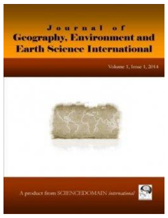

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# Physico-chemical Effects of Active Mining of Rare-metal (Sn, Nb and Ta) and Bacteriological Assessment in Lafia Mining Site, Southwestern Nigeria

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### *Authors' contributions*

*This work was carried out in collaboration between both authors. Author Adegbola Odebunmi designed the study, performed the statistical analysis and wrote the protocol. Author Abiola Oyebamiji managed the analyses of the study and wrote the first draft of the manuscript. Both authors managed the literature searches. Both authors read and approved the final manuscript.*

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## ABSTRACT

Environmental assessment is a key to prevent the occurrence of a potential disaster which can arise due to various reasons in the mining field especially active mining of rare metals. This present paper monitors the physico-chemical effect of active mining of rare-metal (Sn, Nb and Ta) and bacteriological assessment of surface water in the active rare-metal mining site. The negative environmental impact exceeded the positive which includes; landscape destruction, ecological destruction, pollution and accidental hazards while the positive impacts are; an increased human population which promoted the agricultural practice and increased settlements.

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Twenty-one (21) water samples and twenty-three (23) eluvial soil samples were collected from the stream within the area and analyzed using the Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) method. The pH, EC and TDS of the surface water were measured with an appropriate instrument. The surface water is slightly alkaline and moderately soft while the EC and TDS were below the recommended range. All the trace elements analyzed for the surface water were all below MPL. The bacteriological analysis revealed the presence of the disease-causing bacteria makes the water unsafe for domestic use (even though the water is free from the presence of heavy metals) and can trigger gastrointestinal illnesses, diarrhoea and vomiting. The metal assessment in the soil samples was calculated using Contamination index and Geo-accumulation index revealed that Arsenic (As) and Cadmium (Cd) are anthropogenically inputted into the environment and have moderately polluted the environment.

There is a need for implementation and enforcement of an environmental law which may just be a means of pollution control within mining districts.

*Keywords: Physico-chemical; active mining; rare metal; bacteriological assessment; Lafia.*

## 1. INTRODUCTION

The study area falls between longitude 2°58'15” and 3°00'45” and latitude 8°14'-8°17'. Notable villages include Komu which is about 20 km east of the area of study. Lafia is a district in Komu in the northern part of Oyo State. It is situated about 150 km northwest of Ibadan and constitutes one of the communities in Itesiwaju Local Government Area of Oyo state, Nigeria.

Africa is a continent located in the southern hemisphere and known for its rich diversity of wildlife including birds, amphibians, reptiles and large mammals. However, in recent years, there have been concerns about significant environmental problems caused by the mining of rare and major metals [1]. Environmental pollution due to the rapid progress of economic development in Africa can cause various problems [2].

A lot of investment is being pumped into mineral development by mineral endowed Countries, and most exploration and exploitation programs have not been designed to cater for environmental reconstruction as well as the overall effect of mining activity. It is worthy to state categorically that mineral exploration and exploitation programs must be carefully carried out under a structured program to prevent environmental degradation. However, this is always not the case especially in the developing countries where semi-skilled and most times unskilled artisans engage in mineral exploitation without adequate mineral exploration to narrow their exploitation phase which often results in environmental degradation.

To evaluate the environmental degradation, the scale of operations involved in exploration, exploitation and processing of a mineral determines the intensity and extent of environmental degradation. Thus, in general, a greater damage is witnessed in the localities where artisan workers do only manual winning of mineral [3]. For an instant, large-scale mining of tin and associated minerals in Jos Plateau has resulted in high degree of degradation of arable land, vegetation and landscape, as well as other environmental problems. Other notable mining districts that have witnessed environmental degradation are limestone quarries in Sagamu, Ewekoro, Ibese, in Ogun State Southwestern Nigeria. Asaka and Gboko mining district have experienced same. [4,5]; have all done various works in the area of environmental assessment and concluded that human activities such as mining could increase the concentration of these metals in the environment if mining operations are not adequately managed. Many studies have shown that some trace elements are extremely persistent in the environment, non-biodegradable and readily accumulate to toxic levels [6]. [7]; worked on contamination indices and heavy metal concentrations in soils of Ibadan and concluded that monitoring of heavy metals is essential towards environmental protection. The level of environmental degradation, as well as trace element concentration in soil and stream sediments at Abuja leather in Komu, was evaluated and the results revealed that elements like Cr, Ni, and Sr showed moderately contaminated using the geo-accumulation index as well as enrichment factor [8].

The mobility and bioavailability of elements associated with rare metal mining in the environment greatly depend on some physico-chemical characteristics of the environment such as pH, textural characteristics, organic matter content, speciation or chemical form and EC [9,10]. The overall variability of soil over the earth's surfaces had been widely documented, and this occasionally leads to environmental and human problems when the abundance of some elements in soils is either too low or too high. Given the many sources, widespread distribution and multiple effects of heavy metals in the ecosystem, contamination of the environment by heavy metals has become not only a local phenomenon but also a global one as well [11]. Hence, they have become significant within the framework of environmental impact assessment. The study is aimed at assessing possible positive and negative environmental impact of modern controlled mining of these pegmatites hosted mineralization and suggests appropriate mitigation plans to neutralize the negative consequences. This would be incorporated into the planning and design of modern mining in the area.

## 2. DESCRIPTION OF THE STUDY AREA

The topography of the area is undulating and flat at some portion. The vegetation covers most of the area is typically southern Guinea Savannah woodland physiognomy, and floristic composition is reflected in soil/water relations and effective soil depth [12]. The project area belongs to the marginal areas of southwest Nigeria climatic zone characterized by a mean annual temperature of 27°C. The rainy season spans form April/May to October/November. This is usually followed by a period of the dry season from November to April.

The stream within the area is dendritic and seasonal.

### 2.1 Land Use

In term of land use, the area may be divided into

1. Savannah woodland and shrub savanna
2. Mining land; and
3. Agricultural land

The savanna woodland and shrub Savannah is by far the largest category and supports extensive grazing by the Fulani: fuelwood extraction and lumbering. Mining is restricted to the pegmatitic ridges and their adjacent valleys where the mined materials are washed to obtain the concentrate. Agricultural land supports such cropping as grains, cereals, and small tubers.

### 2.2 Socio-economic Environment

The people are mainly of the merged tribe although they are dominated by the northerners. Their main religions are Christianity and Islam. The semi-permanent settlements in the area are the mining town called Abuja Leather where the informal small-scale miners moving to areas of supposed better winnings while some of the Fulani hamlets are temporary with their locations shifting with the dictates of their agrarian economy. The people of this area engage in three main economic activities: crop agriculture, and mining. The level of infrastructure development in the area is extremely low. Only one primary school, which is in dilapidated conditions, is seen in the area. Lack of potable water, poor access road and lack of healthcare facilities are their most pressing problems.

## 3. MATERIALS AND METHODS

The study involves systematic geological mapping on a scale of 1: 50,000. Eight (8) samples of pegmatite and granite gneiss of equal numbers were collected for petrographic examinations. A total of twenty-three (23) eluvial soils and twenty-one (21) water samples were collected, and the sampling pattern was largely dictated by accessibility and geometry of the study area. The temperature and pH of the water samples were determined at the time of collection using thermometer and pocket Digital pH meter respectively. Other parameters were determined in the laboratory using standard analytical procedures. The eluvial soil samples were collected by employing the interval sampling technique in which samples were collected at a depth of 1-5 cm. The actual sampling points were determined with the use of Global Positioning System (GPS) and later plotted on the topographical map of the study area.

Eluvial soil and water samples were analyzed using the Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) method. The major elements and trace elements are given in parts per million (ppm). The procedure employed involves digestion of representative sample eluvial soils using nitric acid (the water samples were acidified on the field). About 0.5 g of each sample was measured into the dry digested tube. 3-4 drops of distilled water were added to the wet sample. 5 ml of HCl was added to wet the sample, and the solution was stirred. 5 ml of nitric/perchloric acid was added in the ratio 3:2 and stirred. The digesting tube was left overnight heating. The samples were leached out with 6 ml HCl in a tube and made up to 20 ml mark with distilled water. To avoid caking, the content was shaken vigorously, and the resulting solution is referred to as a stock solution. The stock solution was used directly to determine the elements. It is becoming increasingly accepted as a tool for trace element and isotopic analysis as a result of the very low detection limits, good accuracy and precision. This technique consists of sample introduction system, referred to as Nebulizer, the ICP torch, the high-frequency generator, the transfer optics, the spectrometer, the interface and computer.

A digested solution of the sample to be analyzed is introduced into the ICP torch as an aqueous aerosol, the light emitted by the atoms or ions in the ICP is converted to an electrical signal by a photomultiplier in the spectrometer. The intensity of this electrical signal is compared to a previously measured intensity of a known concentration of the element, and the concentration value is then computed.

## 4. GEOLOGICAL SETTING OF PROJECT AREA

The area of study is dominantly by granite gneiss, and pegmatites occur as low-lying intrusions into the rocks (Fig. 1). There are also quartz veins intruding the larger rock bodies.

### 4.1 Granite Gneiss

These gneisses are predominantly in the study area. They are mainly composed of biotite, quartz and ferromagnesian minerals as observed. The biotite also forms bands, but they are not as prominent as the feldspar bands. Quartz veins intrude the rock body. From thin section, studies, minerals observed are quartz biotite, microcline and plagioclase feldspars. Muscovite occurs as elongated minerals and exhibits its characteristic pleochroism.

### 4.2 Pegmatites

Pegmatites in Nigeria are characterized by a distinct linear belt which extends in the NE-SW direction. [13,14] described the compositional trends and confirmed the rare metal mineralization potential of Precambrian pegmatites of Komu area southwestern Nigeria.

Pegmatites in the area of study are poorly exposed. However, results of the geological mapping suggest that they occur in two distinct modes: as tabular bodies and irregularly shaped bodies. The primary mineral assemblages are albite, microcline, quartz, muscovite, sericite, black tourmaline (Shorl), columbite-tantalite. Albite is the most abundant of these minerals and forms coarse crystalline graphic intergrowth with quartz. Most of the microcline display characteristic crosshatch.

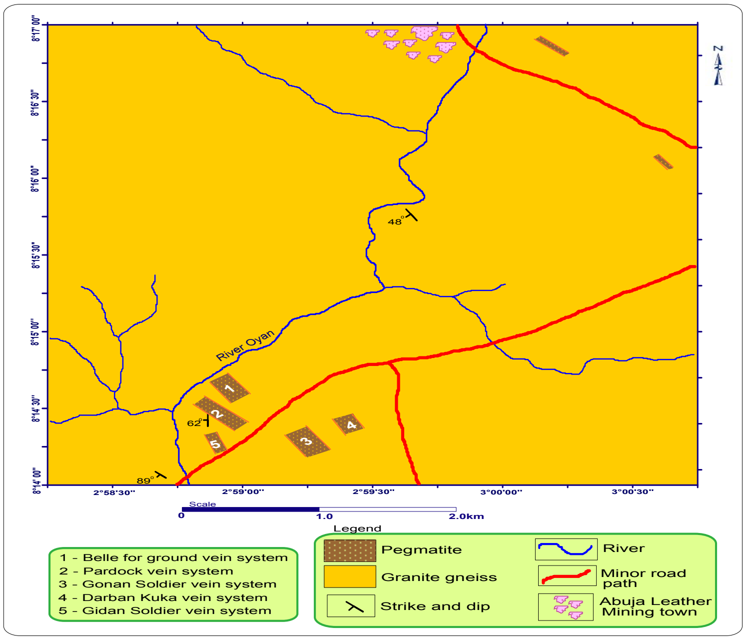

**Fig. 1. Geological Map of the study area**

## 5. RESULTS AND DISCUSSION

### 5.1 Environmental Impact of Mining

There are various expected environmental impacts produced by exploitation of a mineral of interest which is also a function of size and location. Manifestations of specific impacts are in the air, water, soil, earth surface, flora and fauna, and human beings [15,16]. Apart from the above-enumerated effects, swamp creation deterioration of groundwater, erosion of soil, noise and percussion from rock blasting, generation of dust, smoke and fumes; production of noxious gases and ground vibration [17].

However, it is not only negative impacts that are experienced in the environment, but few positive ones are also recorded.

#### 5.1.1 Negative impact of modern mining

(i) Landscape destruction: The little soil on the pegmatite ridges were removed by mining. The Mining has created pits, which is filled with water as almost permanent features of the landscape. The creation of mine pits, spoil heaps, and tailings spreads have affected the aesthetic qualities of the landscape. These pose a danger to human as well as livestock if not reclaimed and rehabilitated.

(ii) Destruction of the ecosystem: Plants and animals are most times the first to be affected by mining programs. For instance, deforestation of the Lafia mining site and environment during the mine development has eliminated some plants and animals which depend on them for survival and cover will have moved elsewhere. Furthermore, noise generated from blasting has also frightened away the animals. [18] concluded that ecosystem suffers not only disequilibria but also pronounced degradation with dire consequences on the food chain.

(iii) Air, water and noise pollution: Particles of varying chemical compositions are inhaled and lodge in human lungs (has a substantial effect on the miners) causing lung damages and respiratory problems [19]. According to [20] and [21], clouds of dust generated from the mining of intrusive rocks often contain 71% silica. Inhaling such dust results in silicosis which is capable of disabling an exposed person and subsequently, leads to death [22]. Road and settlement construction within the mining district and mineral washing also increased the sediment load of the streams. Large quantities of dust are raised especially during the dry season, which may aggregate lung disease while mining operation has created an island of noise in an otherwise tranquil environment. This if not controlled will impair hearing of mine employees.

(iv) Potential Hazards: Increased local traffic, the use of excavators, explosives and machines in the processing units will generate significant road and industrial accident risks. Mining operations frequently upset the equilibrium in the geological environment, which can trigger off certain geological hazards such as landslides, subsidence, flooding, erosion and tremors together with their secondary effects. Minor tremors are generated due to the blasting of rocks, and the villages will experience unpleasant earth movements when rocks are blasted [23]. Furthermore, exposure to natural radiation emitted by some radioactive minerals is another potential hazard as the radiation intensity increases where the minerals are concentrated.

#### 5.1.2 The positive effect of modern mining

(i) Human population, as many more people were attracted because of new economic opportunities in the area.

(ii) Settlement patterns and dynamics, since the influx of people, will swell the population of existing villages. The mining companies built temporary settlements for their workers. This has promoted social services, such as schools, religious centres and roads which the mine has attracted into the area and boosted subsistence agriculture; through demand for local crops to feed the swelling population.

### 5.2 Results of Surface Water Analysis

Most of the trace elements in the water samples are below the detection limit. Some of the elements analyzed for in the soil and stream sediments that are found in the water samples occurred in ppb and they are; $Ca^{2+}$ (1.6 – 72.8), $Mg^{2+}$( BDL – 4.39), $Na^{+}$ (1.63– 75.0), $K^{+}$ (BDL – 25.4), Cu (BDL – 0.391), Zn (BDL – 0.29), Cd (BDL), Pb (BDL), Fe (0.32 – 0.93), Ni (BDL –

0.26). The anion analysed in the samples are; $SiO_2$ (BDL-9.0), $HCO_3^-$ (6.10-79.3), $Cl^-$ (5.0-109.0), $SO_4^{2-}$ (15.0-76.0), $NO_3^-$ (1.2-8.9), $PO_4^{3-}$ (0.005-0.030).

The pH plays a significant role in the mobility of metals. Low pH values often significantly increase metal mobility while High pH values decrease the mobility of metals. The pH values of the surface water were measured in-situ, and the values range from 7.0 to 7.8. This suggests that they are slightly alkaline (Table 4).

The values of EC for the surface water range from 150.2 to 324.4*µS/cm*. The measured data suggest that there was no uniform pattern of distribution in the values of electrical conductivity.

The results of the total hardness in this study revealed that the samples were moderately soft. The result obtained in this study fell within the permissible limits of 500*µs/cm* set by the WHO. The EC levels recorded were all lower than the MPL stipulated by WHO. The TDS represents the amount of inorganic substances (salts and minerals) such as Calcium ion ($Ca^{2+}$), Magnesium ($Mg^{2+}$), Hydrogen tricarbonate (iv) ($HCO_3^-$), Tricarbonate (iv) $CO_3^{2-}$, trioxonitrate (v) ($NO_3^-$) and Tetraoxophosphate (vi) ($PO_4^{3-}$). The values of total dissolved solids (TDS) values in surface water range from 112.7 to 243.3 *mg/L*. This indicates different distribution pattern from one sample to the other. The high TDS is always associated with unusual health conditions in human [24]. However, the TDS was below the recommended range.

Most of the trace/heavy metals are below the detection limit. The concentration of the elements analyzed is tabulated in (Table 1) while the summary is in (Table 4). The range of concentration of cations in the surface water around Lafia area are; $Ca^{2+}$( 1.6-72.8), $Mg^{2+}$( 0-4.39), $Na^+$(1.63-75.0), $K^+$(0-108.3) while the selected trace metals have the following concentration; Cu (0-0.391), Zn (0-0.29), Cd (BDL), Pb (BDL), Fe (0.10) and Ni (BDL-0.043). The $SiO_2$ in the sample have a range of (4.0-10), $HCO_3$ (6.1-79.3), $NO_3$ (BDL), $PO_3$(0.005-0.03) and Cl (5.0-109). A Piper plot of the major elements separated the groundwater types (Fig. 2). This plot indicated that $Ca^{2+}$ and $Na^+$ were the major cations, whereas $SO_4^{2-}$ and $HCO_3^-$ dominated the anionic species.

From the result obtained, it was discovered that most heavy metals associated with mining of rare metal is significantly low and some are below the detection limit (BDL). The concentration of nitrate in water samples depends on the nitrification activities of microorganisms. The values obtained are all below MPL set by WHO. Water that is concentrated with nitrate is harmful especially to infants causing methaemoglobinaemia otherwise called infantile cyanosis or blue baby syndrome if consumed [25]. Excessive levels of nitrate in drinking water may cause serious illness and sometimes death due to shortness of breath [26]. However, the results in all cases fall within the MPL set by WHO. In this study, chloride values are lower than the MPL. Although chlorine is needed in a small amount of cell growth, however, high Cl make water unpalatable and unfit for drinking and livestock.

### 5.3 Bacteriological Analysis of the Surface Water around Lafia Mining Site

Humans are in contact with millions of bacteria every day, and nearly all of them are harmless. Some of these small organisms are responsible for waterborne illnesses. Total coliforms are one group of mostly harmless bacteria that live in soil and water, as well as the intestines of animals. The presence of total coliforms in drinking water can indicate that more dangerous germs, particularly faecal coliforms, have contaminated the water. Fecal bacteria in drinking water are usually the result of contamination by a nearby sewer, septic tank, or animal yard.

In the study area, it was observed that there are pit toilets and no construction of the modern septic tank. Furthermore, most of the artisan miners defecate near the stream and some in the stream while bathing. The choice of washing in the stream is because there is no groundwater facility in the area. Some dig shallow well which is only functional during the wet season. Thus, they solely rely on the stream water for domestic use. Furthermore, animal dung is also funded downstream. This is because cattle herdsmen allow their cattle drink from the stream and it was however deduced that the traces of cattle dung found could result from this activity. The result of colony count is presented in (Table 3).

The presence of the disease-causing bacteria makes the water unsafe for domestic use (even though the water is free from the presence of heavy metals) and can trigger gastrointestinal illnesses, diarrhoea and vomiting. It can be life-threatening for infants and children. Chlorine, ultraviolet or ozone treatment will kill or inactivate the bacteria and other harmful germs in drinking water.

**Table 1. The result of chemical characteristics (cations and trace metals) of surface water around Lafia area**

| Sample ID | Ca$^{2+}$ (ppm) | Mg$^{2+}$ (ppm) | Na$^{+}$ (ppm) | K$^{+}$ (ppm) | Cu (ppm) | Zn (ppm) | Cd (ppm) | Pb (ppm) | Fe (ppm) | Ni (ppm) |
|---|---|---|---|---|---|---|---|---|---|---|
| A 1 | 4.80 | 0.195 | 5.23 | 2.11 | 0.039 | 0.000 | 0.000 | 0.000 | 0.78 | 0.015 |
| A2 | 16.0 | 0.683 | 6.86 | 8.49 | 0.021 | 0.000 | 0.000 | 0.000 | 0.63 | 0.014 |
| A3 | 9.60 | 0.195 | 8.56 | 6.17 | 0.016 | 0.006 | 0.000 | 0.000 | 0.65 | 0.004 |
| A4 | 12.0 | 0.488 | 6.95 | 8.27 | 0.391 | 0.080 | 0.000 | 0.000 | 0.91 | 0.043 |
| A5 | 28.8 | 4.390 | 25.3 | 1.43 | 0.018 | 0.000 | 0.000 | 0.000 | 0.32 | 0.006 |
| A6 | 9.60 | 0.390 | 22.00 | 16.20 | 0.016 | 0.006 | 0.000 | 0.000 | 0.48 | 0.004 |
| A7 | 4.00 | 0.488 | 6.120 | 3.68 | 0.020 | 0.000 | 0.000 | 0.000 | 0.50 | 0.025 |
| A8 | 4.00 | 0.146 | 1.630 | 0.000 | 0.036 | 0.001 | 0.000 | 0.000 | 0.39 | 0.007 |
| A9 | 21.6 | 0.000 | 4.100 | 3.860 | 0.037 | 0.027 | 0.000 | 0.000 | 0.76 | 0.011 |
| A10 | 4.80 | 0.342 | 3.550 | 1.870 | 0.000 | 0.005 | 0.000 | 0.000 | 0.32 | 0.014 |
| A11 | 1.60 | 0.146 | 2.760 | 4.660 | 0.002 | 0.005 | 0.000 | 0.000 | 0.85 | 0.000 |
| A12 | 12.0 | 0.537 | 4.450 | 25.40 | 0.017 | 0.000 | 0.000 | 0.000 | 0.54 | 0.018 |
| A13 | 1.60 | 0.293 | 6.300 | 1.400 | 0.066 | 0.001 | 0.000 | 0.000 | 0.64 | 0.000 |
| A14 | 28.8 | 0.439 | 17.70 | 4.92 | 0.032 | 0.013 | 0.000 | 0.000 | 0.63 | 0.033 |
| A15 | 8.00 | 0.439 | 8.840 | 2.960 | 0.014 | 0.001 | 0.000 | 0.000 | 0.89 | 0.018 |
| A16 | 72.8 | 2.245 | 34.00 | 23.60 | 0.019 | 0.020 | 0.000 | 0.000 | 0.61 | 0.028 |
| A17 | 36.0 | 1.650 | 75.00 | 10.83 | 0.004 | 0.028 | 0.000 | 0.000 | 0.34 | 0.029 |
| A18 | 64.0 | 1.562 | 32.10 | 4.820 | 0.048 | 0.000 | 0.000 | 0.000 | 0.73 | 0.033 |
| A19 | 5.60 | 0.390 | 7.050 | 3.320 | 0.051 | 0.007 | 0.000 | 0.000 | 0.85 | 0.016 |
| A20 | 20.8 | 0.927 | 41.70 | 8.660 | 0.000 | 0.018 | 0.000 | 0.000 | 0.53 | 0.000 |
| A21 | 48.0 | 1.075 | 27.60 | 4.660 | 0.004 | 0.29 | 0.000 | 0.000 | 0.93 | 0.26 |

**Table 2. The result of chemical characteristics (anions) of surface water around Lafia area**

| Sample number | SiO$_2$ (ppm) | HCO$_3^-$ (ppm) | Cl$^-$ (ppm) | SO$_4^{2-}$ (ppm) | NO$_3^-$ (ppm) | PO$_4^{3-}$ (ppm) |
|---|---|---|---|---|---|---|
| S1 | 9.0 | 12.2 | 12.5 | 22.0 | 2.1 | 0.011 |
| S2 | 9.0 | 24.4 | 11.5 | 24.0 | 3.6 | 0.009 |
| S3 | 4.0 | 24.4 | 12.0 | 33.0 | 2.5 | 0.014 |
| S4 | 0.0 | 6.10 | 10.5 | 29.0 | 7.4 | 0.020 |
| S5 | 10 | 42.7 | 19.0 | 38.0 | 3.0 | 0.016 |
| S6 | 4.0 | 12.2 | 29.5 | 36.0 | 1.7 | 0.019 |
| S7 | 4.0 | 18.3 | 5.00 | 35.0 | 2.8 | 0.012 |
| S8 | 8.0 | 6.10 | 9.50 | 25.0 | 3.4 | 0.005 |
| S9 | 8.0 | 6.10 | 15.0 | 27.0 | 4.9 | 0.028 |
| S10 | 8.0 | 30.5 | 12.5 | 33.0 | 2.7 | 0.016 |
| S11 | 6.0 | 12.2 | 8.50 | 34.0 | 1.5 | 0.018 |
| S12 | 8.0 | 18.3 | 18.0 | 29.0 | 3.9 | 0.030 |
| S13 | 8.0 | 6.10 | 10.5 | 32.0 | 2.6 | 0.020 |
| S14 | 8.0 | 12.2 | 20.0 | 15.0 | 2.8 | 0.014 |
| S15 | 4.0 | 24.4 | 18.5 | 23.0 | 1.2 | 0.019 |
| S16 | 8.0 | 36.6 | 67.0 | 70.0 | 8.9 | 0.020 |
| S17 | 6.0 | 24.4 | 109.0 | 35.0 | 7.1 | 0.015 |
| S18 | 4.0 | 79.3 | 39.5 | 35.0 | 6.0 | 0.016 |
| S19 | 8.0 | 12.2 | 16.5 | 76.0 | 3.8 | 0.020 |
| S20 | 4.0 | 30.5 | 51.0 | 53.0 | 1.5 | 0.015 |
| S21 | 4.0 | 54.9 | 16.2 | 38.0 | 5.0 | 0.012 |

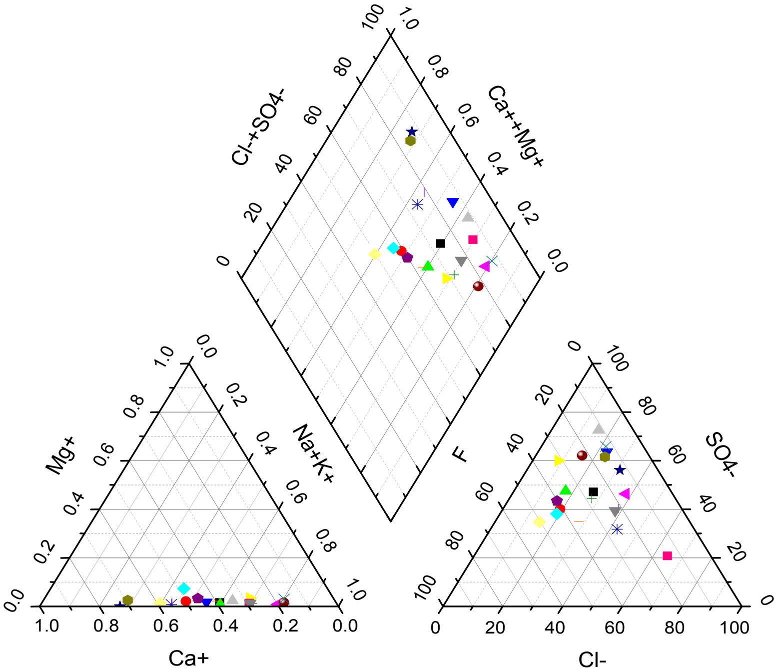

Fig. 2. Piper plot showing the major surface water types

Table 3. The result of the bacteriological analysis of surface waters around Lafia area

| S/n | Chlorine residual | Colony count (MPN) | MPN coliform organism |
|---|---|---|---|
| S1 | 0 | 30 | 30 |
| S2 | 0 | 80 | 80 |
| S3 | 0 | 40 | 40 |
| S4 | 0 | 10 | 10 |
| S5 | 0 | 20 | 20 |
| S6 | 0 | 20 | 20 |
| S7 | 0 | 20 | 20 |
| S8 | 0 | 10 | 10 |
| S9 | 0 | 40 | 40 |
| S10 | 0 | 20 | 20 |
| S11 | 0 | 10 | 10 |
| S12 | 0 | 20 | 20 |
| S13 | 0 | 5 | 5 |
| S14 | 0 | 10 | 10 |
| S15 | 0 | 20 | 20 |
| S16 | 0 | 10 | 10 |
| S17 | 0 | 20 | 20 |
| S18 | 0 | 40 | 40 |
| S19 | 0 | 30 | 30 |
| S20 | 0 | 10 | 10 |
| S21 | 0 | 30 | 30 |

**MPN- Most Probable Number*

### 5.4 Geochemical Analysis Results for Trace Elements in the Topsoils

Following the Food and Agricultural Organisation [27] classification, the soils in the area are ferric ambisols, ferric acrisols, ferric luvisols and chromic luvisols. They range texturally from stony sandy clay barns. The clay content of topsoil lies between 4.0-19.6% while the subsoil lies between 15.7 – 20.5% of clays. The sand fraction in the top soils is between 57.2 – 92.0% while the subsoil has between 15.7-20.6% of clays. The sand fraction in the top soils is between 70.9 – 77.8% while in the subsoil it is 61.7 – 68.4%. A total of twenty-three samples (23) were analyzed. The elements selected are Mo, Cu, Pb, Zn, Ni, As, Cd, Cr, Th, and Co. Results for the metals were measured in ppm as presented in (Table 5). The concentration of the trace elements in the top soils ranges from: Cu (8.8 – 92.7 ppm), Pb (3.3- 26.20 ppm), Zn (7 - 130 ppm), Ni (1.6- 86.9 ppm), Co (5.0 – 84.5 ppm), Th (4.10 – 31.7 ppm), Cd (BDL – 1.80 ppm), Cr (79 – 226 ppm), and As (BDL – 2.40 ppm). The average results of the trace elements concentration observed, showed a decreasing order of magnitude as in Cr > Zn> Cu >Ni > Co > Th > Pb> Mo > As> Cd.

**Table 4. Summary of the physico-chemical and bacteriological parameters of waters around Komu area compared with [28] standard**

| Parameters | N | Min | Max | Mean | S. D. | HPL (WHO) | MPL (WHO) |
|---|---|---|---|---|---|---|---|
| Elevation (m) | 21 | 318.00 | 484.00 | 410.33 | NC | | |
| TDS (*mg/l*) | 21 | 112.7 | 250.0 | 154 | 180 | 500 | 1000 |
| EC (*$\mu$S/cm*) | 21 | 150.2 | 324.4 | 260.59 | 280.01 | 1000 | 1400 |
| pH | 21 | 7.0 | 7.8 | 7.2 | ----- | 7.0 – 8.5 | 6.5 – 9.2 |
| Temp ($^0$C) | 21 | 24.8 | 29.5 | 26.70 | 1.312 | Variable | Variable |
| MPN | 21 | 5 | 80 | 23.57 | NC | NM | NM |
| Ca$^{2+}$ (ppm) | 21 | 1.6 | 72.80 | 19.73 | 20.351 | 75 | 200 |
| Mg$^{2+}$(ppm) | 21 | 0.00 | 4.39 | 0.84 | 0.998 | 39 | 150 |
| Na$^+$ (ppm) | 21 | 1.63 | 75.0 | 16.56 | 17.958 | 150 | 200 |
| K$^+$ (ppm) | 21 | 0.00 | 25.4 | 7.01 | 6.903 | 10 | 15 |
| SiO$_2$ (ppm) | 21 | 0.00 | 10.00 | 6.29 | 2.53 | 20 | NM |
| HCO$_3^-$ (ppm) | 21 | 6.1 | 79.30 | 23.53 | 18.227 | 500 | 1000 |
| Cl$^-$ (ppm) | 21 | 5.0 | 109 | 24.37 | 24.614 | 200 | 500 |
| SO$_4^{2-}$ (ppm) | 21 | 15.0 | 76 | 35.33 | 14.72 | 150 | 250 |
| NO$_3^-$ (ppm) | 21 | 1.2 | 8.9 | 3.73 | 2.11 | 20 | 45 |
| PO$_4^{3-}$ (ppm) | 21 | 0.005 | 0.03 | 0.017 | 0.006 | NM | NM |
| Cu (ppm) | 21 | 0.00 | 0.391 | 0.04 | 0.082 | 1.0 | 1.5 |
| Zn (ppm) | 21 | 0.00 | 0.29 | 0.02 | 0.064 | 0.2 | 5.0 |
| Cd (ppm) | 21 | 0.00 | 0.00 | 0.00 | NC | 0 | 0.005 |
| Pb (ppm) | 21 | 0.00 | 0.00 | 0.00 | NC | 0 | 0.05 |
| Fe (ppm) | 21 | 0.32 | 0.93 | 0.63 | 0.197 | 0.3 | 1.0 |
| Ni (ppm) | 21 | 0.00 | 0.26 | 0.027 | 0.055 | 0 | 0.02 |

*HPL- Highest Permissible Level; MPL- Maximum Permissible Level*
*NC – Not Calculated; NM – Not Mentioned*

**Table 5. Trace and heavy metal content of soils around Lafia area mining site**

| Sample number | Mo | Cu | Pb | Zn | Ni | As | Cd | Cr | Th | Co |
|---|---|---|---|---|---|---|---|---|---|---|
| LS1 | 1.0 | 32.2 | 26.0 | 24.0 | 12.3 | 1.2 | 1.1 | 183 | 12.0 | 43.0 |
| LS2 | 1.4 | 20.0 | 11.6 | 14.0 | 8.3 | 2.3 | 0.7 | 81 | 4.1 | 26.1 |
| LS3 | 5.7 | 78.5 | 11.4 | 129.0 | 55.7 | 1.0 | 0.5 | 113 | 7.9 | 25.7 |
| LS4 | 0.5 | 13.8 | 6.4 | 8.0 | 3.6 | 1.2 | 0.8 | 117 | 12.4 | 12.5 |
| LS5 | 0.1 | 8.8 | 3.3 | 7.0 | 1.6 | 0.0 | BDL | 89 | 10.0 | 5.0 |
| LS6 | 0.3 | 13.4 | 6.3 | 10 | 2.7 | 0.9 | 0.5 | 79 | 9.5 | 32.9 |
| LS7 | 0.7 | 8.8 | 12.2 | 20.0 | 13.1 | 1.4 | 0.0 | 111 | 26.0 | 24.6 |
| LS8 | 7.4 | 13.4 | 10.0 | 130.0 | 65.3 | 0.9 | 0.6 | 101 | 17.0 | 49.2 |
| LS9 | 1.3 | 30.8 | 23.1 | 30.0 | 15.3 | 1.3 | 0.4 | 156 | 25.1 | 20.1 |
| LS10 | 0.4 | 90.5 | 5.8 | 10.0 | 2.9 | 0.8 | 0.0 | 100 | 25.7 | 18.6 |
| LS11 | 5.7 | 34.7 | 12.3 | 121.5 | 59.4 | 1.0 | 0.7 | 138 | 20.2 | 84.5 |
| LS12 | 1.0 | 12.4 | 18.2 | 14.0 | 7.7 | 1.9 | 0.9 | 101 | 31.7 | 20.6 |
| LS13 | 1.4 | 92.7 | 11.2 | 13.0 | 8.2 | 2.4 | 0.7 | 145 | 20.8 | 20.3 |
| LS14 | 2.6 | 24.0 | 15.1 | 52.0 | 24.5 | 1.7 | 1.0 | 226 | 23.0 | 18.7 |
| LS15 | 0.6 | 18.0 | 11.3 | 21.6 | 7.6 | 0.9 | 1.0 | 129 | 18.3 | 31.5 |
| LS16 | 0.1 | 45.4 | 5.0 | 10.5 | 3.1 | BDL | 1.8 | 108 | 11.0 | 29.3 |
| LS17 | BDL | 28.8 | 17.4 | 11.4 | 3.1 | BDL | 1.0 | 103 | 18.9 | 23.0 |
| LS18 | 11.1 | 45.7 | 10.2 | 90.8 | 86.9 | BDL | 0.9 | 116 | 17.4 | 37.0 |
| LS19 | 1.5 | 43.8 | 11.7 | 14.0 | 8.4 | 2.4 | 1.1 | 105 | 12.0 | 13.0 |
| LS20 | 1.0 | 85.0 | 26.2 | 23.9 | 12.2 | 1.1 | 0.4 | 134 | 20.4 | 17.2 |
| LS21 | 5.8 | 20.1 | 11.3 | 92.1 | 50.0 | 1.1 | 0.7 | 106 | 19.8 | 21.0 |
| LS22 | 0.5 | 32.4 | 6.5 | 8.0 | 3.6 | 1.2 | 0.7 | 87 | 11.2 | 26.0 |
| LS23 | 0.1 | 14.0 | 3.4 | 9.3 | 2.1 | BDL | 0.8 | 82 | 15.1 | 24.3 |
| CS | 2.0 | 29.0 | 19.0 | 72.0 | 24.0 | 0.1 | 0.8 | 46 | 21 | 18 |

**Table 6. Statistical analysis of the above data**

| Elements | Minimum | Maximum | Mean | Std. deviation |
|---|---|---|---|---|
| Mo | .00 | 11.10 | 2.18 | 2.91 |
| Cu | 8.80 | 92.70 | 35.09 | 26.75 |
| Pb | 3.30 | 26.20 | 11.99 | 6.53 |
| Zn | 7.00 | 130.00 | 37.57 | 42.45 |
| Ni | 1.60 | 86.90 | 19.89 | 24.81 |
| As | .00 | 2.40 | 1.07 | 0.75 |
| Cd | .00 | 1.80 | .71 | 0.41 |
| Cr | 79.00 | 226.00 | 117.82 | 34.67 |
| Th | 4.10 | 31.70 | 16.93 | 6.82 |
| Co | 5.00 | 84.50 | 27.13 | 15.87 |

The statistical description of the concentration of the trace elements in the soil samples within the study area is shown in (Table 6). The mean concentration of Mo, Cu, As, Cr, and Co have their concentration exceed that in the control sample (sample collected where there are no mining activities taken place) while Pb, Zn, Ni, Cd and Th have their concentration below that in the control sample.

## 5.5 Coefficient of Pearson's Correlation

The coefficient of Pearson's correlation measures the strength of a linear relationship between any two variables on a scale of -1 (perfectly inverse relation) through 0 (no relation) to +1 (perfect direct relation). This method is particularly useful for testing the strength of the association between two random variables, and it provides information on the sources and pathways of the metals. The closer the correlation coefficient is to 1, the stronger the relationship between the two elements, as the correlation coefficient approaches zero, it indicates that the elements under consideration are uncorrelated while correlation coefficients of -1 indicate a negative relationship between the elements. Correlation analyses reveal similarities in the behaviour of pairs of elements while marked differences in element correlations may indicate dissimilar source materials, leaching or physico-chemical depositional characteristics [29]. Correlation coefficients between 0.9 to 1 is deemed very high, Correlation coefficients between 0.7 to 0.9 is considered to be high, between 0.5 to 0.7 is moderate, 0.3- 0.5 low correlation and <0.3 is low correlation. From the (Table 7), it was seen that Mo shows strong and positive correlation with Zn, and Ni likewise Zn also shows strong and positive correlation with Ni (Figs. 3, 4, and 5). Pb displays a weak but positive correlation with Cr, Zn and Ni show weak but positive correlation.

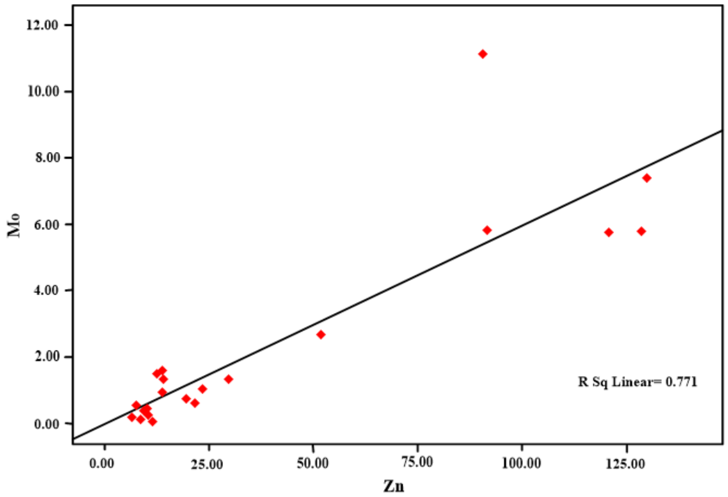

**Fig. 3. Scattered plot of Mo and Zn**

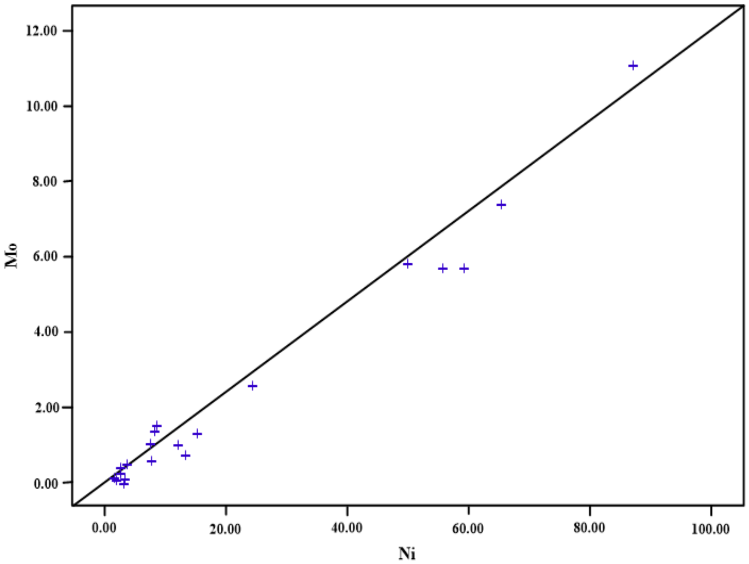

Fig. 4. Scattered plot of Mo and Ni

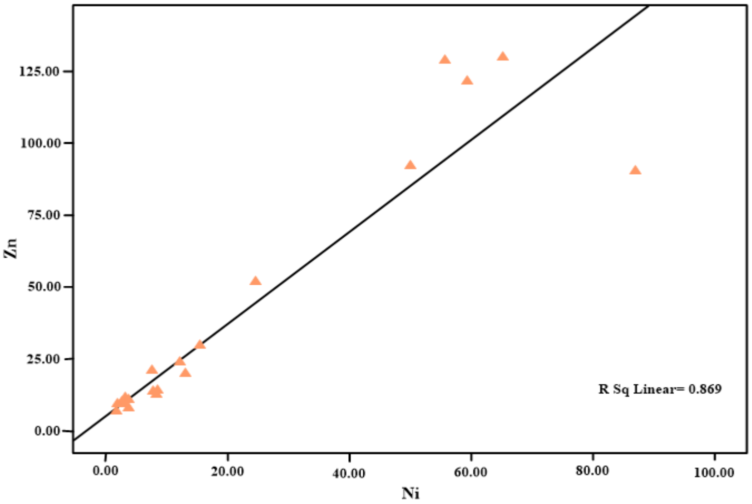

Fig. 5. Scattered plot of Zn and Ni

**Table 7. Results of Pearson's correlation matrix for soils in the study area**

| | Correlations | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Mo** | **Cu** | **Pb** | **Zn** | **Ni** | **As** | **Cd** | **Cr** | **Th** | **Co** |
| Mo | 1 | | | | | | | | | |
| Cu | 0.09 | 1.00 | | | | | | | | |
| Pb | 0.00 | 0.17 | 1.00 | | | | | | | |
| Zn | **0.88** | 0.08 | 0.06 | 1.00 | | | | | | |
| Ni | **0.99** | 0.08 | 0.05 | **0.93** | 1.00 | | | | | |
| As | -0.12 | 0.13 | 0.32 | -0.10 | -0.15 | 1.00 | | | | |
| Cd | 0.02 | -0.09 | 0.06 | -0.04 | 0.00 | -0.03 | 1.00 | | | |
| Cr | 0.09 | 0.17 | **0.58** | 0.15 | 0.13 | 0.26 | 0.21 | 1.00 | | |
| Th | 0.03 | 0.08 | 0.37 | 0.02 | 0.05 | 0.13 | -0.21 | 0.33 | 1.00 | |
| Co | 0.47 | -0.08 | 0.08 | **0.59** | **0.55** | -0.12 | 0.17 | 0.12 | 0.00 | 1.00 |

## 5.6 Factor Analysis

Factor analysis is to represent a large number of variables in the original data by significant smaller number of 'factors' each of which is a linear function of the original variables. As a result, a limited number of factors will usually account for approximately the same amount of information as do the much larger set of original variables. Factor analysis was done following the steps described by [30]. Factor analysis can be used to delineate geochemical association of metals within media, metal sources or in some cases sources of mineralization. The result obtained from the factor analysis was used to infer the processes responsible for the metal concentration of the samples in the study area. The principal component analysis for soil revealed a three (3) factor model. (Table 8).

**Factor 1:** Factor 1 consists of Mo, Zn, Co and Ni. Zn, Co, and Ni are siderophilic (having a strong affinity for metallic phase and usually depleted in the silicate portion of the earth) and are well correlated with one another.

**Factor 2:** This factor consists of the following metals Pb, Th, Cr and As. As and Th show weak correlation with the other elements and thus can be inferred that they are anthropogenic influenced.

**Factor 3:** Cd is poorly correlated with other elements, but they are anthropogenically introduced into the soil. This may be a result of weathering and erosion of rocks into the mining environment.

## 5.7 Contamination Index

The contamination index is obtained by comparing the observed heavy metal concentration with the control values for soil (calculated background value for stream sediment and water). This is an expression of the level of contamination of soil by metals is expressed by the formulae below;

$$Contamination\ Index = \frac{Cm}{Bm}$$

Where $Cm$ and $Bm$ are the concentration of the metal in the sample and background respectively.

Where the contamination factor CI values are less than 1.5, it indicates that the occurrence of metal is due to natural processes, but where it is greater than 1.5, it suggests that it is due to anthropogenic sources [31]. Using the background values of the control sample, the contamination Index values were generated. Arsenic (As) and Chromium (Cr) were anthropogenically introduced into the environment. Lead (Pb), Cadmium (Cd), Thorium (Th), Copper (Cu) and Zinc (Zn) are geogenic. Metals like Co, Cu, Mo and Zn display anthropogenic input at some sample locations (Table 9, Fig. 6). The prominent location and sampling identity LS11 where it is very close to the mine.

**Table 8. Result of principal component analysis for soils in the study area**

| | **Component** | | | **Communalities** |
|---|---|---|---|---|
| | **1** | **2** | **3** | **Extraction** |
| **Mo** | .937 | -.115 | -.102 | 0.902 |
| **Cu** | .095 | .341 | -.356 | 0.252 |
| **Pb** | .134 | .819 | .126 | 0.704 |
| **Zn** | .951 | -.068 | -.092 | 0.917 |
| **Ni** | .974 | -.087 | -.099 | 0.966 |
| **As** | -.134 | .569 | -.036 | 0.343 |
| **Cd** | .059 | .027 | .889 | 0.795 |
| **Cr** | .235 | .773 | .284 | 0.734 |
| **Th** | .087 | .593 | -.359 | 0.487 |
| **Co** | .689 | -.063 | .295 | 0.566 |
| Initials | 3.32 | 2.089 | 1.26 | |
| % of Variance | 33.17 | 20.89 | 12.60 | |
| Cumulative % | 33.17 | 54.06 | 66.66 | |

**Table 9. Contamination index for metals in soil**

| Sample ID | Mo | Cu | Pb | Zn | Ni | As | Cd | Cr | Th | Co |
|---|---|---|---|---|---|---|---|---|---|---|
| LS1 | 0.50 | 1.11 | 1.37 | 0.33 | 0.51 | **12.00** | 1.38 | **3.98** | 0.57 | **2.39** |
| LS2 | 0.70 | 0.69 | 0.61 | 0.19 | 0.35 | **23.00** | 0.88 | **1.76** | 0.20 | 1.45 |
| LS3 | **2.85** | **2.71** | 0.60 | **1.79** | **2.32** | **10.00** | 0.63 | **2.46** | 0.38 | 1.43 |
| LS4 | 0.25 | 0.48 | 0.34 | 0.11 | 0.15 | **12.00** | 1.00 | **2.54** | 0.59 | 0.69 |
| LS5 | 0.05 | 0.30 | 0.17 | 0.10 | 0.07 | 0.00 | 0.00 | **1.93** | 0.48 | 0.28 |
| LS6 | 0.15 | 0.46 | 0.33 | 0.14 | 0.11 | **9.00** | 0.63 | **1.72** | 0.45 | **1.83** |
| LS7 | 0.35 | 0.30 | 0.64 | 0.28 | 0.55 | **14.00** | 0.00 | **2.41** | 1.24 | 1.37 |
| LS8 | **3.70** | 0.46 | 0.53 | 1.81 | **2.72** | **9.00** | 0.75 | **2.20** | 0.81 | 2.73 |
| LS9 | 0.65 | 1.06 | 1.22 | 0.42 | 0.64 | **13.00** | 0.50 | **3.39** | 1.20 | 1.12 |
| LS10 | 0.20 | 3.12 | 0.31 | 0.14 | 0.12 | **8.00** | 0.00 | **2.17** | 1.22 | 1.03 |
| LS11 | **2.85** | 1.20 | 0.65 | **1.69** | **2.48** | **10.00** | 0.88 | **3.00** | 0.96 | **4.69** |
| LS12 | 0.50 | 0.43 | 0.96 | 0.19 | 0.32 | **19.00** | 1.13 | **2.20** | **1.51** | 1.14 |
| LS13 | 0.70 | 3.20 | 0.59 | 0.18 | 0.34 | **24.00** | 0.88 | **3.15** | 0.99 | 1.13 |
| LS14 | 1.30 | 0.83 | 0.79 | 0.72 | 1.02 | **17.00** | 1.25 | **4.91** | 1.10 | 1.04 |
| LS15 | 0.30 | 0.62 | 0.59 | 0.30 | 0.32 | **9.00** | 1.25 | **2.80** | 0.87 | **1.75** |
| LS16 | 0.05 | 1.57 | 0.26 | 0.15 | 0.13 | 0.00 | **2.25** | **2.35** | 0.52 | 1.63 |
| LS17 | 0.00 | 0.99 | 0.92 | 0.16 | 0.13 | 0.00 | 1.25 | **2.24** | 0.90 | 1.28 |
| LS18 | **5.55** | 1.58 | 0.54 | 1.26 | **3.62** | 0.00 | 1.13 | **2.52** | 0.83 | 2.06 |
| LS19 | 0.75 | 1.51 | 0.62 | 0.19 | 0.35 | **24.00** | 1.38 | **2.28** | 0.57 | 0.72 |
| LS20 | 0.50 | 2.93 | 1.38 | 0.33 | 0.51 | **11.00** | 0.50 | **2.91** | 0.97 | 0.96 |
| LS21 | **2.90** | 0.69 | 0.59 | 1.28 | **2.08** | **11.00** | 0.88 | **2.30** | 0.94 | 1.17 |
| LS22 | 0.25 | 1.12 | 0.34 | 0.11 | 0.15 | **12.00** | 0.88 | **1.89** | 0.53 | 1.44 |
| **LS23** | 0.05 | 0.48 | 0.18 | 0.13 | 0.09 | 0.00 | 1.00 | **1.78** | 0.72 | 1.35 |

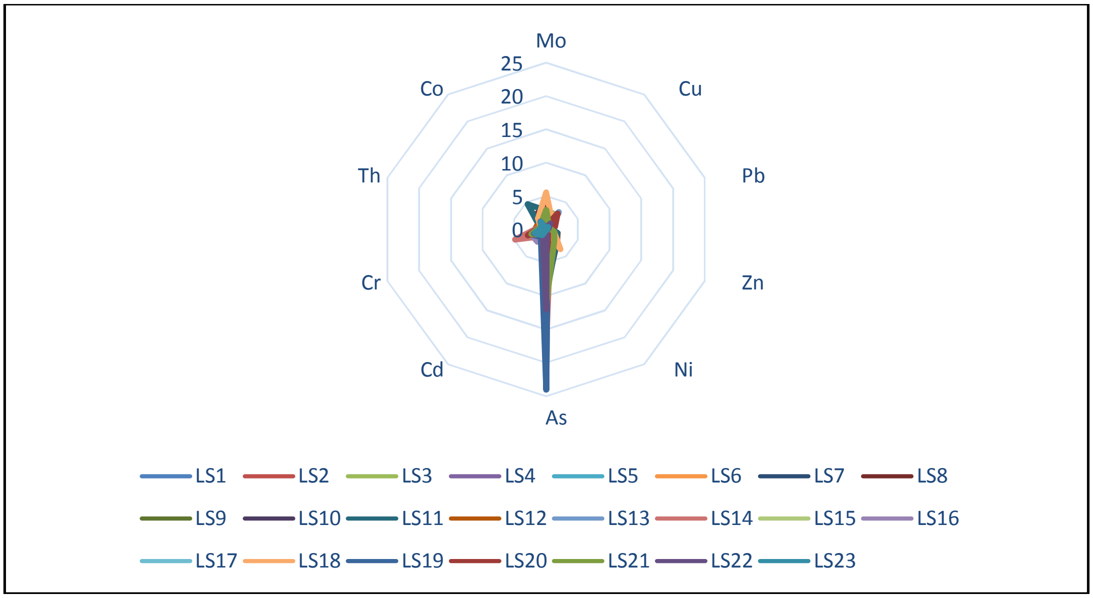

**Fig. 6. Contamination index (CI) of different metals in soils of the study area**

### 5.8 Geo-Accumulation Index

This was introduced by [32] for determining the extent of metal accumulation in sediments. It is expressed as;

$$\mathrm{Igeo} = \log_2\left[\frac{(Cm)}{(1.5*Bm)}\right]$$

Where $Cm$ is the concentration of metals in the study area and $Bm$ is the concentration of the same metal at the control site, 1.5 is a factor for possible variation in the background concentration due to lithological variation.

The Geoaccumulation index (Igeo) for the quantification of trace elements accumulation in soil is shown in (Table 10). Interpretation with references to the seven-grade classification (Table 11) according to [32] indicates that the soils are unpolluted for most of the elements except for As and Cr with moderate enrichment (Fig. 7).

**Table 10. Igeo index for metals in soil**

| Sample ID | Mo | Cu | Pb | Zn | Ni | As | Cd | Cr | Th | Co |
|---|---|---|---|---|---|---|---|---|---|---|
| LS1 | -0.48 | -0.13 | -0.04 | -0.65 | -0.47 | 0.90 | -0.04 | 0.42 | -0.42 | 0.20 |
| LS2 | -0.33 | -0.34 | -0.39 | -0.89 | -0.64 | 1.19 | -0.23 | 0.07 | -0.89 | -0.01 |
| LS3 | 0.28 | 0.26 | -0.40 | 0.08 | 0.19 | 0.82 | -0.38 | 0.21 | -0.60 | -0.02 |
| LS4 | -0.78 | -0.50 | -0.65 | -1.13 | -1.00 | 0.90 | -0.18 | 0.23 | -0.40 | -0.33 |
| LS5 | -1.48 | -0.69 | -0.94 | -1.19 | -1.35 | 0.00 | 0.00 | 0.11 | -0.50 | -0.73 |
| LS6 | -1.00 | -0.51 | -0.66 | -1.03 | -1.12 | 0.78 | -0.38 | 0.06 | -0.52 | 0.09 |
| LS7 | -0.63 | -0.69 | -0.37 | -0.73 | -0.44 | 0.97 | 0.00 | 0.21 | -0.08 | -0.04 |
| LS8 | 0.39 | -0.51 | -0.45 | 0.08 | 0.26 | 0.78 | -0.30 | 0.17 | -0.27 | 0.26 |
| LS9 | -0.36 | -0.15 | -0.09 | -0.56 | -0.37 | 0.94 | -0.48 | 0.35 | -0.10 | -0.13 |
| LS10 | -0.88 | 0.32 | -0.69 | -1.03 | -1.09 | 0.73 | 0.00 | 0.16 | -0.09 | -0.16 |
| LS11 | 0.28 | -0.10 | -0.36 | 0.05 | 0.22 | 0.82 | -0.23 | 0.30 | -0.19 | 0.50 |
| LS12 | -0.48 | -0.55 | -0.19 | -0.89 | -0.67 | 1.10 | -0.12 | 0.17 | 0.00 | -0.12 |
| LS13 | -0.33 | 0.33 | -0.41 | -0.92 | -0.64 | 1.20 | -0.23 | 0.32 | -0.18 | -0.12 |
| LS14 | -0.06 | -0.26 | -0.28 | -0.32 | -0.17 | 1.05 | -0.08 | 0.52 | -0.14 | -0.16 |
| LS15 | -0.70 | -0.38 | -0.40 | -0.70 | -0.68 | 0.78 | -0.08 | 0.27 | -0.24 | 0.07 |
| LS16 | -1.48 | 0.02 | -0.76 | -1.01 | -1.06 | 0.00 | 0.18 | 0.19 | -0.46 | 0.04 |
| LS17 | 0.00 | -0.18 | -0.21 | -0.98 | -1.06 | 0.00 | -0.08 | 0.17 | -0.22 | -0.07 |
| LS18 | 0.57 | 0.02 | -0.45 | -0.08 | 0.38 | 0.00 | -0.12 | 0.23 | -0.26 | 0.14 |
| LS19 | -0.30 | 0.00 | -0.39 | -0.89 | -0.63 | 1.20 | -0.04 | 0.18 | -0.42 | -0.32 |
| LS20 | -0.48 | 0.29 | -0.04 | -0.66 | -0.47 | 0.87 | -0.48 | 0.29 | -0.19 | -0.20 |
| LS21 | 0.29 | -0.34 | -0.40 | -0.07 | 0.14 | 0.87 | -0.23 | 0.19 | -0.20 | -0.11 |
| LS22 | -0.78 | -0.13 | -0.64 | -1.13 | -1.00 | 0.90 | -0.23 | 0.10 | -0.45 | -0.02 |
| LS23 | -1.48 | -0.49 | -0.92 | -1.06 | -1.23 | 0.00 | -0.18 | 0.07 | -0.32 | -0.05 |

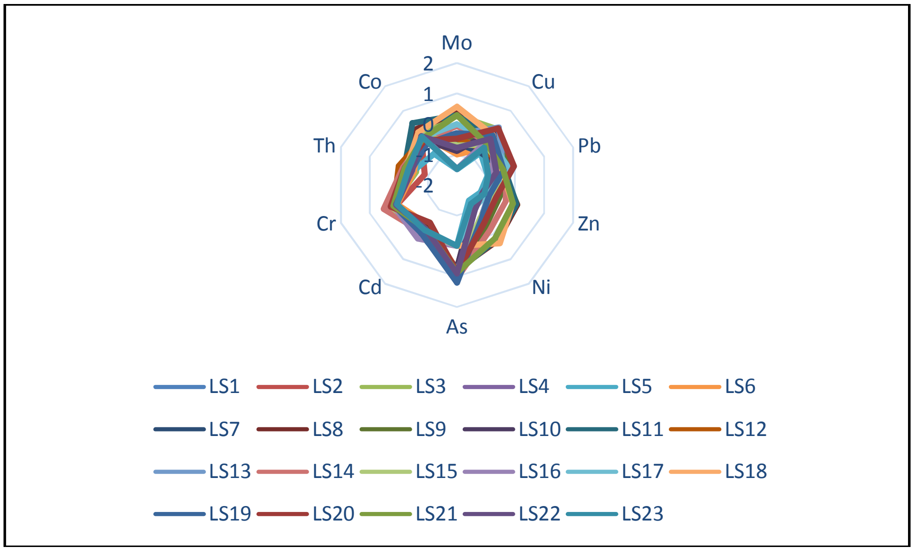

**Fig. 7. Geo-accumulation index (Igeo) of different metals in soils of the study area**

**Table 11. Geo-accumulation index classes proposed by [32]**

| Classes | Ranges | Indications/Soil quality |
|---|---|---|
| 0 | Igeo<0 | Practically Uncontaminated |
| 1 | 0<Igeo<1 | Uncontaminated to moderately contaminated |
| 2 | 1<Igeo<2 | Moderately contaminated |
| 3 | 2<Igeo<3 | Moderately to heavy contaminated |
| 4 | 3<Igeo<4 | Heavily contaminated |
| 5 | 4<Igeo<5 | Heavily to extremely contaminated |
| 6 | 5<Igeo | Extremely contaminated |

## 6. CONCLUSIONS

The study area is underlain by granite gneiss and pegmatite (which occur as low-lying intrusions into the granite gneiss). The granite gneiss predominates the study area and is mainly composed of quartz, feldspars and biotite. The pegmatite occurs as a coarse-grained rock and main trends in NNW-SSE direction. The primary mineral assemblages are albite, microcline, quartz, muscovite, sericite, black tourmaline (shorl), columbite-tantalite.

Negative and positive impact of the work in progress was reviewed. The negative impact exceeded the positive which includes; Landscape destruction, Ecological destruction, pollution and accidental hazards while the positive impacts are; an Increased human population which promoted the agricultural practice, the building of settlements as well as religious centres.

The pH values for the surface water indicate they are slightly alkaline Their EC and TDS values indicate their varying distribution pattern from one sample point to another. The results of the total hardness in this study revealed that the samples were moderately soft. The result obtained in this study fell within the permissible limits of 500*µs/cm* set by the WHO. The EC levels recorded were all lower than the Maximum permissible level (MPL) stipulated by WHO. The values of total dissolved solids (TDS) values in surface water range from 112.7 to 243.3 *mg/L*. The TDS was below the recommended range. All the heavy/trace elements analysed for the surface water were all below MPL.

The bacteriological analysis of the surface water around Lafia mining site revealed the presence of the disease-causing bacteria makes the water unsafe for domestic use (even though the water is free from the presence of heavy metals) and can trigger gastrointestinal illnesses, diarrhoea and vomiting. It can be life-threatening for infants and children. Chlorine, ultraviolet or ozone treatment will kill or inactivate the bacteria and other harmful germs in drinking water. The geochemical analysis of the soil sample revealed that Arsenic (As) and Cadmium(Cd) are anthropogenically inputted into the environment using the contamination index and have moderately polluted the environment.

### 6.1 Impact Mitigation

An overall environmental management plan (E.M.P) must be designed to minimize the adverse impacts of mining in Lafia districts. Specific measures included in the overall E.M.P will include:

i. The proposed mining design ensures that pit sides slope back at a stable angle.
ii. Mining and infrastructure development is already preceded by a careful study of the existing vegetation cover in the affected area. These have included a collection of nature plant seeds to recreating local plant ecology when the area is reclaimed after mining.
iii. Loss of landscape aesthetics will be tackled through the proper mine design, (in place) mine land reclamation, and this includes re-vegetation and landscaping of all facilities associated with the mine. These are already designed.
iv. Indigenous people are being educated and warned of health risks associated with standing bodies of water in this environment.
v. Also, provision of improved water supply for local communities through the sinking of boreholes water should be embarked upon.
vi. To reduce road and industrial accident risks, machinery operators and vehicle drivers are being educated to follow safety regulations. Safety tools will be provided for employees and visitors as standard wear at all times and places.

vii. An adequately staffed and equipped clinic to provide for minor ailments and first and assistance in case of accidents is to be provided.
viii. Mine tailings should be strictly monitored and managed to prevent further contamination of the soil in the environment.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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