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ENVIRONMENTAL CONSEQUENCES OF THE EXPLORATION AND EXPLOITATION OF SOLID MINERALS I N NIGERIA: A STUDY OF TIN IN JOS AND COAL IN ENUGU

By

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ABSTRACT:

The discovery phase of a mine's operation through the closing phase can all have significant detrimental consequences on the environment. Nigeria has a variety of minerals, and the environment may be impacted by their discovery or utilisation. This essay's goal is to assess the environmental impact of mining for tin and coal in Enugu and the Plateau, respectively. The coal mines in Enugu are utilised to represent places with closed mines, whereas the Jos field in Plateau State is utilized as an instance of investigation for zones with active miners. A field survey, direct mapping of mining operations, evaluation of the effects of exploration and exploitation, documentation analysis, and observations are all part of the technique employed for this study. Evaluation of the environmental effects of mining for coal and tin is included in the outcomes. It is hoped that Nigeria would be able to implement and enforce some minimal environmental criteria for the exploration and extraction of solid minerals as a result of the study's findings. Best management techniques could also be implemented for recovering surface mines.

Keywords: environmental, implications, Exploration, Exploitation, Tin, Coal.

1.0 Introduction

A naturally happening component or chemical compound that is crystalline in nature and created as an outcome of geological procedure is known as a mineral (Nickel, 1995). They exist as aggregates, which are frequently called rocks (Oshin, 2003). Depending on their makeup and intended usages, minerals can be divided into the following categories: "*metallic minerals (such as iron and gold); industrial minerals (such as limestone and baryte); construction minerals (such as gravel sand and rock aggregates); gemstones (such as emerald and topaz); and mineral fuels (Coal and hydrocarbons)*".

Any mineral must have undergone exploration before it can be used. Geological mapping, airborne geophysical mapping, geochemical examination, and reserve estimation are all part of the exploratory phase. Exploitation operations may start once a mineral deposit has been shown to be economically feasible (Newman, et al., 2011). The mining of the pertinent mineral constitutes the exploitation step of a solid mineral. When a mineral deposit is found at a shallow depth (such as with coal and tin), mining may be done either open-pit or underground (coal). According to Newman et al. (2010) and Al-Usmani (2011), "*mining causes a variety of environmental harms that are depicted in a flow diagram by Ashton, Love, Mahachi, and Dirks*

(2001), Pring, Otto, and Naito (1999), and Miranda et al (2003)". Nigeria is given with a diversity of large-scale solid mineral resources that are extensively dispersed over almost all of the federation's states, including the Federal Capital Territory. "*Some of the minerals in Nigeria and their current prices were given by Aigbedion and Iyayi (2007), Mallo (2012), and Adekoya, Kehinde-Philips, and Odukoya (2003)".* A number of unfavourable reports about illegal gold and mercury mining in Northern Nigeria have surfaced. If mining operations are not closely supervised and best procedures are not implemented, the results could be disastrous. As a result, environmental protection is necessary, and mining operations must be closely monitored.

The goal of this paper is to examine the environmental influence of mining for tin on the Plateau and coal in Enugu. The coal mines in Enugu are utilised to represent places with closed mines, whereas the Jos field in Plateau State is utilization as an instance of a study for zones with active miners. With the help of this study, Nigeria should be able to establish and uphold certain minimal environmental requirements for the exploration and mining of solid minerals. Best management techniques for regaining surface mines could also be implemented.

Studies on specific environmental components, such as water and ecology, were covered in earlier research on the environmental effects of "*solid mineral exploration and exploitation (SMEE)"* in Nigeria, but these studies rarely covered the complete ecosystem. Using the Normalized Differential Vegetation Index (NDVI), Musa and Jiya (2011) evaluated the effect of mining operations (MO) on vegetation in the Jos Plateau and came to the conclusion that tin MO had a significant negative impact on the study area's natural ecology and had deprived creatures and florae of their natural habitation. Gyang and Ashano (2010) evaluated the impacts of MO on water excellence in a few chosen areas of the Jos Plateau and came to the conclusion that tin mining had no appreciable impact on the water quality in the area. Ndace and Danladi (2012) evaluated the biophysical effects of tin MOs in Jos and came to the deduction that MO had a substantial impact on the local ecology. As a result, it is important to monitor mining sites, assess the environmental harm they have caused, conduct mitigation studies, and conduct routine inspections to keep these operations in check.

2.0 Methodology

This report's methods is a survey by thorough observation and plotting, direct diagramming of mineral extraction, evaluation of the search and exploitation influences (which was completed by attending the site and assessing each influence on the atmosphere, landscape, lithosphere, and hydrosphere); and document analysis using literature review; and observations (physical). Each approach offers different chances to learn as much as you can about the possible environmental impact of mineral search and extraction activities.

In order to learn more about the effects that exploration and exploitation activities have on the ecosystem, two specific study areas with various mineral kinds were visited. The study involved visits to the northern and southern sections of Nigeria to observe the types of assessment and exploitation operations conducted and their effects on the ecosystem. Tin-containing Jos Plateau in the north and coal-rich Enugu in the south were chosen as the locations for Nigeria's mining operations. These locations were picked because mining operations are still taking place there

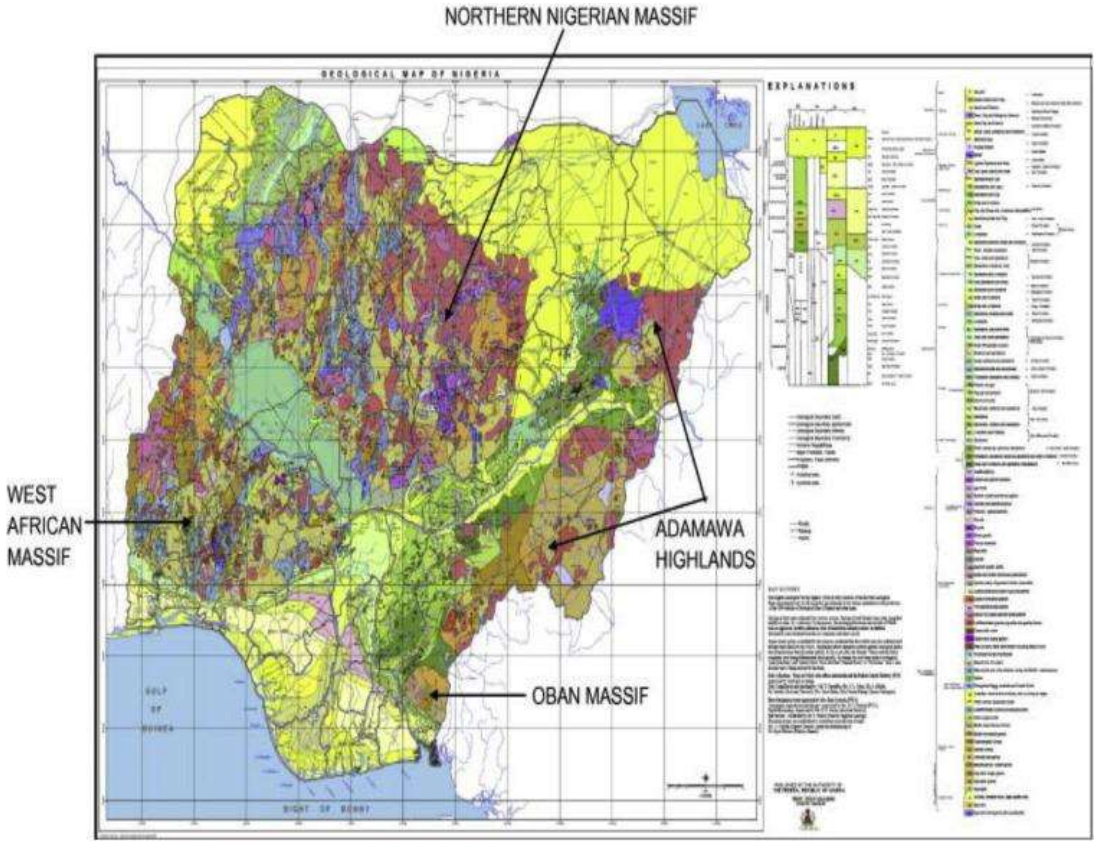

Fig. 1. Geological map of Nigeria.

As previously said, Nigeria is blessed with numerous, diverse mineral resources that may be found throughout the country's different geological terrains. The geological map of Nigeria is shown in Fig. 1. The Pre-Cambrian Basement Complex of Nigeria and Cretaceous Sedimentary rocks are distributed roughly equally. Significant solid mineral deposits, including gold, iron, tin, and other gemstones, are found in the older and younger granites that are associated to the basement complex rocks. Coal and other hydrocarbons are found in sedimentary rocks (coal).

2.1. Tin (cassiterite)

According to fact existing in literature, The Jos Plateau, which has an

area of 8600 km2 and is situated in the heart of Nigeria, is roughly 104 km from north to south and 80 km from east to west. With a 600 m fall to the nearby lowlands, it has sharp cliff sides. The Jos Plateau's southern portion is situated in the Benue lowlands and stretches toward the River Benue flood plain. The location is located in latitude 10°11'N and longitude 8°55'N and 9°30'E. (Musa & Jiya, 2011; Ndace & Danladi, 2012). Sediments are limited to valley alluvium in the geological sequence of the Jos Plateau and its surroundings, which is nearly exclusively composed of plutonic and volcanic rocks from four primary age groups (Table 1). Younger Granites, a number of non-orogenic intrusives, and related volcanics make up the majority of the region's geology. The Younger Granite province's focus point is the Jos Plateau, which is also the main location of the associated tin and columbite deposits. Rhyolites and acid tuffs, which make up the majority of the early volcanic components, are preserved by cauldron subsidence or in severely degraded vents. These were replaced by ring-dykes and plutons made of riebeckite-granite, biotite, and horn mix. There are also minor basic and intermediate rocks present. Recent evidence indicates that the Younger Granites are Jurassic in age.

Quaternary	Newer Basalt	Lava flows and volcanic cores
Tertiary-Quartenary	Alluvium	
Lower Tertiary	Older Basalt	Lava flows now largely decomposed overlying alluvium
Jurassic	Younger Granite	Granites, Porphyries and rhyolites
Pre-Cambrian to Lower Paleozoic	Crystalline Basement	Migmatites, gneiss and older granites

Table 1. A generalized succession of rock in the Jos Plateau and environs.

Because it makes copper more durable, tin, one of the oldest mineral deposits in Jos-Plateau, is significant. "S*ince then, tin ore has been mined in numerous locations around Nigeria, including the Plateau Province, Bauchi, and Ilesha, with more than 80% of the production coming from the Jos Plateau. This is due to the country's booming mineral exploration and exploitation industry. Tin exploration began around the beginning of the 20th century. Tin was concentrated in old stream beds and washed down from the younger granite outcropping sections, and because the Plateau's plains were flat, open cast mining was utilised to extract it"* (Gyang & Ashano, 2010).
"Tin was mined from the Jos Plateau, with the cassiterite mineral coming from the plateau highlands. There was a rapid increase in production from 1.36 tons in 1904 to 5573 tons over a period of ten years, and the highest production level was 15,842 tons in 1943. An unmined reserve of about 3500 tons is still believed to exist in the sub-basalt tin of Ngell" (Mallo, 2012).

2.2. Coal

Although coal is now recognised to exist in several areas of Nigeria, Enugu coal has received the greatest attention. The coal deposits found in Nigeria are located in "Coal-measures," which are geological units. The Anambra Basin is where the majority of the coal measures (Fig. 2) are found, although they are also found in other Nigerian rocks including Lamja, Gombe, Lafia-Obi, and Afikpo in Imo and Bauchi states. "*The Owupka and Okaba coal mines are in Benue State, while the Okpara mine is in Anambra State"* (Ezekwe & Odukwe, 1980; Godwin, 1980). British geologists found coal outcrops in 1909, and mining operations in Enugu began in 1916. The Enugu region has five coal seams, according to results of thorough geological drilling and mapping. According to Coker (2003), "*the coal seams are of good quality and dip to the west or West-North-West (WNW) at a low angle of 1°–3°. Six fault systems striking WNW are located within the coal beds".*

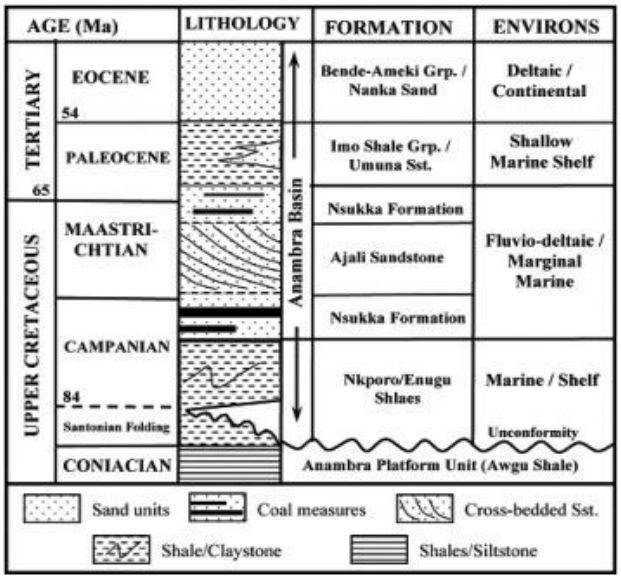

Fig. 2. Anambra basin Origin and stratigraphy (Tijani &Nton,2009).

"Lignite, sub-bituminous, anthracite, and bituminous coal are the four main varieties (Idris, Onaji, Aberemi, & Aroke, 2016). Sub-bituminous, the predominant type found in Nigeria, is a little lower in quality than bituminous" (Ezekwe & Odukwe, 1980; Godwin, 1980). At Enugu, the Nigerian Coal Corporation (NCC) runs four automated long wall faces (Godwin, 1980). CPE-

TEMEC (2009); Godwin (1980); Ogunsola (1990) said as follows:

> *Both the open-cast mining method and the underground mining method can be used to extract coal. Nigeria's most widely used coal mines are in Enugu, where NCC had two underground mines. Commercial production there began in 1916, and coal production peaked there in the late 1950s at about 920,000 tonnes annually. Following this, due to the Nigerian civil war, which began in 1966 and caused the mines to be abandoned and flooded, production significantly declined until there was no coal produced at all in 1968. After the war, production started up again in 1972. Coal mining was automated in 1976, however the automation was unsuccessful, and the corporation has since experienced numerous issues, leading to the eventual abandonment of the mines at an impasse*

3.0 Results

3.1. Direct mapping of mining activities and the field survey

"Geological mapping and remote sensing" are two methods of mineral exploration that have minimal environmental impact. Cutting traverses, pitting, trenching, and drilling are necessary for thorough geological diagramming and ground geophysical monitoring. With the exception of drilling-related groundwater aquifer contamination, noise and vibration, destruction of vegetation, and fluid disposal, these activities have very little of an environmental impact (Al-Usmani, 2011; Ezeaku, 2012; Musa & Jiya, 2011).

Exploiting solid minerals includes site groundwork, quarrying, treating minerals, moving raw resources to processing location(s), and "*mine closure or abandonment*". Injuries to flora, ecological disruption, degradation of the ecosystem, radiation, dangers, geological risks, and socioeconomic problems are just a few of the detrimental repercussions of extraction on the environment (Aigbedion & iyayi, 2007; Miranda et al., 2003).

3.2. **Evaluation of the effects of exploration and exploitation; examination and observations of the documentation.** Since exploitation of tin and coal has been ongoing for many years and has gone through the exploration stage, the impact of this activity is pretty clear. It is envisaged that the environmental effects of mining for tin and coal will serve as important precedents for developing a thorough "*environmental management standard for the mining industry"*.

3.2.1. Tin (cassiterite)

The principal "*morphological units of the Jos Plateau and the neighbouring Kaduna-Bauchi plains"* were formed as a result of erosion that occurred in the mining sites on the Jos Plateau after the Younger Granites were formed. Early Tertiary lava flows from the Older Basalts overlaid alluvium that the Plateau Rivers had previously deposited. The clays from the basalts have largely broken down into laterite-covered laterite that has been split by subsequent erosion. The majority of Nigeria's cassiterite output comes from later alluvial deposits, while the highly conserved "*cones and lava flows of the Newer Basalts*" were produced during a different volcanic activity. It is well known that "*alluvial concentration shed from the Younger Granites"* accounts for nearly all of the Plateau's tin production. Nevertheless, there are extracted from "*pegmatites*" (Macleod, et al., 1971). The underground river channels and pegmatites have been mapped using a variety of geophysical approaches, including "*magnetic, gravity, electrical resistivity, and seismic refraction*". Due to the fact that these techniques employed precut traverses, they had no effect on the environment.

Jos has a steady landscape with some vegetation. Trenching and pitting, the most common mining technique, had a negative impact on the hydrosphere and the terrain. Open pit mining is the primary method of exploitation, which has led to wasteland formation, harm to normal drainage systems, pollution, and the ruin of natural habitats (surface and groundwater). Additionally, smelting releases airborne toxins. Additionally, it was discovered that various additional minerals, including "*tin-derived byproducts monazite, pyrochlore, and xenotime, are radioactive*". The presence of radiation adulteration cannot be totally removed because many abandoned mines traditionally treated these other minerals as

discarded and deserted them in tailing ponds or left them uninhibited.

Abandoned open pit mines produce mining ponds, which accelerate erosion. These pools lack the ability to support any kind of life since they are filled with tailings in massive quantities. Accidents are likely to happen at these pools because they aren't fenced in and are adjacent to populated areas. Water pollution in the form of surface and groundwater is the most harmful consequence. "*Since pits are excavated to look for pegmatites that hold gemstones, and then those pits and trenches are abandoned, poor land or hummocky topography interrupted by irregular holes and trenches, the present interest in gemstones has further worsened the destruction of the environment*" (Adekoya et al., 2003).

3.2.2. Coal

The risks to the environment that MO in the Enugu field has caused include: "*Subsidence (e.g. Iva valley); Mine waste dumps which change the existing topography; Pollution of rivers, streams and groundwater by acid water from the mines; Flooding of the mine by acid water which can corrode machinery and affect the health of miners; Inadequate ventilation which also affects the well-being of the miners; Air pollution resulting from coal dust"*

4.0 Discussions

4.1. Possible environmental consequences of minerals exploration and exploitation operations

4.1.1. Environmental consequences of tin mining

The devastation of pastoral land in the search for "*cassiterite, mine dumps, mine tailings including radioactive waste, and mine ponds"* are a few of the environmental harms brought on by "*tin mining in Jos-Plateau*". Numerous people have died as a result of these mine ponds. "*Radioactive minerals*" were also free into the environment while mining for tin. Erosion contributed to soil dilapidation by instigating loss of soil nutrients and organic matter as well as harm to the qualities of the soil and crops. There was no established control for mineral extraction, dispensation, or reclamation prior to the 1946 approval of the first Mining Law. Even with the inclusion of environmental safety in the control of mining activities in the 1946 Act, the environment was not adequately shielded from the damaging effects of mining. "*The cost of a lack of environmental protection in the Act is evident in the Plateau tin mining fields*" (Chindo, 2012).

4.1.2. Environmental consequence of coal mining

Waste rock (WRs) produced during coal MO is a significant source of "*acid mine drainage (AMD) (discharges carrying high loads of sulphide oxidation products and associated metals)*". AMD is a serious environmental contamination issue in mines because it typically contains hazardous heavy metals. "*Water quality, aquatic life, and the health of people, plants, and animals*" are all negatively impacted by AMD. The underground mining technique was used at the coal mines in Enugu. The overburden-covered coal is exposed to iron sulphide (pyrite) in this type of mining, and when unwanted rock covering sulphides is open to air, an oxidation response happens that leads to the generation of sulfuric acids. The key bases of the "*byproduct of sulphide oxidation are iron sulphide minerals, notably pyrite and pyrrhotite, which are found in metallic ores, coal beds, and layers above and below the coal exposed to oxygen and water*". Due to the extremely low pH of surface and subsurface water, the water's acidity and concentrations of dissolved metals increase. AMD, an outdated coal mine, has the potential to contaminate groundwater, surface water, and the health of the populations that depend on this consuming water and agriculture if it is not properly managed. "*Water pumping keeps the water tables low when a mine is actively running, but in closed and abandoned mines, the rebound of water tables exacerbates the issue".*

Flooding is a substantial issue that is present. Abandoning a mine won't solve the flooding issue because mine water will still continue to flow into the river. Both the acid mine drainage issue and the flood control issue would need to be resolved in order to restart this abandoned mine

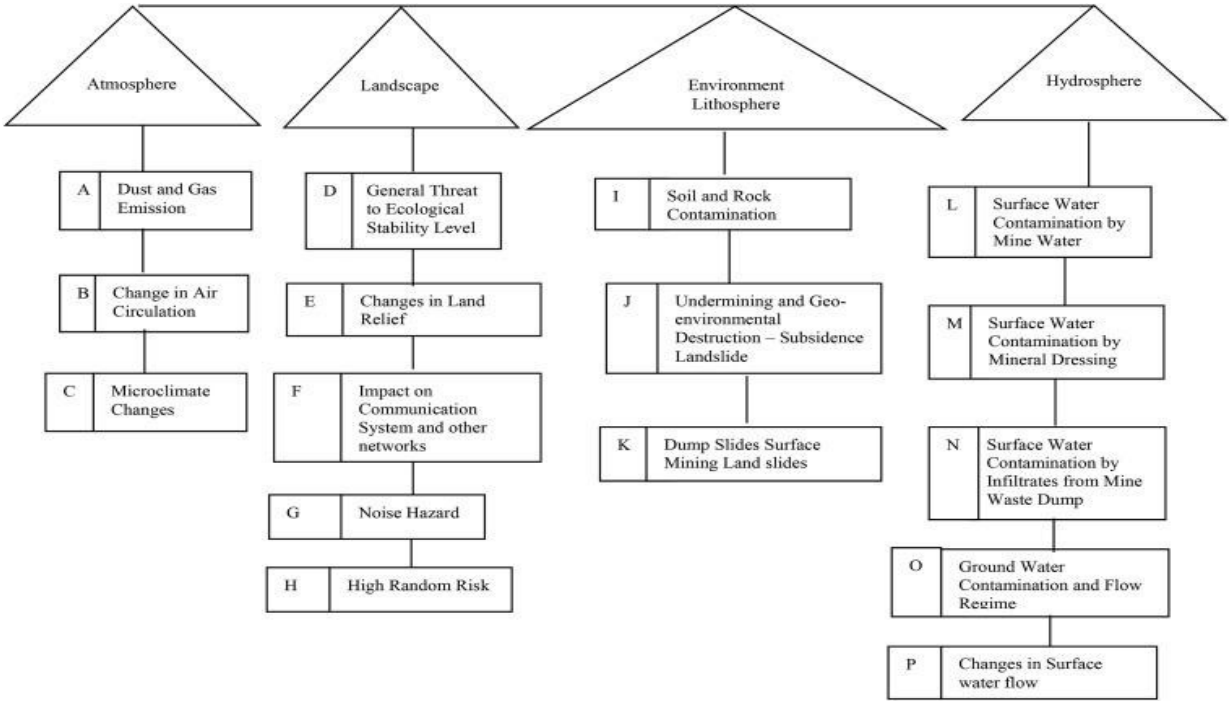

Figure 3. Main environmental pollution hazards caused by the exploitation of mineral resources

4.2. The necessity for finest management practices

Mining operations have an effect on the lithosphere, hydrosphere, atmosphere, and landscape, as seen in Fig. 3. Fig. 3 illustrates how the extraction of mineral resources results in pollution.

4.2.1. Atmosphere

- **Dust and gas emissions**: This was mentioned in the context of mine development activities and is primarily experienced during blasting operations and the building of roadways. Air pollution from dust and gas can cause illnesses including catarrh and silicosis. Methane, a greenhouse gas, is one of the main gases released into the environment by the coal mining industry. Coal transportation systems and stockpiles also contribute to noise pollution, dust, and fume emissions. "*Health issues are brought on by radioactive byproducts of tin mining in the Jos Plateau, such as monazite, pyrochlore, and xenotime*". Numerous mining locations on the Jos Plateau left the majority of these minerals as waste, which resulted in fatalities. These fatalities were linked to the high radiation levels from the monazite-rich sand that was used to build the homes that the inhabitants resided in.
- **Changes in air circulation:** These are particularly common in poorly ventilated underground mines, though they can also occur during mining due to the use of explosives and other chemicals. If neglected, this could result in the demise of mine workers. The air circulation in a coal mine using an underground mining method may change as a result of the explosive gas contained in the coal seam being mined.
- **Micro climate change:** "*The energy necessary for the extraction and transportation of minerals can increase acid rain and contribute to global warming because of the heavy-duty machines used in operations, which have a tendency to emit greenhouse gases that can contain the emitted heat from the*

earth's surface". Trees, houses, and even animals can be harmed by acid rain.

4.2.2. Landscape

- **A general threat to ecology**: Deforestation is a significant ecological issue that is involved in mine building and mine development activities. The environment is typically completely devastated, and there is significant soil disturbance. Additionally, the development of mines causes soil erosion, it promotes a number of environmental variations related to disturbed regions and may cause a change in the species of plants growing in a community as well as a loss of habitat for native animals and plants.
- **Changes in land relief**: Soil disturbance brought on by mine development leads to soil erosion. The transport of silt, dirt, and pollutants into rivers and streams results in the loss or alteration of land relief. "*Impact on available networks and other networks: Activities like blasting can result in lightning, which can alter the communication system and other networks".* Noise pollution at mine sites is a serious risk due to machine operation, drilling, and blasting. "*When miners are operating on potentially hazardous mining sites without donning personal protective equipment (PPE) such helmets, nose masks, eye protection glasses, gloves, safety boots, and visibility clothes, this is referred to as a high random risk circumstance. A mine worker working with explosives during blasting without a nose mask and gloves creates a high level of risk".*

4.2.3. Lithosphere

- **Soil and rock contamination**: Typically, this happens as a consequence of the weighty metals present in the rock and soil.
- **Subsidence and landslides:** Through MOs, there are changes in the symmetry of the "*geological environment*" that have certain effects and dangers, including avalanches, subsidence, and earthquakes. Due to the coal mining that caused water to be diverted into the mines, the Iva valley experienced subsidence.
- Workers running the risk of falling into unprotected, poorly marked abandoned shafts and pits, such as those found in underground coal mines, are also present.
- **Dump slides and surface mining landslides:** When blasting takes place, small earthquakes happen, generating uncomfortable ground movements (landslides) that result in building cracks.

4.2.4. Hydrosphere

According to inquiries the following are features of hydrosphere:

i. Surface water contamination by mine water*: acid mine drainage (AMD) occurs when minerals and coal deposits containing sulfide minerals, e.g. pyrite (FeS_2) are exposed to air, thus releasing sulfuric acid causing the pH of the water to become very low (as low as 2). AMD in an abandoned coal mine in Enugu had negative effects on the quality of both groundwater and surface water. Mine water is a huge problem which is a danger to aquatic life and adversely affects the health of communities that rely on this water source for drinking-water and agriculture. (ii)* ***Surface water contamination by mineral dressing****: chemical agents (e.g. cyanide or sulfuric acid) used in processing ores can spill, leak, or leach from the mine site into water bodies thereby contaminating or polluting the water. These chemicals are highly toxic to both humans and wildlife. ii.* Surface water contamination by infiltrates from a mine waste dump*: mine construction results in soil disturbance where soils and sediments (mine wastes) are transported into streams and rivers, resulting in the loss or alteration of habitats for aquatic organisms, as well as changes in water quality.*

(iii) ***Ground water contamination and flow regime:*** *the breakdown of pyrite and other sulphides by water or air releases acid, sulphate and metals into the environment.*

(iv) ***Changes in surface water flow****: siltation of rivers can occur, which changes the water flow. Siltation occurs when there is a build-up of fine solid particles on the bed of a river. Large quantities of mine dumps are produced during mining activities, and because these dumps are unstable, they can easily be blown away by wind when dry and eroded by heavy rain when wet. Thus, rain and wind transport fine particles into nearby water or rivers, forming a build-up of suspended solids and finally siltation*.

From the aforementioned, it is evident that the ecology will continue to be impacted by mining and prospecting for solid minerals. Lessening these consequences and doing mining site rehabilitation are the best courses of action. Best Management Practices adoption has become crucial (BMPs). According to Norman, et al., BMPs are specialised methodologies that support an integrated approach to mining (1997). They also apply to planning and reclamation.

Several rules are established such the Mineral and Mining Decree of 1999, that deal with a number of issues, including environmental protection. Nevertheless, it is vital to impose severe penalties on those who violate environmental protection laws.

> *Environmental impact studies are now required for all new development projects under Decree 86 of 1992, and recommends environmental audits for all existing projects. The 1995 sectoral Environmental Impact Assessment (EIA) recommendations from the Federal Environmental Protection Agency (FEPA) and Federal Ministry of Environment (FMEnv) for solid minerals, beneficiation, and the metallurgical process must be followed. The updated Berlin Guidelines from 1999 should also be adopted by the government, miners, and other industry stakeholders in the solid mineral sector.*

5. Conclusions and recommendations

5.1. Conclusions

In many nations, the national economy is based largely on the extraction of mineral resources. However, there is an urgent need to focus on the consequences of these exploitation operations, like reckless places, biodiversity loss, the use of chemicals that pose health concerns to communities and mine employees, etc. The reduction of waste and the adoption of best practises need to receive more attention, and they must be made legally binding. It was determined from the studies done that the mining of tin and coal has significant environmental effects.

It was clear that "*the Plateau's topography*" is littered with hazardous "*mining ponds*" that have damaged the area and pose health risks to both people and animals. Deforestation had a significant negative "*impact on the natural environment*", and the absence of vegetation in the mine sites made them more prone to erosion. In the mine sites, there were a number of forgotten "*mine ponds and mine spoils*". Tin byproducts that were preserved as waste and put in tailing ponds or left in abandoned mines are to blame for the pollution in the mine region. While best practises have not been implemented at many of the mining sites on the Jos Plateau, some of the abandoned mine ponds—some of which were utilised for irrigation and block production—have occasionally been remedied. Additionally, "*the abandoned mine in Enugu was heavily contaminated with poisonous heavy metals that are harmful to animals, plants, and water. There were instances of flooding, loss of the natural landscape, and land degradation*". The Ministry of Mines and Steel Development (MMSD) must act quickly to address a significant AMD issue because none of the core guidelines for the mining industry had been accepted and no corrective action had been taken.

In these mining areas, there is little to no enforcement of the mineral regulations, and there is little monitoring. On the grounds that there are significant inefficiencies and inadequate oversight, it can be claimed that the MMSD's goal has not yet been met. If not adequately controlled, the country's growing interest in mining solid minerals would cause more environmental damage.

5.2. Recommendations

While the country will benefit financially from the resurgence of interest in mining solid minerals, environmental damage will only increase if it is not adequately controlled. The case studies of tin in Jos and coal in Enugu make it abundantly evident that these minerals' extraction involves severe environmental risks. The appropriate rules governing mineral exploration and extraction should be strictly enforced. Additionally, severe penalties must be implemented on offenders. An environmental audit needs to be done for Jos and Enugu, and restoration work needs to get going. The main tenets of the 1999-revised Mining Sector Berlin Guidelines must be adopted and upheld by the government, experts, and all other parties involved. All parties involved in the exploration and utilisation of solid minerals need to be in constant communication and education. It is important to raise awareness of the utilization methods used for exploration and exploitation ought to solve environmental issues, assist in mitigating current worries, gauge the severity of current issues, forecast the location of pollutants in the environment (both surface and subsurface), and plan amenities that will significantly lessen environmental issues.

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