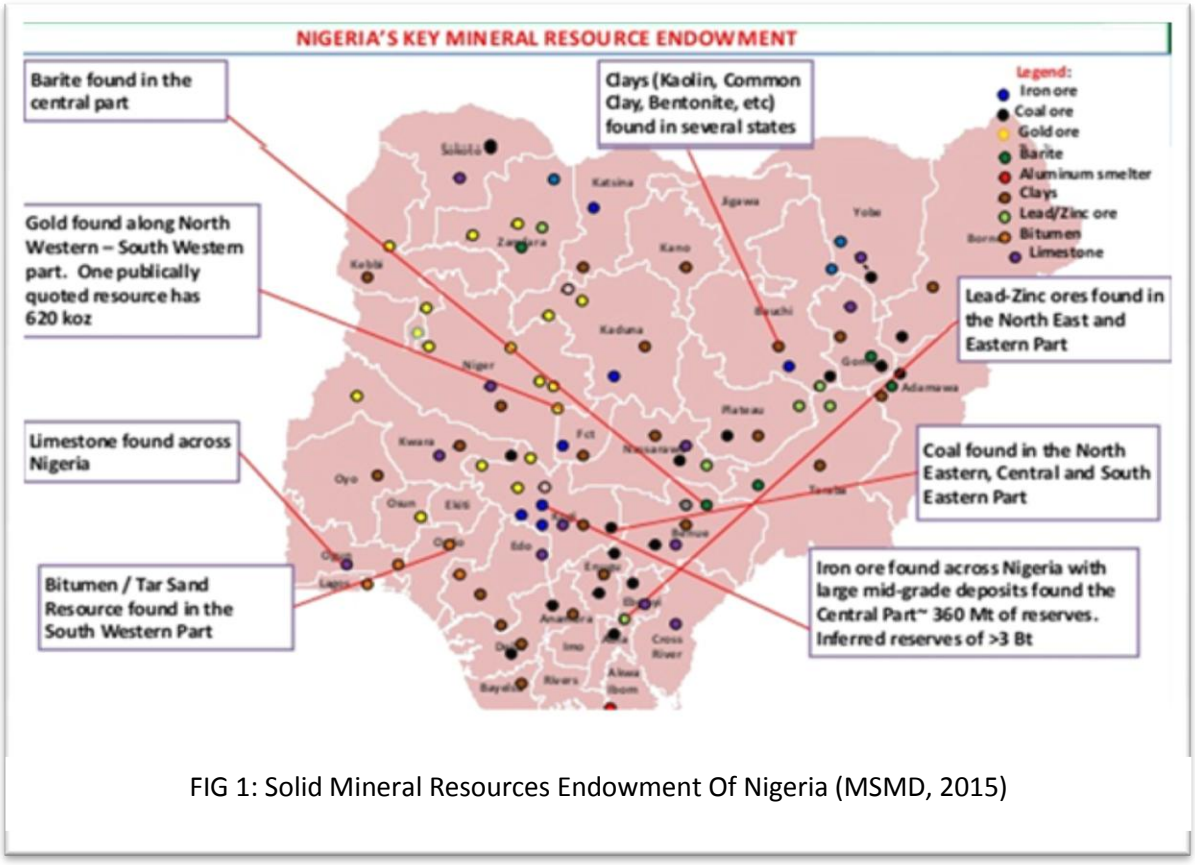

FIG 1: Solid Mineral Resources Endowment Of Nigeria (MSMD, 2015)

a). Opening: This is the construction of shafts and audits, which provide access from the surface either to the entire mineral deposit or to its part that will allow for mining methods development works such as ventilation system and the haulage of men, materials and equipment to and fro the mineralized zone.

b) Development: This is the construction of interconnected audits or cross-cuts that divide the deposit into isolated production units, including levels, panels and pillars depending on the specific type of mining operation to be adopted.

c) Stopping: This is the process of extracting minerals from the production unit. The stopping pattern to be adopted defines the underground mining method or system applicable in the circumstance (Okeke, 2013; 2017).

d) Room and Pillar and Long Wall Mining Methods: are used for bedded deposits while cut & fill, stopping and block caving methods are used for vertical or near vertical lodes and veins. The support system of the overburden rock mass in underground mining also influences the choice of mining method. Thus, room and pillar mining method is naturally supported. Cut and fill stopping methods are artificially supported while long wall and block caving method are unsupported. Table 2 summarizes the types of mining methods.

Table 2: Classification of Mining Methods

	Surface Mining	**Underground Mining**	
i	Strip Mining: Contour Strip & Area strip mining	i	Room & pillar mining
ii	Open Pit Mining (also called Open Cut Mining)	ii	Cut-and-fill Stopping
iii	Quarrying	iii	Long Wall mining
iv	Alluvial Mining (for placer deposits)	iv	Block Caving Mining
v	Auger Mining	v	Ocean Mining (dredging of manganese from ocean beds)
		Vi	Solution mining of Salts (e.g. Salt deposits-halite)

Source: Okeke (2017).

4.0 Environmental Impacts of Solid Mineral Resources Development

The environmental hazards associated with mining, processing and development of minerals resources have long been studied by many scholars, such as Obioha and Nwachukwu (2007), Azubuike (2011), Okeke (2013), Nnabuihe et al. (2016), and many others. They all agree that mining activities generate various impacts to the environmental including land degradation, water pollution, erosion and gulling. These impact mankind, aquatic and endangered species and the entire ecosystem in one negative way or the other. For example, generation of SO_2, SO_3, CO, CO_2 which can combine with moist or water to form acid mine drainage and acid rain, production of dangerous gases such as methane lead to outbreak of fire/bush burning (Bateman, 1959; Akpeke, 2008; Offordile, 2010). These impacts are summarized in the steps that follow.

4.1 Environmental Problems

Environmental problems of mineral resources development can be looked at from the following perspectives because of the high risk, pollution effects and socio-cultural problems associated with them. All the processes of the development aspects of solid minerals generate wastes and tailings in one way or the other which can be categorize as follows:

4.2 Heavy Minerals Impacts

A heavy mineral is a mineral with density > 2.9g/cm^3 or atomic weight > Ni (Goldschmidt, 1954). They include Pb, As, Hg, Cd, Cr, U, Th etc. Chromium (CrIV in its hexavalent form) and arsenic (As) are carcinogens; cadmium causes a degenerative bone disease; and mercury and lead damage the central nervous system (Nnabuihe et al., 2016). Certain heavy metals such as cobalt, copper, manganese, molybdenum, vanadium, strontium, zinc, and iron, are essential to health in trace amounts, but at excessive levels they can be detrimental to the organisms and environment. These metals are systemic toxicants known to induce adverse health effects in humans, including cardiovascular diseases, developmental abnormalities, neurologic and neurobehavioral disorders, diabetes, hearing defect/loss, hematologic and immunologic disorders, and various types of cancer, for the case of lead poison in Zamfara State Nigeria.

4.2.1 The Main Pathways of Exposure include ingestion, inhalation, and dermal contact. The severity of adverse health effects is related to the type of heavy metal and its chemical form, and is also time- and dose- related.

4.3 Land Degradation Impact

Weathering/denudation, erosion, gulling and mass movement are some of the land degradation and devastating problems (Goldschmidt, 1954) of solid mineral exploration and mining. These may result from mine tailings, waste dumps, indiscriminate excavation, abandonment of mined pits (Fig. 3), non-reclamation of mined land. Destruction of environmental aesthesis, land use and land planning, land subsidence, caving and rock fall, displacement of people and homes are prevalent problems associated with solid minerals mining activities (Bateman, 1959; Nnabuihe et al., 2016).

4.4 Dust, Particulate Matter and Air Pollution Impacts

Dust, particulate matter and air pollution are other aspects of environmental impacts which result mainly from crushing and pulverization of rocks and solid minerals (Fig. 4). The dust and particulate matter generated from mining, processing and development of solid mineral resources go into the atmosphere polluting the air, affecting vision, causing lung diseases and cough, aggravating cancer and asthma (Nnabuihe et al., 2016).

4.5 Desertification

Solid minerals exploration and mining usually involve massive clearing of crustal vegetation and plants. This exposes the bare land making it more prone and susceptible to desert encroachment, and negatively affects man, animals, plants, agricultural productivity, land use/planning and particularly the endangered species.

4.6 Impact on Climate change

One of the major global problems of solid minerals exploration and mining is climate change effect. This is mainly associated with the mining and processing of radioactive minerals such as thorite (ThO_2) and uraninite (UO_2) mined in the Younger Granite around Jos and Plateau States in northern Nigeria for (Th and U) metals, and their waste dumps and tailings. These minerals in their radioactive decay processes spontaneously disintegrate radiating and giving out excess energy capable of negatively affecting the global environmental temperature. Hence the global temperature has been rising steadily with the increasing number of mines and world population since the year 1888 – 2000 (Fig. 5).

4.7 Water Pollution Effects

Solid minerals exploration and mining generate unwanted gases, e.g. methane (CH_4) out bust is capable of causing fire outbreak, bush burning thus devastating the environment. CO_2, SO_2, may be generated which are capable of combing with oxygen and moist to form carbonic acid and sulfuric acid respectively. These can fall as acid rain or form acid drainage, which damages

zinc, corrodes pipes and other metallic structures, affects plants and aquatic organisms (Teme, 2001; Offodile, 2010).

Fig. 3: Abandoned mined pit Ishiagu Area, SE. Nigeria (Obioha, 2018).

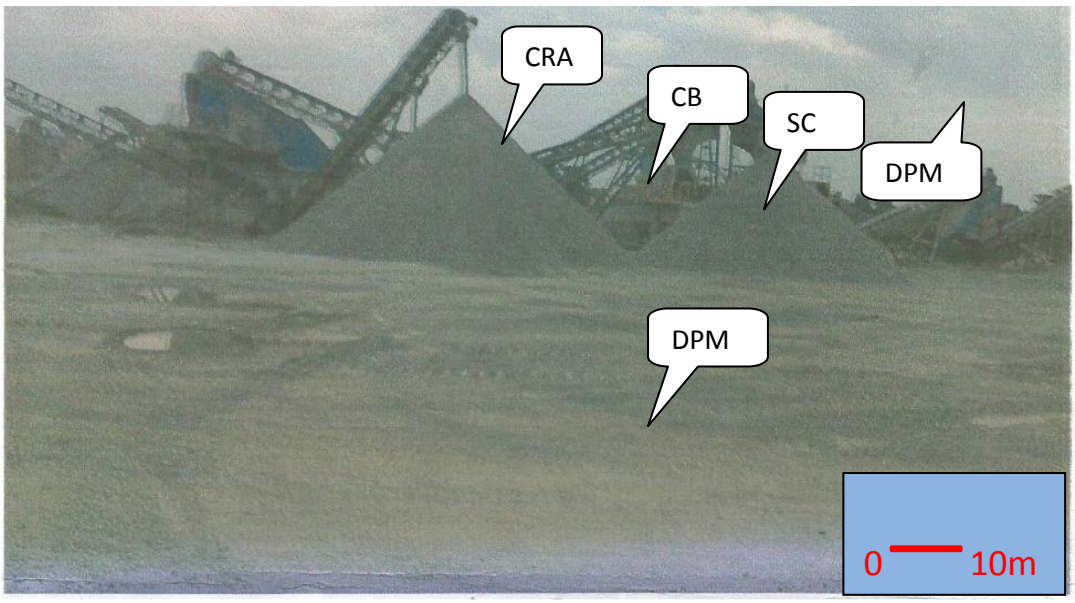

Fig. 4: Particulate matter and dust generation at a rock crushing site in Ishiagu Area, SE. Nigeria (Obioha, 2018). PC = primary crusher; SC = Secondary crusher; CB = Conveyor belt; CRA = crushed rock aggregates; DPM = Dust & particulate matter on the ground and in atmosphere.

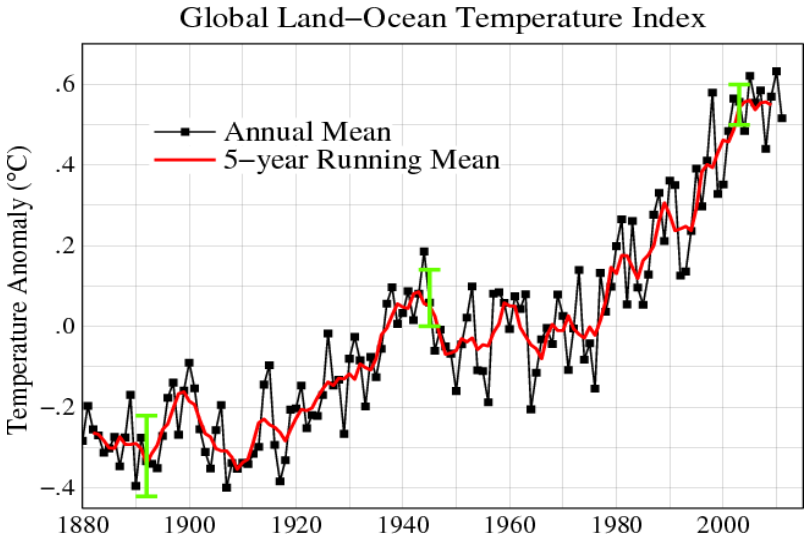

Fig.5: Global Land-ocean temperature change- 1880 to 2000.

This has been rampant in Nigeria, for example, the cases of Ogoni Land, Rivers State, Eket area of Akwa Ibom State and Oguta area in Imo State, where both marine and fresh water pollution had resulted in the death of plants, animals and fish, and negatively affected agricultural productivity leading to food insecurity and land use planning impairment.

4. 8 Health Impacts

Health related problems are other impacts of mining activities negatively affecting peoples' life and socio-cultural behavior. These result from the introduction of dangerous, toxic and carcinogenic metals, mine dumps and tailings into the environment. These contaminate and pollute the air, water and land / soil making them unfit for man, animals and plant health. For example, these toxic chemicals can cause cancer, diarrhea, whooping cough, lung problems etc. In addition to health impacts these cause socio-cultural and serious economic hardship to the people.

5.0 Mitigation Of Impacts

The problems mitigation focuses on the goals for the benefit of people and natural systems, aimed at:

Elimination of pollution, pollutants and toxicants in the air, water, soil/land, buildings, manufactured goods, and food, preservation of biodiversity and protection of endangered species, elimination and reduction of land degradation including erosion, flooding, gulling, mass movement and other forms of environmental destruction (Teme, 2001; USEP), Conservation and sustainable use of resources such as water, land, air, energy, raw materials, and other natural resources, halting human-induced global warming, which represents pollution, a threat to biodiversity and human population and growth, shifting from fossil fuels

to renewable energy in electricity, heating and cooling, and transportation, which addresses pollution, global warming, and sustainability. Establishment of nature reserves for recreational purposes and ecosystem preservation. Sustainable and less polluting waste management system including waste reduction (or even zero waste), reuse, recycling, composting, waste-to-energy conversion, and anaerobic digestion of sewage sludge should be adopted in trying to achieve these objectives.

Governmental, non-governmental, and other stake holders, multinationals, the Clean Nigeria Association (CNA), The Federal Ministry of Solid Mineral Resources (FMSMR), NMGS (Nigerian Mining Geosciences Society), DPR (Department of Petroleum Resources), Federal Ministry of Transport and the Federal Inland Water Ways, FME (Federal Ministry of Environment) should cooperate to effect immediate containment of pollution incidents. Government should enact and enforce rules and regulations to protect the environment, including the water, soil/land, air, animals, vegetation and the entire biodiversity from pollution and contamination. The use of satellite imagery, area photographs, geographic information systems (GIS) and other environmental friendly geological, geophysical and geochemical approaches should be adopted to reduce pollution incidents and deaths. It is suggested that environmental impact assessment (EIA) should be conducted before setting up a project. Containment, treatability, bioremediation should be carried out immediately to clean up any pollution occurrences where pollution has already occurred.

6.0 Conclusions and Recommendations

Mineral resources of Nigeria are the natural endowment of the country. They form the pivot on which the life of the citizens revolves, and thus are very inevitable notwithstanding the associated impacts of the exploration, mining, beneficiation and development operations. For example, metals and industrial minerals are the mainstay of the nation's engineering and industrial development, could contribute immensely to both domestic and foreign exchange earnings. But the exploration, mining and beneficiation stages are characterized by various environmental problems, hence, sustainable environmental friendly exploration and exploitation approaches must be devised to stop/reduce hazards, diseases, death of people, animals and plants, by preserving our water, air and soil/land quality. If actualized these projects will provide job opportunities for our teeming youths, generate huge domestic and foreign revenues, revitalize our social-cultural and economic environment and add in the mitigation of impacts caused to our ecosystem by mineral resources exploration and development.

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