

## **Relationship between Metal Concentrations in Galena Ore and Soil Samples from Galena-rich Farmlands**

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### **Authors' contributions**

*This work was carried out in collaboration between all authors. Authors AUI designed, supervised and wrote the protocol of the study. Author ISE co-supervised and proofread the work. Author LAE managed the analyses and literature searches of the study and wrote the complete draft. All authors read and approved the final manuscript*

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### **ABSTRACT**

One of the Nigerian minerals (galena ore) within galena deposit region in Torkula, Benue state, was characterized along with its vicinity farmland soils for possible relationships in their geo-physico-chemical compositions. Both classical (titrimetric & gravimetric) and instrumental analytical techniques were adopted. Contamination factors revealed different categories of pollution by heavy metals while the metal loading in the ore and ore-rich soils shows no statistical difference for Pb and other key metals at  $p < 0.05$ . Hence, the possibility of leaching of toxic metals from mineral ores, their transport and distribution to surrounding environment cannot be over emphasized.

*Keywords: Contamination; Galena; metals; environment; pollution; soil; farmlands.*

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## 1. INTRODUCTION

The danger that toxic metals cause to the health of man has been studied and documented well. Relatively efficient mining activities causes plenty waste, release to water and atmosphere, and a report of surrounding pollution in closely communities and environment [1]. Due to the disturbance and acceleration of nature's slowly occurring geochemical cycle of metals by man, most soils of rural and urban environments may accumulate one or more of the heavy metals above defined background values high enough to cause risks to human health, plants, animals, ecosystems, or other media. Heavy metals exist naturally in the soil surrounding from the pedogenetic processes of weathering of parent materials at levels that are regarded as trace ( $<1000 \text{ mg kg}^{-1}$ ) and rarely toxic [2,3,4].

The buildup of toxic minerals and metalloids can contaminate the Soil by the release of pollutants from the growing industries, disposal of wastewater irrigation metal wastes, animal manures, mine tailings, coal combustion residues paints and leaded gasoline, land application of fertilizers, sewage sludge, pesticides, atmospheric deposition and spillage of petrochemicals [2,3]. The soils are usually the highest carrier of toxic metals when introduced to the surrounding by anthropogenic activities that are mentioned above. Heavy metals are made up of an ill-defined group of inorganic chemical hazards, and those most usually found at contaminated sites are lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), cadmium (Cd), copper (Cu), mercury (Hg), and nickel (Ni). The availability of heavy minerals in soil can seriously block the biodegradation pollutants that are organic [5]. Toxic minerals pollution of soil can be dangerous to ecosystem and humans by direct intake and contact with polluted in the food chain, intake of polluted ground water, low quality of food through phytotoxicity, food insecurity due to decrease land use for agriculture and the problem of land tenure system [6,7]. Changes in their chemical forms (speciation) and bioavailability are, however, possible.

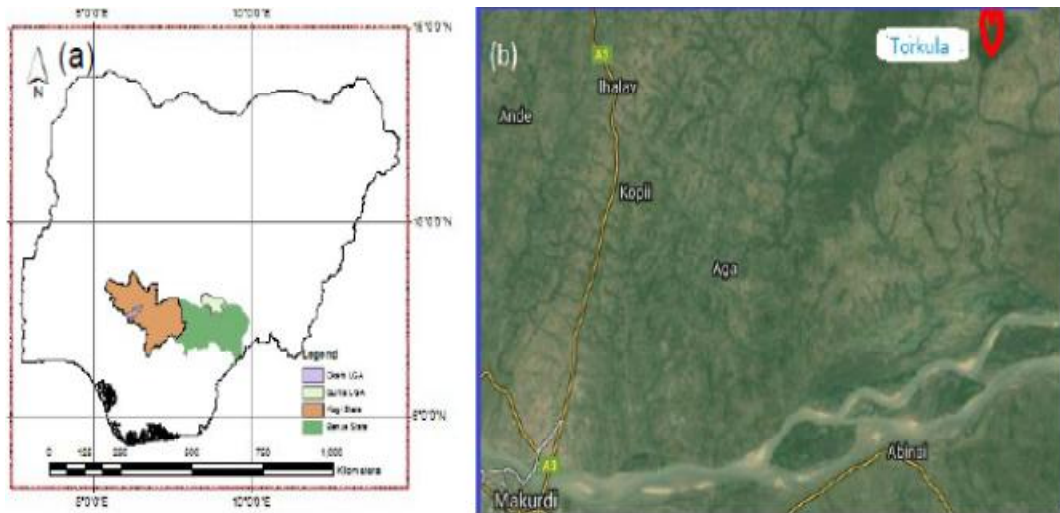
Nigeria is rich in different kinds of mineral ores of different types starting from different kinds of stones, metals that are precious and also industrial minerals like barite, kaolin, gypsum and marble. While many are not yet exploited in Nigeria's and the mineral falls into four main essential categories: metallic, fossil fuels, non-metallic and radio-active mineral [8]. Galena

(PbS) is the primary ore of lead which is mainly used in making lead-acid batteries; however, significant amounts are also used to make lead sheets and shot. This chief ore of lead occurs in both igneous and sedimentary rocks [9]. Common sulphites with which Galena associates sulphide minerals, such as sphalerite (ZnS), pyrite (FeS<sub>2</sub>), chalcopyrite (CuFeS<sub>2</sub>) and arsenopyrite (FeAsS) [10]. The largest deposit of galena in Nigeria has been documented [11] to be Abakaliki in Ebonyi State, stating that Nigerian Mining Corporation has indicated proved reserves of up to 711, 237 tonnes [9].

Extraction or mining results to erosion of the soil and contamination of the surrounding by producing pollutants during mining, cleaning and metal processing. When mining activities stop, it can continue to cause environmental pollution from the littered waste, and contamination of surrounding water by released leachate, until the actual recovery is done [12]. Matthews et al. [13] reports that metals that are toxic like Cd, Pb, Cu, Zn Mg and Ni, concentrations level in river soil, water with plant crop in the site of mining was analyzed using AAS. The metallic soil levels were smaller than the real soil composition from time to time and limits that are maximally allowed by toxic minerals in soils. Metallic concentration level in water was within WHO and FEPA limits that is permissible. This study focused on mineral (galena ore) survey, preliminary characterization and estimation of heavy metals (Lead, Manganese, Cadmium, Chromium, Zinc, Nickel, Copper and Iron) in soils and Ore samples within Galena deposit region in Torkula, Nigeria (Fig. 1).

## 2. MATERIALS AND METHODS

Routine classical analytical techniques were adopted for physicochemical parameters (pH, bulk density, conductivity, moisture content and particle size) of the Ores and soil samples from each region. For functional group analysis, FTIR spectrum was recorded on a Fourier Transform Infrared Spectrometer (Agilent technologies Cary 630), micro structural morphology of ore was carried out with scanning electron microscope (SEM; Phenomenon, MVE016477830). UV-Visible (Agilent 8453E) spectrophotometer was used to study the spectral profile of the ores, Atomic Adsorption Spectrophotometer (Varian AA240FS) was used to estimate the concentration of metals. All reagents used are analytical grades except otherwise stated.



**Fig. 1. Map of (a) Nigeria and (b) Torkula showing sampling state and sites respectively (Google Earth Image, 2016)**

## 2.1 Sampling Area

The study area (Torkula galena ore region; Fig. 1b) is located in Guma local government area of Benue State, in the North central Nigeria (Fig. 1a). It lies within Latitude 7°55'N and Longitude 8°48'E. The inhabitants of the study area are engaged in subsistence agriculture. A major characteristic of this type of agricultural practice is that there is no extensive application of technologies e.g. fertilizers, manufacturing industry is not developed. The inhabitants of the area are engaged in mining because of existence of galena ore in the area with characteristic evidence of indiscriminate disposed mine tailing in the area.

## 2.2 Sampling of the Ores

The mineral samples were handpicked randomly from regions around the depot and stored in a nitric acid pre-treated dry polypropylene bag, well labeled, taken to the laboratory and stored under the ambient condition in the lab [14].

## 2.3 Sampling of the Soil

Soil sampling technique reported by Onianwa, [14] and Smejkalova et al. [15] were adopted. Four top soil samples from 0–15 cm was randomly collected by scooping surface soil of the sampling areas (east, west, north and south) using a stainless steel hand trowel, also four soil samples were randomly collected each from

three different farmlands within the vicinity of both sites A and B. The soil samples were stored in a nitric acid pre-treated and dry polypropylene bags and were well labeled, taken to the laboratory and stored under ambient condition prior to analysis.

## 2.4 Sampling for Control Experiment

Table 1 represents the sample codes and their description. Soil outside mineral depot region (1000 m) away from the mining areas was taken for control experiment. All the samples collected were stored under ambient condition [14,15].

## 2.5 Stock and Standard Solutions and Calibration Curves

Stock and Standard Solutions and Calibration Curves for each metal Cd, Cr, Pb, Mn, Ni, Fe, Zn and Cu were prepared following standard procedures earlier reported.

## 2.6 Pretreatment of Soil Sample

Method by Onianwa [14], and Smejkalova et al. [15] were adopted. Soil samples were manually sorted to remove pebbles and coarse materials, and were air-dried under ambient conditions that are inside the laboratory for seventy-two hours. The dried soil samples were passed through a 2 mm sieve to eliminate coarse particles; the soil samples were ground to fine powder in a disc mill crusher in preparation for analysis.

**Table 1. Sample codes for Galena Ores and the regional soils from farmlands**

S/No	Sample Codes	Description
1	Galena Ore	Galena ores from Torkula, Benue State
2	G-Soil	Soil samples around Galena ore depot
3	G-Soil-FLA	Galena ore contaminated Soil from Farmland, A
4	G-Soil-FLB	Galena ore contaminated Soil from Farmland, B
5	G-Soil-FLC	Galena ore contaminated Soil from Farmland, C
6	G- Ref -Soil	Control from farmland, far from galena depot

## 2.7 Physicochemical Parameters

Standard procedures documented for pH [16], Bouyoucous hydrometer method for particle size analysis [17], bulk density [18], conductivity measurement [19] and Moisture content [20] were adopted and carefully followed with slight modification in reacting mass and volume consideration.

## 2.8 Digestion of Soil Samples

According to Smejkalova et al. [15] and Anderson [21], 10 g each of the fine grained soil sample was weighed into 250 mL teflons beakers earlier treated by soaking in dilute nitric acid (0.001 M) overnight and dried in oven at 50°C. 10 mL nitric acid and 30 mL HCl analar grade reagent was added to each beaker and heated in boiling water in a water bath for two hours. The resulting digests was filtered into 50 mL volumetric flasks and made up to 50 mL mark with distilled water. Procedural blank was prepared by heating 15 mL 2 M nitric acid in 50 cm<sup>3</sup> distilled water for two hours, filtered and made up to 100 mL mark with distilled water.

## 2.9 Digestion of Galena Ore Samples

In the method reported by Greaney [22], the Ore samples was crushed to fine possible fraction, 10 g of the crushed sample was transferred into a beaker already washed by soaking in dilute nitric acid (0.001 M) overnight and dried in oven at

50°C. 10 mL of 70% nitric acid (HNO<sub>3</sub>) and 30 mL Hydrochloric acid (HCl) was added in the beaker and covered with a watch glass and heated for one hour at the temperature of 350°C. The sample was allowed to cool to room temperature and filtered through Whatman filter paper No 1 in a glass funnel into 50 mL volumetric flask. The reaction vessel was rinsed several times with distilled water to recover any residual metals into 50 mL volumetric flask and the filtrate was made up to mark with distilled water.

## 2.10 Metal Characterization Using AAS

The digested sample solutions of soil and mineral Ore in 50 mL volumetric flasks was quantified for heavy metals; Cadmium (Cd), Chromium (Cr), Manganese (Mn), Nickel (Ni), Iron (Fe), Zinc (Zn), Lead (Pb) and Copper (Cu) by use of flame atomic absorption spectrometry (FAASVarianAA240FS). This method was previously reported by Monisha et al. [23].

## 2.11 FTIR Characterization of Mineral

FT-IR measurements were recorded on FTIR model Agilent technologies Cary 630 FTIR machine). Spectrometer in the region of 400-4000 cm<sup>-3</sup> supplied with OMNIC software. The samples was prepared by grinding 2 mg of the solid sample with 50 mg of KBr. Before every analysis, the background was collected and subtracted from the spectrum of the sample. Two hundred scans at a resolution of 4cm were recorded for each sample [24].

## 2.12 SEM Characterization of Mineral

The mineral samples were microscopically characterized by the use of Scanning electron microscopy (SEM), model MVE016477830 SEM machine. The most obvious requirement is that the specimen was cut to size. The size depends on the microscope and could range from a few centimeters in a normal SEM to a few inches in a specially designed SEM; subsequent fine polish was done using diamond-abrasive paste or alumina suspension. Polished samples was then cleaned thoroughly and etched chemically or thermally to reveal surface contrast.

## 2.13 UV-visible Spectral Profile

Minimum of 1 g of the fine ground ore samples (Galena Ore, Iron Ore and Soil samples) was weighed into 100 mL beakers, and 2 mL of 11.81 conc of HCl was added this was further diluted

with 25 mL of deionised water and filtered using watman no. 1 filter paper. The blank was prepared by diluting 1 mL of 11.81 M of HCl with 25 mL of deionised water [25].

### 3.14 Estimation of Contamination Factor ( $C_n^1$ )

The level of metal contamination was assessed using the method proposed by Hakanson [26] based on integrating data for a series of eight specific heavy metals was adopted. This method is based on the calculation for each contamination factor ( $C_n^1$ ). The  $C_f$  is the ratio obtained by dividing the mean concentration of each metal in the Ores and soil around the Ore ( $C_{0-1}^i$ ) by the baseline or background value (Concentration in presumably unpolluted soil [ $C_n^1$ ]).

Contamination factor ( $C_f^1$ )

$$\frac{C_{0-1}^i}{C_n^1} = \frac{\text{Mean value of metal}}{\text{Mean value of control}}$$

$C_f^1$  is defined according to four categories as follows:  $C_f^1 < 1$  - low contamination Factor;  $1 > C_f^1 > 3$  - Moderate contamination factor;  $3 < C_f^1 < 6$  - considerable contamination factor and  $C_f^1 > 6$  very high contamination factor.

### 2.15 Data Analysis and Comparative Study

The data thus obtained was computed and subjected to statistical analysis using the student t-test.; test of significance was set at 95%

confidence level. Description statistics for each parameter was based on mean and standard deviations. The mean values were compared with results of similar studies in Nigeria and other countries including their allowable permissible limits of WHO and USEPA.

## 3. RESULTS AND DISCUSSION

### 3.1 Physical Examination of Samples

Fig. 2 is photograph showing mineral ores and soils from farmlands around their vicinities. The samples were physically examined and observed that Torkula galena appeared rocky, G-Soil has both grain and rocky appearance while G-Soil-FLA, G-Soil-FLB, G-Soil-FLC and G-Ref-Soil has sand and lumps.

### 3.2 Physicochemical Parameters

Results of the physicochemical parameters of mineral ores and there corresponding soil samples; pH, Conductivity, Bulk density, Moisture content and Particle size are presented in Tables 2 and 3.

### 3.3 pH of Galena Ore and Soil Sample

The pH of Galena ore and soil samples solutions are within 6.80 to 7.06, with the highest value in control sample. The galena ore have the mean pH value of 6.95. The majority of the soil has pH values between 3 and 4.0. Generally the pH variations are subtle and all acidic, which is indicative of high quantity of sulphides and limited neutralizing capacity to the mine dumps [27].

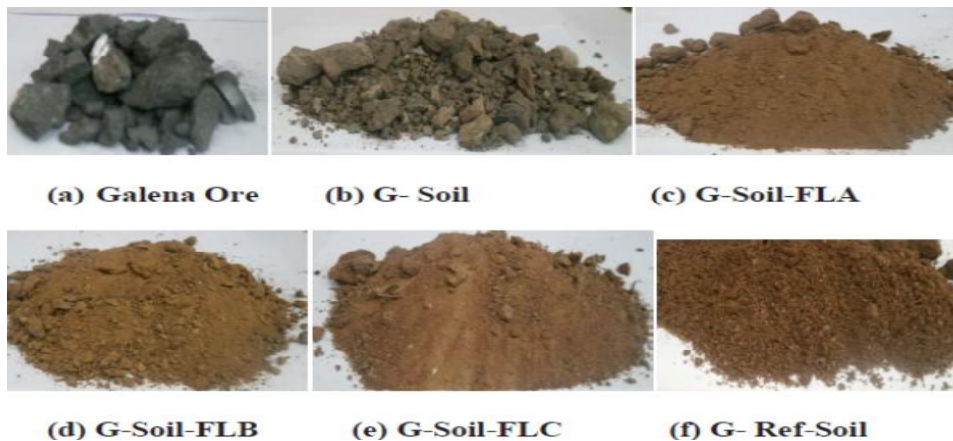


Fig. 2. Presentation of (a) Galena Ore, (b-e) Soils from different farmlands (f) Control soil sample

**Table 2. Physicochemical characteristics of Galena Ore and soil samples from Torkula**

Samples	Parameters			
	pH	Conductivity ( $\mu\text{S}/\text{cm}$ )	Bulk density ( $\text{g}/\text{cm}^3$ )	Moisture content
Galena- ore	6.95 $\pm$ 0.0001	260 $\pm$ 0.00	4.42 $\pm$ 0.0003	9.4 $\pm$ 0.00
G-Soil	7.03 $\pm$ 0.0003	352 $\pm$ 1.33	1.62 $\pm$ 0.0003	20.9 $\pm$ 0.003
G-Soil-FLA	6.93 $\pm$ 0.0003	452 $\pm$ 0.33	1.36 $\pm$ 0.0001	20.3 $\pm$ 0.01
G-Soil-FLB	6.80 $\pm$ 0.01	395 $\pm$ 1.33	1.18 $\pm$ 0.0003	26.2 $\pm$ 0.01
G-Soil-FLC	6.99 $\pm$ 0.00	449 $\pm$ 0.33	1.58 $\pm$ 0.0001	19.8 $\pm$ 0.01
Galena-Soil	7.06 $\pm$ 0.0001	310 $\pm$ 1.33	1.78 $\pm$ 0.0003	14.3 $\pm$ 0.00

**Table 3. Particle size of soil samples from Torkula Galena Ore rich region**

Samples	Parameters		
	Silt (%)	Clay (%)	Sand (%)
G-Soil	17.28 $\pm$ 0.0003	23.35 $\pm$ 0.0001	59.37 $\pm$ 0.0001
G-Soil-FLA	12.56 $\pm$ 0.0001	16.08 $\pm$ 0.0001	71.36 $\pm$ 0.0003
G-Soil-FLB	16.00 $\pm$ 0.0030	22.64 $\pm$ 0.0001	61.35 $\pm$ 0.0003
G-Soil-FLC	8.100 $\pm$ 0.0100	24.63 $\pm$ 0.0001	67.35 $\pm$ 0.0001
NG-Soil	9.570 $\pm$ 0.0001	18.07 $\pm$ 0.0001	75.36 $\pm$ 0.0003

### 3.4 Conductivity ( $\mu\text{S}/\text{cm}$ ) of Galena and Soil Sample

The result of Galena Ore and soil sample shows the conductivity ranges; 260  $\mu\text{S}/\text{cm}$  to 452  $\mu\text{S}/\text{cm}$ . The highest mean value in G-Soil-FLA while the least value is in Galena ore. Soil samples in the study area reported by Onyeobi and Imeoparia [27] ranges from 150 to 610  $\mu\text{S}/\text{cm}$ , which is in good agreement with results of present study. This could be as a result of the saline nature of the soil, due to the scattered salt springs in the area [27].

### 3.5 Bulk Density ( $\text{g}\cdot\text{cm}^{-3}$ ) of Galena Ore and Soil Sample

The bulk density of Galena ore and soil samples from Torkula ranged from 1.18 to 4.42  $\text{g}/\text{cm}^3$ . Least value was found in G-Soil-FLB. High bulk density ( $>1.5 \text{ g}/\text{cm}^3$ ) reduces water infiltration and plant root penetration resulting in increase in surface water pollution [28,29]. Bulk density of productive natural soils generally ranges from 1.1 to 1.5  $\text{g}/\text{cm}^3$ . High bulk density limits rooting depth in mine soils.

### 3.6 Moisture (%) of Galena Ore and Soil Sample

The moisture (%) content of Galena ore and soil sample from Torkula ranged from 9.4 in Galena ore and 26.2 in G-Soil-FLB. Average moisture

content of 5% was found to be sufficient for the plant growth [30].

The result of particle size had the higher value of sandy which ranged from 59.37% to 75.36% followed by clay ranging from 16.08% to 24.63% and silt ranged from 8.10 to 17.28% to 16.00% (G-Soil-FLB). David et al. [31] reported particle size of soil from five places which ranged from 5.10% to 65.8% (clay) and 13.1 to 78.4% (silt) and sand from 10.8 to 64.0%. The result from the present study is in variance with the result reported by David et al. [31]. Waste soil with low sand from ( $<40\%$ ) are not suitable for waste land filling [29,32,33] since they are rapidly permeable and could allow large quantities of leachates from the waste and finally to the ground water resources.

### 3.7 Scanning Electron Microscopy (SEM) of Galena Ore

Fig. 3 is SEM microphotograph of mineral ore carried out using Scanning Electron Microscopy to determine the surface morphology of the particles. The result obtained is Shows images with grain- like micro aggregates, that could support easy delamination and subsequent leaching of metals from ore into surrounding soils. This is unlike the galena SEM images reported by Nedjar and Barkat [24], for electrochemically altered galena with elongated species that looks like nano tubes.



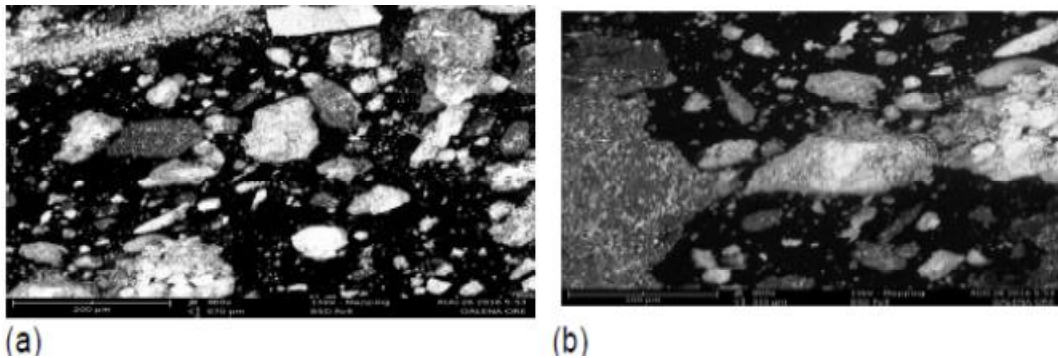


Fig. 3. SEM images of Galena recorded at (a) 400x (b) 800x magnifications

### 3.8 Fourier Transform Infra-red (FT-IR) Spectroscopic Study

Fig. 4 is the spectra of galena ore and surrounding farmland soils. FTIR Characterization was carried out to determine the molecular interaction (s) and functional groups of the mineral ores. Different intensity peak values were recorded to enable easy identification of the functional groups involved. According to results in Table 4, FTIR spectra shows characteristic bands of Galena and Galena rich soils within 2322  $\text{cm}^{-1}$ , 2187-2012  $\text{cm}^{-1}$ , 1379-1009  $\text{cm}^{-1}$ , 893-875  $\text{cm}^{-1}$ , 835  $\text{cm}^{-1}$  confirms that  $\text{HPO}_4^-$ , cyanide ion, thiocyanate ion and related ions, Si-O stretching,  $\text{CrO}_4^-$  ion and  $\text{HSO}_4^-$  ion which may be from,  $\text{NaHPO}_4 \cdot \text{H}_2\text{O}$ ,  $\text{NaCN}$ ,  $\text{ZnCrO}_4 \cdot 7\text{H}_2\text{O}$  and  $\text{BaSO}_4 \cdot \text{H}_2\text{O}$  compounds respectively, were found to be actively present. These functional groups are common to both ore and soil samples.

### 3.9 UV-Visibe Spectral Profile of Mineral Ores and Soil Samples

Table 5 represents the UV -Vis spectral information of the mineral ores and their corresponding soil samples. The result of the Uv-Visible analysis shows that galena ore and soil samples gave the  $\lambda$  max of 206 nm (ore),

324 nm and 324 nm (soils) with the following absorbance 0.672, 0.849 and 0.657 respectively, the closeness in  $\lambda$  max for the two soil samples could be an indication that the mineral ores has leached some or part of its contents into the neighboring soil at an equal compositional extent.

### 3.10 Mean Concentration in mg/kg of Heavy Metals in Soil around Galena Ore

Table 6 shows results of the mean concentration in mg/kg of heavy metals in soil around galena ore was analyzed using AAS.

#### 3.10.1 Cadmium (Cd) concentration

The Highest and least concentration of cadmium was 0.118 mg/kg and 0.021 mg/kg for galena ore and G-Soil-FLA respectively. These were lower than the permissible limits set by United States environmental protection agency USEPA and also lower than the 36.5 mg/kg reported by Eze [34]. Cd is more volatile than most heavy metals and significant amount is released to the atmosphere during the processing also through weathering of the sulphides (abandoned mine wastes). The source of Cd is anthropogenic [27].

Table 4. FT-IR analysis for Galena Ore and soil samples within Galena rich region

Vib. Freq. ( $\text{cm}^{-1}$ )	Functional groups	Observed freq. ( $\text{cm}^{-1}$ )				Assignment
		Galena Ore	G-Soil	G-Soil-FLA	Ref-Soil	
2322	$\text{HPO}_4^-$	2322	-	2322	2322	$\text{NaHPO}_4 \cdot \text{H}_2\text{O}$
2186-2012	Cyanide ion, thiocyanate	2087	-	2012	2186	$\text{NaCN}$
1379-1009	Si-O Streching	1379	-	1028	1009	$\text{SiO}_2$
893-875	$\text{CrO}_4^-$	875	893	893	893	$\text{ZnCrO}_4 \cdot 7\text{H}_2\text{O}$
835	$\text{HSO}_4^-$	835	-	-	-	$\text{BaSO}_4 \cdot \text{H}_2\text{O}$

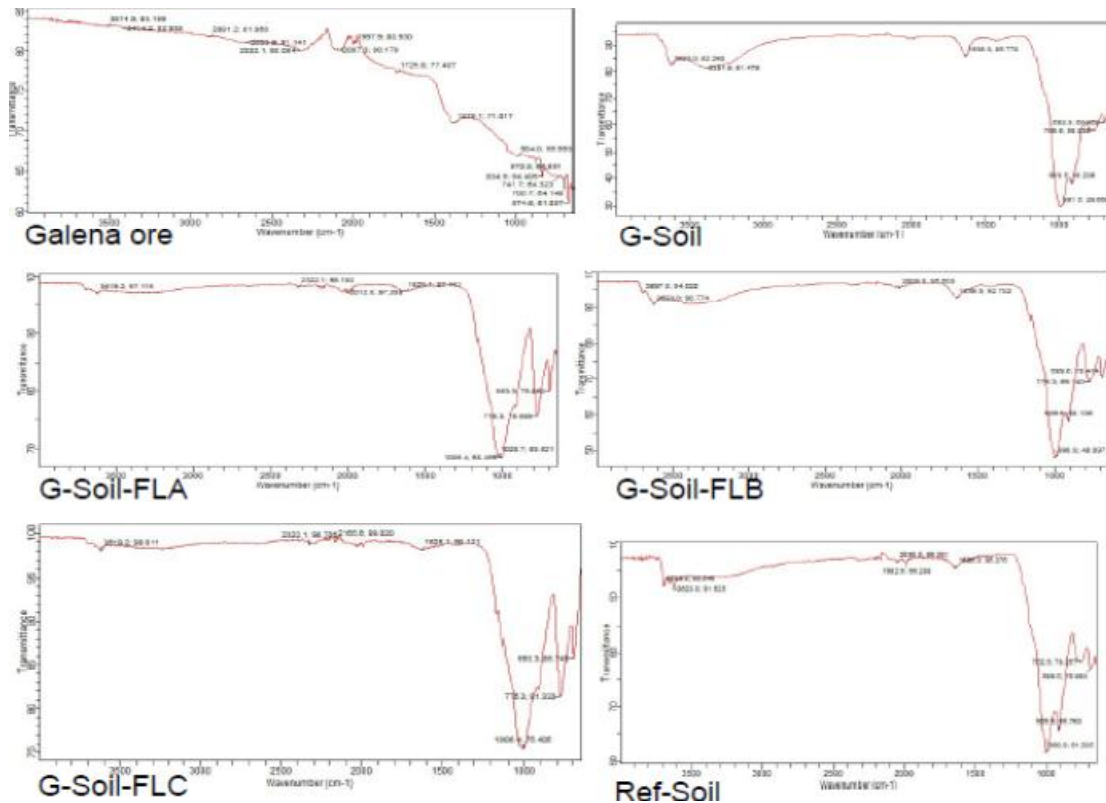


Fig. 4. FTIR Spectra of galena ore and soil samples within galena rich farmlands

Table 5. UV-Visible Spectra Information of Galena Ore and its corresponding soil samples

Samples	$\lambda$ Max(nm)	Abs.
Galena ore	206	0.672
G-Soil	324	0.849
G-Soil-FLA	324	0.657

**3.10.2 Lead (Pb) contents**

Lead mean concentration was 510.719 mg/kg and 99.353 mg/kg as shown in Table 6 this was higher than 127 mg/kg reported by Onyeobi [27], likewise the permissible limit of 420 mg/kg set by USEPA. Pb values therefore reflect the presence of mine wastes and tailings resulting from mining activities [27].

**3.10.3 Zinc (Zn) concentration**

The mean concentration of zinc was 40.465 mg/kg and the lowest was 4.819 mg/kg as shown in Table 6 this was lower than 63 mg/kg reported [27] as well as 95 mg/kg maximum permissible

limits set by WHO. Zinc is an essential macronutrient for plants but is phytotoxic in excess photoxicity may cause decrease crop yield and quality and likelihood and Zn transfer into the food chain.

**3.10.4 Manganese (Mn) concentration**

Manganese ranges from 115 mg/kg and the lowest was 4.677 mg/kg. This was lower than 248 mg/kg reported by Onyeobi [27]. The maximum permissible limits for Mn set by WHO [35] and USEPA [36] was in the range of 770-850 mg/kg. The presence of Mn could be as a result manganiferous siderite gangue in the area [27].

**3.10.5 Nickel (Ni) concentration**

The highest mean concentration of Nickel was 0.73 mg/kg and the lowest was 0.013 mg/kg. This was lower than the 15 mg/kg set for soil in United Kingdom lower than 12.05 mg/kg reported by Salah et al. [37]. Ni was also relatively immobile, limited by co-precipitation with limonite and by hydrolysis.



**Table 6. Mean concentration in mg/kg of heavy metals in soil around Galena Ore**

<b>Metals</b>	<b>G-Soil-FLA</b>	<b>G-Soil-FLB</b>	<b>G-Soil-FLC</b>	<b>G-Soil</b>	<b>G-Ref-Soil</b>	<b>Galena Ore</b>
Cd	0.021 ± 0.0007	0.070 ± 0.0003	0.029 ± 0.0001	0.050 ± 0.0003	0.025 ± 0.0001	0.118 ± 0.0003
Cr	0.631 ± 0.0010	0.359 ± 0.0009	0.990 ± 0.0007	0.829 ± 0.0011	0.899 ± 0.0013	0.341 ± 0.0003
Ni	0.013 ± 0.0033	0.000 ± 0.0036	0.216 ± 0.0045	0.739 ± 0.0023	0.113 ± 0.0031	0.032 ± 0.0012
Mn	4.677 ± 0.0005	25.66 ± 0.0006	18.55 ± 0.0014	115.8 ± 0.0011	35.88 ± 0.0013	6.511 ± 0.0003
Zn	4.819 ± 0.0004	13.10 ± 0.0007	10.62 ± 0.0007	40.47 ± 0.0013	9.747 ± 0.0010	9.839 ± 0.0005
Cu	ND	0.012 ± 0.0003	2.780 ± 0.0009	4.187 ± 0.0022	0.301 ± 0.0050	ND
Pb	99.3530±0.0004	110.198±0.0002	117.425±0.0003	510.719±0.0016	125.919±0.0005	453.445±0.0049

*ND- Not detected*

**3.10.6 Chromium (Cr) contents**

Chromium has the highest and least mean concentration to be 0.990 mg/kg and 0.341 mg/kg as reported for G-Soil-FLB and the ore respectively. This was lower than the permissible limits of 400 mg/kg set by United Kingdom. The low values of Cr recorded in the soils around the mines could also suggest very low mobility for these elements during weathering and soil formation [27].

**3.10.7 Copper (Cu) concentration**

The highest mean Cu concentration was 4.187 mg/kg. Cu availability in soils has no link with gaena ore since it was not detected in the ore itself. The highest value was far below the permissible limits of 45 mg/kg set by USEPA. Cu concentration in soils is generally from mineralization. Cu is very mobile in weathering environment. This is the reason why it can hardly be found in excess in soils. What is generally experienced is Cu deficiency in soils. Cu deficiency in soils can generally lead to serious reduction of yield in cereals. Cu deficiency in

humans may cause anaemia, poor growth, degeneration of the nervous system and bone demineralisation leading to osteoporosis and bone fractures [38].

**3.11 Pollution Assessment Based on Contamination Factor (Cf)**

Table 7 shows results of metal Cf for galena ore and soils around Galena ore rich region.

Result from galena rich region indicated that Cd was low in G-soil-FLA, considerable in galena ore and moderate in G-soil, Cr was low in all, Ni was low in galena ore, G-Soil-FLA and very high in G-Soil. Mn was low in galena ore and G-Soil-FLA but considerable in G-Soil. Zn was moderate in galena ore, low in G-Soil-FLA and considerable in G-Soil, Cu was low in both galena ore and G-Soil-FLA but very high in G-Soil. Pb was considerable in galena ore and G-Soil while low in G-Soil. The computation was however based on the control sample (not certified reference material) which itself is characterizes by high metal load.

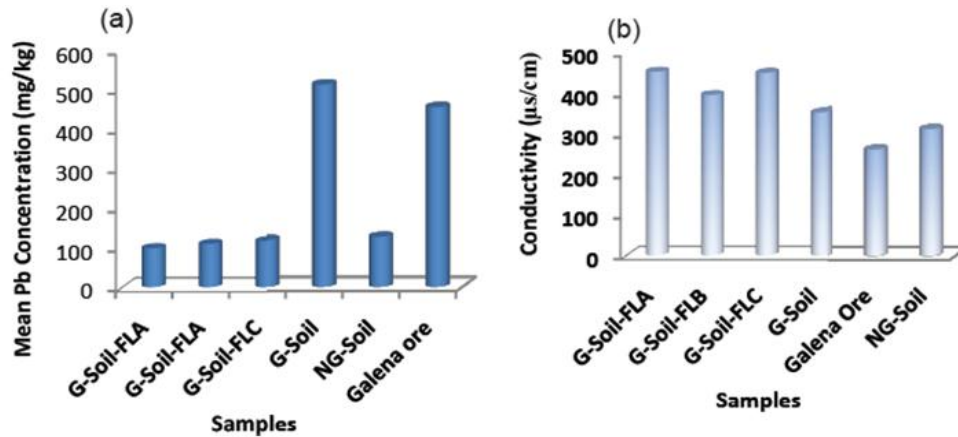


Fig. 5. (a) Mean Lead concentration and (b) Mean Conductivity of galena ore and galena rich soils from farmlands

Table 7. Heavy metal contamination factor (cf) for galena ore and soils around galena ore rich region

Metals	Contamination factor and Category					
	Galena Ore	Category	G-Soil	Category	G-Soil-FLA	Category
Cd	4.72	Considerable	2.00	Moderate	0.84	Low
Cr	0.37	Low	0.92	Low	0.70	Low
Ni	0.28	Low	6.53	Very high	0.11	Low
Mn	0.18	Low	3.22	Considerable	0.13	Low
Zn	1.00	Moderate	4.15	Considerable	0.49	Low
Cu	0.00	Nil	13.9	Very high	0.00	Nil
Pb	3.60	Considerable	4.05	Considerable	0.79	Low

**Table 8. Statistical test of significance (p < 0.05) comparing physicochemical parameters and metal contents between G-Soil and G-Soil-FLA, G-Soil-FLB, G-Soil-FLC**

Parameters	Statistics			
	Test	F	p-value	Comment
<b>physicochemical</b>	pH	4.4618	0.0676	S.d
	Conductivity	0.0003	0.9860	S.d
	Bulk density	0.1049	0.7540	S.d
	Moisture	0.0583	0.8150	S.d
<b>Particle size (Soils only)</b>	Sand	0.0456	0.8363	S.d
	Silt	0.9913	0.3500	S.d
	Clay	0.0415	0.8440	S.d
<b>Heavy metals</b>	Cd	3.523800	0.097330	Sd
	Cr	9.806281	0.013984	N.s
	Cu	0.002950	0.958014	S.d
	Ni	22.71407	0.001420	N.s
	Mn	0.115500	0.742700	S.d
	Pb	12.69649	0.007366	Ns
	Zn	0.391370	0.549010	S.d

*N.s- not significant, S.d-significantly different*

### 3.12 Comparative Study

Table 8 (above) summarises and compares results from statistical test of significance. This justifies or not whether the soils metal load is contributed by the mineral ore. There is no significant difference for Cr, Ni and Pb when compared statistically. It is an indication that the metals are evenly transported and distributed to the farmlands, while that of Cd, Cu, Mn and Zn have significant difference. The physicochemical parameters analysis of variance shows significant difference in the pH, conductivity, bulk density, moisture content and particle size. Results for lead is an indication of possible leaching, transport and distribution of lead from the ore to neighbouring farmland soils.

### 4. CONCLUSION

The mineral (Galena) ore from Torkula, Nigeria was successfully surveyed and estimated. *The Ore* with their neighboring soil samples obtained were investigated for their physicochemical parameters, (pH, Conductivity, Bulk density, Moisture content and Particle size), and analysis of Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn using Atomic Absorption Spectrometry. Physicochemical analysis of Galena rich soil indicates that the pH of Galena ore falls within the neutral boundary, an exception is the Galena Ore and G-Ref-Soil which are neutral. Conductivity of the samples was found to be relatively high and linked to the presence of soluble salts in the soil. SEM analysis of the ore

samples revealed grain like micro aggregates which could be prone to fragmentation and leaching of contents. Generally, the result obtained for lead as compared with standards was high, indicating that exposure can be dangerous to health and the nearby environment as revealed by the contamination factor.

### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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