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Assessing the Environmental Consequences of Precious Metals Mining in Northwestern Nigeria

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Abstract:- This study was carried out to evaluate the environmental impacts of mining of precious metals in Anka and Gusau in Zamfara state. Specific areas of interest are Brithway Minerals (BM) and the artisanal mine site in Sunke (MW). Representative Samples of soil and water were collected and the concentrations of heavy metals (Pb, Zn, Ni, Cd, As, Mn, Hg) as well as their physiochemical properties were analyzed using standard analytical procedures. Results of the analysis show values of heavy metals such as lead and mercury above the threshold limit when compared with World Health Organization (WHO) standards for drinking water and ECDGE (European Commission Directorate General for Environment). Lead values higher than 0.01mg/L were recorded in all water samples analyzed and get extremely high in abandoned ponds consequent upon mining activities. Field investigation reveals the practice of whole ore amalgamation, the engagement of teenagers, excessive noise and dust from processing, and complete neglect of personal protective equipment (PPE). The need for monitoring, education, and enlightenment on various available environmentally safe and eco-friendly mining technologies that will enhance safe operations was highlighted as possible solutions to curtail health and environmental malaise.

Keywords:- *Heavy metals, threshold limit values, mining and processing, environmental implication.*

I. INTRODUCTION

Precious metal mining has a significant impact on the lives of people and communities involved directly or indirectly in its exploitation (Kesse 1995; Hilson 2000). Mining of precious metals generates huge quantities of waste, which may sometimes account for about 90% of the ore extracted (Adler and Rustler 2007). Concerns over the environmental impact associated with mining have led developed countries to carry out extensive research to understand the nature and cause of the impart (Kelly, 1988) and the develop of environmental policy and regulations aimed at minimizing their environmental effects (Smith, 1987; Egget, 1994). Closely linked and associated with precious metal mining and processing are the activities of small-scale and artisanal miners and the resultant environmental pollution. In the Zamfara lead poison disaster, more than 163 persons lost their lives (The Tide, 2010). Methods adopted for mining and processing of precious metals could be any of surface or underground mining, however regardless of the method adopted or their combination, mining for precious metal must only be carried out with due diligence taking into cognizance the uniqueness of the environment and the geological makeup of the deposit. During mining, in-situ metals are released from their original state and are leached into the surrounding environment, resulting in their accumulation in the immediate environment and increased concentration as mining progresses. These leached metals will eventually raise toxic levels in plants and organisms resulting in a high risk to human health (Montgomery, 2003; Cunningham and Saigo, 2001). The processing of precious metals is another pathway through which health and environmental pollution takes place. In a simple process of gold recovery, mercury is often used because it is cheap and readily available however its bio-toxic effect on the environment is of great concern. Recent innovations geared towards reducing pollution are the Haber technologies, direct smelting method, Igoli, and the use of retorts among other novel approaches. This study is aimed at appraising the impact of mining activities in the study locale through careful field observations and data analysis to mitigate them.

II. LOCATION AND GEOLOGY OF THE STUDY AREA

The area under study is in Gusau and Anka in Zamfara State Nigeria. It is situated at latitude 12010' N and 60 42' E at an elevation of 1538ft. The geology is characterized by very old igneous and metamorphic rocks formed during the Precambrian-paleozoic era. The two major types are the granites and metasediments. The granites, gneisses, and migmatites are resistant to erosion and when weathered produce poor soils while the metasediments made up of phyllites, quartzites, and meta conglomerates, though erosion resistant as well, nevertheless produce fertile soils when weathered. The topographical and geological maps are shown in Figures 1 and 2 in the appendix.

III. LITERATURE REVIEW

The exploration of precious metals dates back to 400BC (Vincent, 1979), with historical records showcasing their utilization across various periods. In Nigeria, gold mining has a nuanced history, with informal, small-scale activities dominating mineral production. Official gold production in Nigeria commenced in 1913, peaking in 1933 and 1943 (Azuibike, 2011). However, the extraction of precious metals has not been without its consequences, evident in environmental pollution and health hazards.

In Zamfara State, Nigeria, over 163 lives were lost due to lead poisoning attributed to mining activities. This emphasizes the urgent need for responsible mining practices and environmental stewardship. Gold extraction processes vary, ranging from surface methods like open-pit and placer mining to underground techniques involving shafts and tunnels. For hard formations, development work follows an assessment, including land clearing and drilling, leading to mine unit operations such as drilling, loading, and haulage.

Mercury, a hazardous substance, is historically used in amalgamation processes to dissolve gold or silver. Artisanal miners commonly employ direct amalgamation (whole ore) or amalgamation of concentrates. Mercury release varies with the method used, with whole ore amalgamation releasing more mercury compared to concentrate amalgamation.

Cyanidation, another extraction process, uses sodium and potassium cyanide solutions to recover gold and silver. Vat leaching, heap leaching, and agitation leaching are common methods. Heap leaching is cost-effective for less valuable ores, while vat leaching and agitation leaching offer greater solution control for higher-value ores.

Efforts towards cleaner production include technologies like the Haber process, replacing mercury and cyanide with non-toxic solutions. Clean gold sluice boxes and direct smelting are also developed to minimize environmental impact. However, challenges persist in finding easily adaptable alternatives to mercury, such as thiourea and thiosulphate.

Precious metal mining has adverse environmental effects, including subsidence, siltation, acid mine drainage, and elevated heavy metal concentrations. Mercury poses long-term threats to ecosystems and human health, particularly affecting artisanal and small-scale miners globally. Heavy metals like cadmium and lead can negatively impact soil and pose health risks, emphasizing the importance of sustainable and environmentally friendly extraction methods.

The process of extracting gold exhibits variations, encompassing surface methods like open-pit and placer mining, as well as underground techniques involving shafts and tunnels. In instances of hard formations, the sequence typically involves development work subsequent to a comprehensive assessment, incorporating tasks such as land clearing, drilling, and subsequent mine unit operations like drilling, loading, and haulage.

Historically, mercury, a hazardous substance, has been employed in amalgamation processes for dissolving gold or silver. Artisanal miners frequently utilize either direct amalgamation (whole ore) or concentrate amalgamation methods. The amount of mercury released varies depending on the technique, with whole ore amalgamation resulting in higher mercury release compared to concentrate amalgamation (Veiga and Hilton, 2002).

Cyanidation, another method of extraction, involves using solutions of sodium and potassium cyanide to recover gold and silver. Common techniques include vat leaching, heap leaching, and agitation leaching. Heap leaching is a cost-effective method for less valuable ores, while vat leaching and agitation leaching provide better solution control for higher-value ores. Advancements toward cleaner production include technologies like the Haber process, designed to replace mercury and cyanide with non-toxic solutions (www.haberscience.com). Clean gold sluice boxes and direct smelting have also been developed to minimize environmental impact. Nevertheless, challenges persist in finding easily adaptable alternatives to mercury, such as thiourea and thiosulphate, as highlighted by Hilson and Monhemius (2006).

Precious metal mining leaves adverse environmental effects, including subsidence, siltation, acid mine drainage, and elevated concentrations of heavy metals. Mercury poses persistent threats to ecosystems and human health, particularly impacting artisanal and small-scale miners globally (Veiga, 1997). The release of heavy metals, including cadmium and lead, can result in various health issues and negatively impact soil, underscoring the importance of sustainable and environmentally friendly extraction methods (Ademoroti, 1996; Kabata-Pendias and Pendias, 1984).

IV. MATERIALS AND METHODS

The approach to this research involves field investigation carried out to ascertain the compliance of miners to basic safety rules, the effect of mining and processing activities on the mining environment consequent upon field study and sample analysis, and an inference drawn based on the results of the investigation.

A. Materials

A global positioning system was used to geo-reference all samples collected. A topographical map of the area, a bottle containing 200ml of 70% nitric acid to preserve the samples before ex-situ analysis in the laboratory, a log book, a mobile digital meter, a digital camera, stainless steel sampling spoons and sampling bags, diggers, cutlasses among other items.

B. Field Investigation

The areas of interest were investigated randomly and environmental features like vegetation and environmental degradation were noted and captured using a digital camera. Information, as it relates to the environment, was obtained from field interactions with miners as well as direct assessment. All sampling points were noted in a log book and Geo-referenced to allow for ease of returning to the area at the commencement of sampling.

C. Sampling

Samples were collected from areas around Brith way's immediate vicinity and an illegal mine site in Sunke. Specifically, they were collected at random from boreholes and wells, abandoned ponds, tailings, streams, areas close to the processing plant, as well as areas susceptible to contamination. The first 20cm of soil were collected in polythene bags while water samples were collected 10cm below the water level. All water samples for ex-situ analysis were preserved by adding a few drops of 70% nitric acid. The samples were coded BM and BW for Brithway Limited and MW and MA for Sunke illegal mine site.

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D. Analysis of samples

➢ *Soil Analysis*

Samples of soils were collected and subjected to physio-chemical analysis. pH, conductivity, and temperature were determined using Bechman 350 pH/temperature/conductivity meter. Moisture content was carried out by dry oven method. Heavy metal concentrations wereanalyzed by atomic adsorption spectrophotometer (Buck 200 model) after being subjected to acid digestion in compliance with ASTM D 3976 and ASTM 1971 standards.

➢ *Water Analysis*

Physio-chemical properties analyzed were the temperature and pH using Bechman 350 pH/temperature/conductivity meter. Dissolve oxygen was done by the electrometric method. Heavy metal concentration was analyzed using an Atomic absorption spectrophotometer (BUCK 200 model).

V. RESULTS AND DISCUSSION

A. Results of Field Investigation

Field assessment reveals an area dotted with abandoned mine ponds, massive excavated mine pits, exposure of teenagers to heavy metals, stunted and ill-grown vegetation around the mining vicinity, tailing dumps adjacent to farmlands, overflow of washing pond resulting in constant deposition of sediments on the surrounding soils and the concomitant effect on plants were visible especially around Brithway Ltd. From field assessment miners were observed carelessly conducting their affairs without the use of personal protective devices and environmentally friendly technology like the retort, thus unknowingly harming themselves due to ignorance and adding in no small measure to the global atmospheric mercury. In some areas, soils have been eaten to depths of about 10m due to acid mine drainage. Whole ore amalgamation with its attendant consequence and the use of improvised grinding machine resulting in incomplete liberation of gold metal from the gold-laden ore, production of extreme dust containing silicates and lead among other heavy metals, as well as noise generation were observed. Some of these observations are depicted in plates 1, 2,3, and 4 in the appendix.

B. Results and Discussion of Sample Analysis

The result for heavy Metal concentration is higher in most soil samples analyzed compared to values from control samples and these findings are presented in tables 1 and 2. The results indicated from the test are as follows; Pb (0.234-100.5), Fe (3.895-937.37), Hg (0.046), Cd (0.008-0.123), Cu (0.013-7.029), Mn (0.101-22.07), Ni (0.234-6.174), and Zn (0.236-2.352). Test for lead in soils indicates that nearly all samples fall below the standard limit of global soils (1.5-80mg/L)(Fifield and Haines, 2000) and below the toxic levels of 100mg/L for agricultural soils (Kabata et al,1984) except MA1 (100.5 mg/L). Most samples show increased values of lead (Pb) above background values and they are indications that the metal is continuously been leached into the environment as a result of mining activities. Zinc values were below threshold limit values of 70mg/L (Kabata *et al*, 1984) and the lower levels of zinc which is far less than the average concentration in soils and water samples of 50-100Mg/l in global soils indicate that the area is virtually zinc-free. Analysis for cadmium shows it falls below the toxic limit of 3mg/L (Bowen 1979) and the estimated toxic level of agricultural soil of 5mg/L (Kabata et al,1984) as well as within the global range of 0.01-2mg/L (Adrino 1986, Aubert and Pinta,1978). Mercury presence was detected in BM1 (0.046) a possible indication of the use of the metal, this calls for further investigation. Though the values are below 840mg/l for soil limit by U.S.EPA the tendency for increased concentration is better considering mercury's hazardous effects on the environment. All soil analysis indicates that heavy metals of lead, manganese, copper, cadmium, and nickel are moderately accumulated above background values except iron values of 1451.31mg/l detected in MA1. This high value is no doubt due to the metal being leached into these portions of the soil and this may be toxic to the soil since it is above the threshold limit.

Analysis of water samples gives the following range of results for each particular metal. Pb (0.123 mg/L-104.618 mg/L), Zn (0.384 mg/L-3.801 mg/L), Hg (0.16 mg/L), Fe (0.550 mg/L-80.30 mg/L), Cu (0.013 mg/L-13.356 mg/L), Cd (0.0102 mg/L-0.0543 mg/L), Mn (0.320 mg/L-69.724 mg/L), Ni (0.201 mg/L-4.263 mg/L).

All analyzed water samples indicated the presence of lead above WHO standards with abandoned ponds and processing points giving value above Threshold Limit Values (TLVs) of 104.618mg/L, thus giving a clear indication that the high concentration was due to leach metals from in-situ rocks into the surrounding water bodies and increase accumulation was due to mining and processing activities. Mercury (0.026 mg/L) was detected in a washing pond in an artisanal mining environment which was not a surprise. This was expected especially as some of the miners were observed engaging in the practice of whole ore amalgamation and thereby washing their tools like shovels, diggers, and pans in the nearby ponds thus polluting them. This is of environmental concern as the ponds are a source of drinking water for most grazing animals and birds. Nickel values were higher than the tolerable limit in all samples analyzed with boreholes and wells giving values just above TLVs. Zinc concentration was below TLVs in all samples with BW1 as the only exception. These higher values above background values and threshold limit values could only be attributed to mining activities among other factors. Water analysis gave higher values of copper (13.356mg/l) and 5.876mg/l near washing ponds and tailing dumps. Concentration in wells, streams, and boreholes falls within the acceptable limit of WHO (2.0mg/L). Sample analysis gives concentration for Fe, Mn, and Cd values below the WHO limit except in samples taken from abandoned ponds, processing areas, and tailings dumps.

Results of physiochemical properties for soil and water are given in Tables 3 and 4. The result shows that soil pH ranges between 5.44-9.12, with most samples falling within the agricultural optimum range of 6.5-6.9. These values obtained so far do not seem to constitute environmental and health risk nor can they assist in lead and cadmium dissolution which occurs in acidic and alkaline environment. Temperature ranges for soil and water samples are between

25-270C which was normal for plant growth and does not seem to have been affected by human activities. Dissolve oxygen values range from 6.12-14.5 with values lower in samples having heavy metal concentration. TDS is seen to be very high in abandoned ponds with a value of 27 mg/L and 6.30 mg/L in processing areas though not up to the permitted level of 1000mg/l. Except for streams and underground water sources (boreholes and wells), TDS is higher for all samples when compared to values from background samples. This underscores the fact that continuous mining and processing needs to be monitored and controlled to stem this tide.

VI. CONCLUSION

From the results so far obtained, it is imperative to note that nearly all increases in values of metal concentration above background values and threshold limit standards set by W.H.O and ECDGE as represented in Table 5, were induced by precious metal mining among other factors within the environment. These metals at higher concentrations have negative implications on the environment (terrestrial and aquatic) and consequently on human and animal health. This calls for concern and needs the cooperation of all to stem the tide. The concentration of heavy metals is more pronounced in water as compared to soils and it shows the ease at which water can be easily affected. In light of the above discoveries, there is a need for environmentally friendly technology like "Igoli" to be introduced, retorts usage encouraged, personal protective device importance re-emphasized, method of extraction using benches enforced and impressed on the operators, and post-mining issues addressed. Workplace safety culture must be impressed, taught, and enforced. More thorough monitoring of mining firms by agencies should also be prioritized by the relevant monitoring agencies saddled with such responsibilities.

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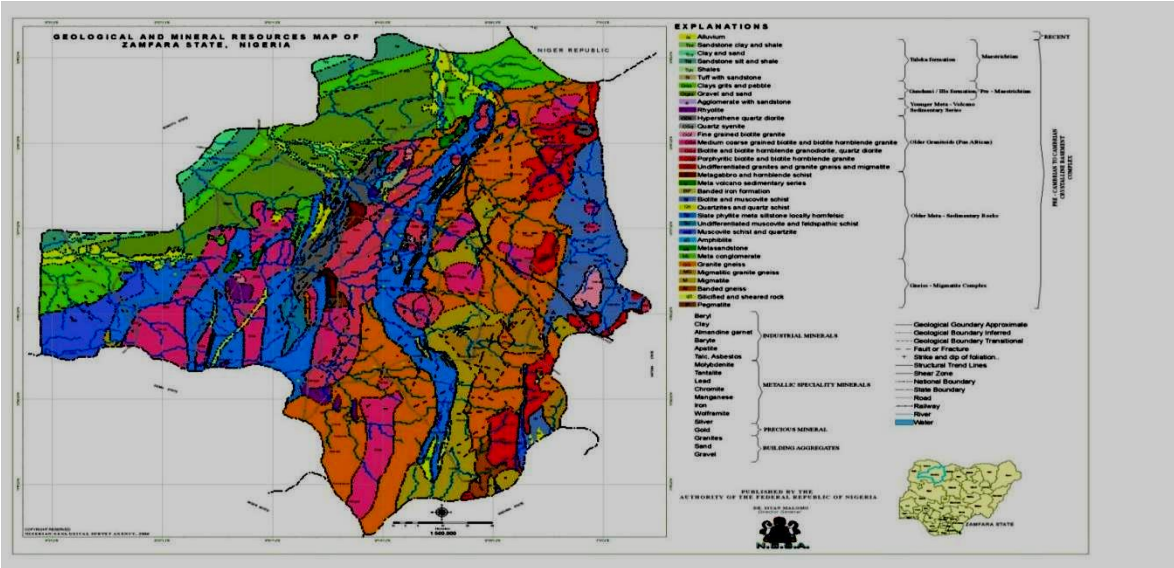
APPENDIX



SCALE 1: 50,000
Fig. 1: Geological Map Of Zamfara State

Fig 2: Map of study areas

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Table 1: Mean result of heavy metals in soils (mg/L)

Samples	Coordinates	Pb	Zn	Cu	Fe	Mn	Ni	Cd	Hg
BM1	N12^0 08' 34.7'' E6^0 46' 03.0''	70.767	1.660	3.612	700.50	11.06	6.174	0.123	0.046
BM2	N12^0 08' 29.9'' E6^0 46' 03.4''	45.25	0.838	2.625	19.024	0.158	3.24	0.04	ND
BM3	N12^0 08' 26.6' E6^0 46' 01.6''	34.997	1.648	7.029	937.37	13.48	4.748	0.12	ND
BM4	N12^0 08'45.0'' E6^0 46'' 05.4'	3.880	1.348	3.560	613.37	1.248	4.03	0.08	ND
BM5	N12^0 08' 18.1' E6^0 46' 01.58'	0.32	0.377	1.045	30.50	0.255	1.325	0.03	ND
MA1	N11^0 52' 39.3'' E5 54 39.4	100.5	2.352	1.150	1451.31	22.07	3.528	0.114	ND
MA2	N11^{0}57'46.11'' E5^0 52' 26''	0.334	0.236	0.013	15.49	0.101	0.308	0.117	ND
MA3	N11^{0}56' 18.6'' E 5^0 53'30.7''	0.885	1.532	0.967	30.43	10	0.234	0.019	ND
MA4	N11^{0}54' 19.5'' E5^0 41' 1.1''	0.674	1.657	0.932	40.53	9.4	0.32	0.008	ND
MA5	N11^{0}52' 32.6'' E5^0 56' 17.4''	0.334	0.236	0.013	3.95	0.101	ND	0.065	ND
CS	N11^{0}55' 32.7'' E5^0 46' 02.3''	0.234	0.265	0.12	7.9	10.5	ND	ND	ND

Table 2: Mean result of heavy metals in water (mg/L)

Samples	coordinates	pb	Zn	Cu	Fe	Mn	Ni	Cd	Hg
BW1	N12^0 08'29.8'' E6^0 46'01.3''	104.618	3.801	13.356	14.37	69.724	4.263	0.024	0.16
BW2	N12^{0}08'32.6'' E6^0 46'05.3''	50.523	1.110	5.256	0.620	5.08	3.882	0.0142	ND
BW3	N120834.3 E6^0 45'59.4''	0.258	0.838	0.034	0.580	0.1538	0.262	0.112	ND
BW4	N12^{0}08'13.6'' E6^0 30'54.4''	0.125	0.564	0.021	0.720	0.125	0.252	0.023	ND
MW1	N12^{0}01'30.6'' E5^{0}30'45.03''	0.123	0.702	0.013	0.620	0.125	0.340	0.0156	ND
MW2	N11^{0}54'19.5'' E0055411.2	0.779	1.488	0.867	1.140	0.530	0.318	0.0102	ND
MW3	N11^0 56'1.6'' E5^0 53'30.7''	0.381	0.405	0.022	3.895	0.570	0.237	0.028	ND
MW4	N11^{0}52'39.1'' E5^0 54' 59.4''	54.256	0.384	1.267	79.212	0.893	0.508	0.342	ND
MW5	N11^{0}55'18.7'' E5^0 54'09.3''	150.256	0.494	1.378	80.30	1.340	0.808	0.0543	0.026
CS	N12^{o}02'00.7'' E6^0 43'25.1''	0.300	0.482	1.282	0.550	0.320	0.201	0.0143	ND

*ND - not detected

Table 3: Summary of physio-chemical properties of soils

Sample no.	Coordinates	pH	Moisture Content(%)	Temperature (^{o}c)
BMI	N12^{0}08’34.7’’ E6^0 46’03’’	7.75	27.5	26
BM2	N12^{0}02’ 9.9’’ E6^{0}46’’03.4’’	9.12	15.5	27
BM3	N120829.9 E6^0 46’01.6’’	6.23	12.0	26
BM4	N12^0 08’ 45’’ E6^0 46’ 05.4’’	5.44	0.06	25
BM5	N12^{0}08’18.1’’ E6^0 46’ 01.5’’	7.7	15	25
MA1	N11^{0}52’39.1’’ E5^0 54’39.4’’	7.4	0.04	26
MA2	N11^{0}57’46.1’’ E5^0 52’26’’	5.65	0.10	25
MA3	N11^0 56’1.6’’ E5^0 53’30.7’’	8.0	14	26
MA4	N11^{0}54’19.5’’ E5^0 54’11.1’’	7.8	15	26
MA5	N11^{0}52’32.6’’ E5^0 46’02.3’’	7.74	0.05	26
CS	N11^{0}55’32.7’’ E5^0 46’02’’	6.20	7.02	25

Table 4: Summary of Physio-Chemical Properties of Water

Sample no	Coordinates	pH	TDS (mg/L)	DO (mg/L)	Temperature (^{o}c)
BW1	N12^{0}08’29.8’’ E6^{0}46’01.3’’	5.38	11.14	6.20	27
BW2	N12^0 08’32.6’’ E6^0 46’05.3’’	5.32	9.70	9.0	27
BW3	N12^0 08’34.3’’ E6^0 45’59.4’’	7.5	14.20	8.20	27
BW4	N12^0 08’34.6’’ E6^0 30’54.03’’	6.89	5.20	16	27
MW1	N12^0 08’13.6’’ E5^0 30’45.03’’	6.5	6.9	13.5	25
MW2	N11^0 54’19.5’’ E5^0 54’ 11.2’’	7.8	15	14.5	25
MW3	N11^0 56’18.6’’ E5^0 53’30.7’’	8.2	13	12.5	27
MW4	N11^0 52’39.1’’ E5^0 54’59.4	6.4	16.30	6.23	27
MW5	N11^0 55’1.7’’ E5^0 54’09.3’’	5.25	27	6.12	25
CS	N12^0 02’00.7’’ E6^0 43’25.1’’	6.5	8.0	12.30	26

Table 5: Allowable Limits of Heavy metal concentration in soils (Mg/L)

Heavy metal (mg/kg)	Austria	Germany	France	Luxembourg	Netherland	Sweden	UK
Cd	1 to 2	1	2	1 to 3	0.5	0.4	3
Cr	100	60	150	100 to 200	30	60	40
Cu	60 to 100	40	100	50 to 150	40	40	135
Ni	50 to 70	50	50	30 to 75	15	30	75
Pb	100	70	100	50 to 100	40	40	300

Source :(ECDGE 2010)

Plate 1: whole ore amalgamation practices

Plate 2: -Huge Landscape destruction

Plate 3: Absence of PPE and direct use of mercury

Plate 4: Teenagers involve in Mining