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RESEARCH ARTICLE

POLLUTION BLOOM: AN APPRAISAL OF THE HAZARDOUS EFFECTS OF MINING OF PRECIOUS STONES IN ZAMFARA STATE

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ABSTRACT

In this appraisal, heavy metal concentrations in soils from Zamfara State were enumerated approximately a decade after the lead poisoning saga using indexes of pollution. The area is enhancement with valuable ores and minerals including gold making mining the most lucrative business in the area. The soils were moderate to slightly basic with a pH range from 6.49 ± 0.12 to 7.96 ± 0.15 (water) and 6.15 ± 0.10 to 7.80 ± 0.17 (KCl). Contamination / pollution (C/P) values reported for cadmium, lead, zinc and copper was 42.66, 0.59, 0.85 and 3.04 in the respective order (severe contamination to excessive pollution). The contamination factor (CF) was greater than the highest factor of 6, indicating very high contamination. The calculated values for geochemical accumulation (Igeo) and ecological risk factor (ERf) for Cd, Pb, Zn and Cu was (19.26, 0.27, 0.38, 1.37) and (1280, 2.95, 0.85, 15.2) respectively while the potential ecological risk index (ERi) was 1299, indicating that the soils were perturbed (polluted). Considering the deleterious effects heavy metals could cause and the resultant health implications, there is need to further remediate the polluted areas so as to avert harm to organisms and humans would consume crops grown in such environment.

KEYWORDS

Contamination factor (CF), heavy metals, mining, native soil, pollution

1. INTRODUCTION

Currently, mining activities in Zamfara State have increased over the last few decades since miners have realized the economic benefits of precious ores. However, this activity is done without regards to the deleterious effects the extraction process would impact on humans and the environment. In 2010, in the village of Dareta and Giadanbuzu in Anka Local Government Area in Zamfara State, approximately 163 persons died of lead contamination through unlawful digging for "gold" and other minerals like limestone and gypsum. Over 70% of those exposed were children with over 46% cases of fatality. Children were susceptible and frequently exposed to the dust and flakes from cracking the supposed "precious stones" (ore). Young kids and crawling toddlers are either on the floor in contact with the flakes or secured behind their mothers backs inhaling particulate matters from the cracking process since miners carry the ores to their homes to process (BBC, 2010; UNICEF/BI, 2011).

As a thriving, active and lucrative industry, miners extract ores by hand cracking into smaller pieces with the aid of hammers. This is then grind to powder (sand) in mills and the precious stone (gold) extracted from the sand using sluicing, panning and sometimes cyanidation. However, the process of cracking the precious stones releases particulates into environmental media (air, water, soil). This illegal mining have subsequently lead to arm banditry and incessant killing with indigenes resorting to harming themselves once such precious ores are found and identified. As reported in Vanguard of Monday, 8th April 2019, most residents have flee the State for safety with the Federal Government of Nigeria issuing a ban on all such illegal mining activities. Plate 1-3 depicts some of the mining activities currently ongoing in the study region.

The major routes of exposure include drinking contaminated water, inhalation of the dust particles in the air and hand to mouth ingestion of the metal residues in plant produce from farms (soil). Similarly, metal poisoning can also come from physical contact with working or mining tools. Particulates and contaminated soils were considered the principal sources of exposure in the affected communities, whose homes were made of earthen materials (mud) (Nuhu *et al*., 2014).

The soil acts as a repository for a myriad of substances and pollutants. It inhabits plants (edible and non-edible) and organisms (earthworms, snails, microorganisms etc.). Species like snails (*Archachatina marginata*) and onions (*Allium cepa L*) are consumed by humans on a daily bases who gets considerable amount of protein and anti-oxidants from them. Thus, if the soil is polluted with high amount of heavy metals, the levels reaching the organisms would be high due to bioaccumulation and since heavy metals are recalcitrant, elimination from the species would be very slow if not impossible and these substances would then be passed on to humans who are the end users and consumers of these viable species (Ogeleka *et al*., 2016).

In this stead, health related diseases would be manifested in the short (acute term) and long (chronic terms) due to these exposures. Heavy metal poisoning can result in severe brain damage, kidney malfunctioning, major organs breakdown, nervous disorders, seizure and coma. Other effects include: reproductive problems, abnormal response to the opposite sex (chemoreceptor alteration), respiratory and memory problems and even

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death on excessive exposure (Patra *et al*., 2007).

The Blacksmith Institute and some International organizations including World Health Organization (WHO), Médecins Sans Frontières (MSF) and Centers for Disease Control and Prevention (CDC), with the active support of the Zamfara State Government and Federal Government of Nigeria assessed the soils for remediation in most of the polluted sites including Bagega and environ. From the environmental appraisal by the Blacksmith Institute, they recommended that metals can be eliminated by the removal of the polluted soils and replacing the topsoils with unpolluted soils and subsequently washing/cleaning of the homes of indigenes and surroundings accumulated with the extracted dust particles. The report confirmed that approximately 282 interiors areas, 107 exterior areas and 23 ponds used for processing were remediated in five (5) communities in the affected areas. Similarly, a large non-engineered landfill in Bagega constructed and prepared for the disposal of wastes from the contaminated soils was also evaluated. Previously, lead levels in the soils in all the villages assessed were above 100000 mg/kg, an alarming amount that have never been recorded in history. The recommended Department of Petroleum Resources (DPR) target and intervention standard for lead is 85 and 530 mg/kg respectively (DPR, 2002). Internationally the standard for lead in residential areas is targeted at 400 mg/kg (Ata *et al*., 2009; Blacksmith Institute, 2014). Initial assessments in the study region, took into consideration human blood samples, soil, water samples and ecotoxicological risk assessment for the evaluation of lead and heavy metal poisoning with remediation conducted by the Blacksmith Institute and other International organizations.

In this research, the heavy metal concentrations in soils from mining sites in Zamfara State were appraised approximately a decade after the lead poisoning saga using indexes of pollution.

Figure 1: Death in the Goldmines (Source: vangaurdngr.com)

Figure 2: Processing of the precious ores (Source: earthmagazine.org; globalhomesmagazine.com)

Figure 3: Children engaged in the processing of gold (Source: hrw.org)

2. Material and Methods

2.1 Study area

The study area was made up of five towns in Zamfara State (Figure 1) while the coordinates of the sampling locations are detailed in Table 1. The sampling locations in these towns were selected based on their closeness along the same pathway where major artisanal gold mining and granite drilling/blasting activities take place. The area is tropical with dry and wet seasons, the rainfall period starts from late April and terminates in October while the dry season starts in November and ends in middle of April. The harmattan season is a brief period spanning barely three months - December to February every year. The mean annual temperature is 38.8 ± 2.2^{o}C with mean annual rainfall of 899 ± 16 mm. However, intense rain usually occurs between the months of August and September. Major activities in the area include mining, farming, trading and agricultural practices amongst others.

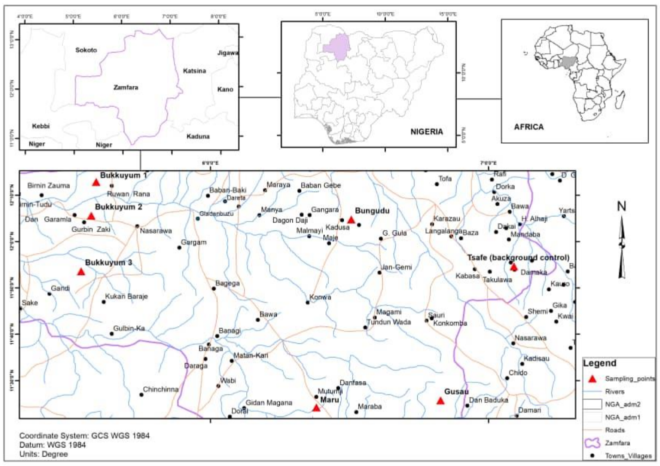

Figure 4: Map of Zamfara State depicting the study area

Table 1: Geographical coordinates for the sampling stations

Sampling Location	Latitude	Longitude
Bukkuyum 1	N 12°12'50.4"	E 5°35'20.4"
Bukkuyum 2	N 12°5'34.8"	E 5°34'15.6"
Bukkuyum 3	N 11°53'34.8"	E 5°32'6"
Gusau	N 11°25'44.4"	E 6°49'37.2"
Bungudu	N 12°4'44.4"N	E 6°30'21.6"
Maru	N 11°24'14.4"	E 6°22'51.6"
Tsafe (background – control)	N 11°54'39.6"	E 7°5'27.6"

The area is enhanced with valuable ores and minerals making it the State with the highest number of ores and minerals. Geologically, the State is characterized by very old igneous and metamorphic rocks, formed during the Precambrian Paleo; State era. Two rock types are found: granites and metasediments. The granites (including undifferentiated granites, gneisses and migmatites are likely resistant to erosion, but when weathered, they result into poor soils. The metasediments, mineral on the other hand, consist of phyllites, quartzites and metaconglomerates.

Although the metasediments are also resistant to erosion, when weathered, they give rise to more fertile soils and account for the fact that the schists are rich in magnesium minerals. In general, the relief of the State bears relationship to its geology. The State's land surface is made up of mainly the high plains. Here can be found a dissected plateau crystalline rocks composed of a series or range hills around Maru, as well as the characteristic and large, steep-sided smooth-dome shaped hills called the inselbergs, exemplified by the Kotorkoshi Hill. It is surrounding the inselbergs and are plains which are used for farming. The general elevation of the land ranges from 244 m to 366 m above sea-level (Physical Setting of Zamfara, 2003).

Two major soil types, ferruginous tropical soils and lithosols dominate Zarnfara State. The ferruginous tropical soils can be found in the northern and central parts of the State, particularly around Gummi, Bukkuyum, Anka and Bakura. Other areas in which such soil occur include Talata Mafara, Zurmi, Birnin Magaji, Shinkafi and Kaura Namoda. The soils are characterized by a sandy surface horizon, with a clayey subsoil, both of which are fertile for agricultural production. They are susceptible to erosion, since the top soil is easily washed off by rainwater, especially if the vegetation cover is removed. On the other hand, lithosols usually associated with ferruginous soils, can be found towards the eastern part of the State, particularly in such areas as Tsafe, Gusau, Maru and Bungudu. The soil is not only of low agricultural productivity but are also susceptible to erosion (Physical Setting of Zamfara, 2003).

2.2 Sample collection

Twelve samples each were collected from seven sampling locations in different Local Government Areas in Zamfara State (Bukkuyum 1, 2, 3, Gusau, Bungudu, Maru and Tsafe) making a total of eight four (84) random samples. The soil was sampled from the topsoil (0 – 15 cm) and bottom soil (15 – 30 cm) and each separately pooled together to make a composite sample. Shortly after collection, dead weed, leaves, stems, sticks, stones and other objects were carefully removed. The soils were air dried, gently crushed and sieved through a 2-mm mesh size sieve and used for analysis of the different parameters for this evaluation.

2.3 Methods for determining pH and metals

pH and heavy metals in the soils were determined using the standard protocol of International Institute of Tropical Agriculture (IITA, 1984).

2.3.1 Soil pH determination

Soil pH was analyzed both in water and KCl using a ratio of soil to water and 1*M* KCl (1:2.5 m/v). The suspension was prepared with occasional stirring using a glass rod and left to stand overnight (Abollino *et al*., 2002). After calibration of the pH meter using buffer 4 and 7, the electrode was dipped into the partly settled soil and the pH measured.

2.3.2. Wet digestion and quantitative determination of heavy metals

For the quantitative determination of metals, two (2) g of the contaminated soils and controls was weighed into a 250 mL container and one (1) mL of conc. perchloric acid, one (1) mL of conc. hydrofluoric acid and three (3) mL of conc. nitric acid was added in a fume cupboard (hood). The mixture was heated strongly until a dense white fume appeared indicating complete digestion. The digest was cooled and the mixture filtered into 100 mL volumetric flask and make up to the mark with double distilled water. The heavy metal levels (cadmium, lead, zinc, copper and iron) in the soil extract was quantitative analyzed using a flame atomic absorption spectrophotometer (Schimadzu AAS model-AA AAS-7000) equipped with the specific hollow cathode lamp. A linear calibration graph having a coefficient (R^2) value of 0.998 ± 0.004 was plotted with a concentration range of 0.2500 mg/L to 2.0000 mg/L.

2.4 Evaluation of the heavy metal status in soil samples

The contamination level of the soils was assessed with the following: contamination/pollution index (C/P), concentration factor (CF), degree of contamination (DC), pollution load index (PLI), geochemical accumulation index (Igeo), ecological Risk factor (ERf) and potential ecological risk index (ERi).

2.4.1 Contamination / Pollution index

The contamination/pollution index C/P was enumerated according to methods adopted from Lacatusu, (2000), Boamponsem *et al*., (2010) and Ogeleka *et al*., (2018). In this study, the target limits stipulated by the Department of Petroleum Resources (DPR) were used for the evaluation (DPR, 2002).

The contamination /pollution index was calculated using the equation:

$$C/_P = \frac{Concentration\ determioned\ in\ the\ medium}{Target\ concentrations\ from\ Reference\ Tables} \quad (1)$$

Table 2 depicts the significance for contamination/pollution index C/P.

Table 2: Significance values for contamination/ pollution index (C/P)

C/PI	Significance
<0.1	Very slight contamination
0.10-0.25	Slight contamination
0.26-0.5	Moderate contamination
0.51-0.75	Severe contamination
0.76-1.00	Very severe contamination
1.1-2.0	Slight pollution
2.1-4.0	Moderate pollution
4.1-8.0	severe pollution
8.1-16.0	Very severe pollution
>16.0	Excessive pollution

Adapted from Lactusu, (2000)

Similarly, the indices were computed with the reference concentrations indicated in Table 3.

Table 3: DPR target and intervention concentrations for soil

Metals	Target values (mg/kg)	Intervention values (mg/kg)
Cadmium	0.8	12
Lead	85	530
Zinc	140	720
Copper	36	190
Iron	N/A	N/A

Source: DPR, (2002)

2.4.2 Contamination factor (CF)

The contamination factor was computed according to equations adopted from Boamponsem *et al*., (2010), Harikumar *et al*., (2009) and Bonnail *et al*., (2016).

$$CF = \frac{M_{contam}}{M_{background}} \quad (2)$$

Where M_{contam} is the metal concentration in the contaminated medium and $M_{background}$ is the concentration of the background metal (reference). The CF classifications are defined in Table 4.

Table 4: Classification of contamination factor

Contamination factor	Classification
CF < 1	Low
1 ≤ CF < 3	Moderate
3 ≤ CF < 6	Considerable
CF ≥ 6	Very high

Source: (Adamu and Nganje, 2010; Okieimen, (2014)

2.4.3 Degree of contamination index (DC)

The degree of contamination (DC) was calculated using the equation given by Adamu and Nganje, 2010, Okieimen, (2014) and Ogeleka *et al*., (2018).

$$DC = \sum CF \quad (3)$$

Table 5 showed the classification of the degree of contamination (DC) of an area.

Table 5: Classification of degree of contamination

Degree of Contamination	Classification
DC < 8	Low
8 ≤ DC < 16	Moderate
16 ≤ DC < 32	Considerable
DC ≥ 32	Very high

Source: (Adamu and Nganje, 2010; Okieimen, 2014)

2.4.4 Pollution load index

The pollution load index (PLI) was computed with the formula given by Yang *et al*., (2009):

$$PLI = \sqrt[n]{\pi CF} \quad (4)$$

Where PLI is the pollution load index, CF is the contamination factor, and n is the number of metals (contaminants). Table 6 showed the classification for PLI.

Table 6: Classification of pollution load index (PLI)

Degree of Contamination	Classification
PLI = 0	Perfect situation (no pollution)
PLI = 1	Baseline levels
PLI > 1	Perturbation or pollution of the medium

Source: (Adamu and Nganje, 2010; Okieimen, 2014)

2.4.5 Geochemical accumulation Index

This index was proposed by Barbieri, (2016) to estimate metal pollution in environmental matrices. It can be quantified using the equation:

$$I_{geo} = Log_2\left(\frac{C_n}{1.5B_n}\right) \quad (5)$$

Where C_n is the enumerated or measured content of the metal (n) and B_n is the geochemical reference (background) value of the metal n. A factor of 1.5 is built in as a correction factor to reduce the effect of likely difference in the background or control values which may be due to lithogenic contributions in the soil. The background concentration or reference value used was the DPR target value (that is the maximum allowable concentration of metals in Nigeria soils (Cd = 0.8 mg/kg, Pb = 85 mg/kg, Zn = 140 mg/kg and Cu = 36 mg/kg) (Table 3 and 9) (DPR, 2002). The classification based on geochemical accumulation is displayed on Table 7 (Huu *et al*., 2010).

2.4.6 Assessment of Ecological Risk

Ecological risk evaluation of metals in soils was appraised using the Ecological Risk factor (ERf) and Potential Ecological Risk Index (ERi) by Adamu and Nganje, (2010). It was used to assess the likely impact introduced by anthropogenic perturbations on natural environment components and living entities (Jiang *et al*., 2014). The ERfis expressed in the relationship below:

$$ERf = TRf \left\{\frac{C_n}{B_n}\right\} \quad (6)$$

Where ERf is ecological risk factor for the metal and TRf is toxic response factor of a certain metal. The toxic response values for each metal is provided in Table 10 and is in the order of Zn=1 < Cu=Pb=5 < Cd=30. C_n is the metal content in the soil and Bn is a background values (reference value of metals in soil). Similarly, for the likely ecological risk index of metals, it was estimated using the relationship provided by Adamu and Nganje, (2010).

$$ERi = \sum ERf \quad (7)$$

Where ERi is potential ecological risk calculated as the sum of ecological risk factor for heavy metals in soil. ERi is single ecological risk factor for the metal. The classification for ecological risk factor and potential ecological risk index for the heavy metals in soils are depicted on Table 7.

Table 7: Classification of Geoaccumulation Index and Ecological Risk

Class	I_{geo}		Ecological risk factor (ERf)		Potential ecological risk Index (ERi)	
1	Igeo< 0	Unpolluted	<2	Depletion to mineral Enrichment	ER_i< 40	low ecological risk
2	0 ≤ Igeo< 1	Unpolluted to moderately polluted	2–5	Moderate enrichment	40 ≤ ER_i> 100	moderate ecological risk
3	1 ≤ Igeo< 2	Moderately polluted	5–20	Significant enrichment	100 ≤ ER_i> 300	considerable ecological risk
4	2 ≤ Igeo< 3	Moderately to strongly polluted	20–40	Very high enrichment	300 ≤ ER_i> 600	High potential ecological risk
5	3 ≤ Igeo< 4	Strongly polluted	>40	Extremely high enrichment	ER_i> 600.	very high ecological risk
6	4 ≤ Igeo< 5	Strongly to very strongly polluted				
7	Igeo> 5	Very strongly polluted				

Source: Huu *et al*., 2010; Hu *et al*., 2017

2.5 Statistical analysis

In order to ascertain the statistical significant, the Student's t at a confidence level of 95 % was used to compare the difference between the metal concentrations in the contaminated soils and the controls. Graphs were also used to represent the various measurements.

3. Results

The results for heavy metals from the contaminated sites and control are depicted in Tables 8 - 11 and Figure 2 and 3.

3.1 pH levels in the soils

The soils were moderately acidic to slightly basic in all locations sampled. pH values measured varied from 6.49 ± 0.12 to 7.96 ± 0.15 (water) and 6.15 ± 0.10 to 7.80 ± 0.17 (KCl) (Figure 2).

The acidity of the soil suspension was measured as pH (water), while the acidity in the soil solution in addition to the acidity reserved in the colloids was determined as pH (KCl). pH (KCl) is usually more acidic than pH (water), however, at pH 7.0 both are neutral. The pH level of a soil determines the amount of metals that would be leached from the soil and the amount residual in the soil. Most plants tolerates slightly acidic to neutral pH range while harmful effects could set in once the pH level drops to the acidic range, although some variety or species of plants still thrive in such conditions (Kacholi and Minati, (2018). The pH values in a typical soil are displayed in Table 8. Soils, which are too acid can be improved by the addition of lime compounds since the liming helps to control the acidity by enhancing the pH. It should be noted that the goals of enhancing soils with lime compounds is to obtain neutrality in the soil colloid, inactivate the Al and subsequently remove hydrogen as water (Pagani and Mallarino, 2014).

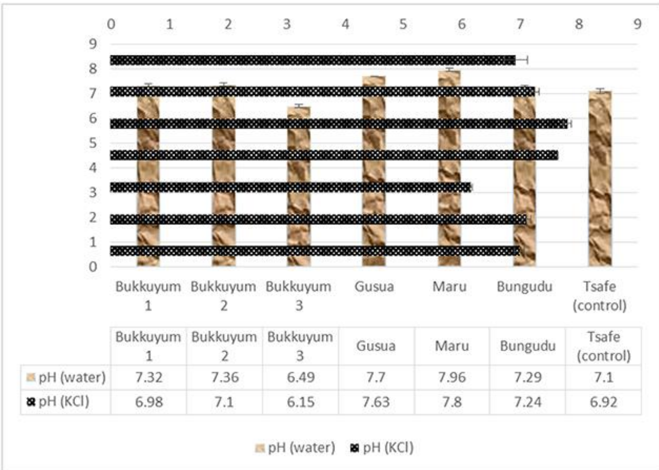

Figure 5: Mean ± SE of soil pH in water and KCl in the study area

Table 8: pH range for standard soils

<5.0	5.5	6.0	6.5-7.5	7.5-8.5	>8.5
Strongly acid	Moderately acid	Slightly acid	Neutral	Moderately alkaline	Strongly alkaline

3.2 Heavy metal concentration in soils

The results of heavy metal levels (Cd, Pb, Zn, Cu and Fe) in the soils from the polluted sites and background were benchmarked against the National regulatory target and intervention limits of the Department of Petroleum Resources, (DPR) (DPR, 2002).

In Table 9, the results presented revealed that most of the metals analyzed (Cd, Pb, Zn and Cu) exceeded the maximum DPR intervention limits of 12, 530, 720 and 190 mg/kg respectively. The intervention value is the maximum allowable concentration above which detrimental effects would manifest on organisms in the environment and health impacts on humans would set in. Cadmium levels ranged from 0.320 ± 0.06 mg/kg (Bukkuyum 1) to 112.587 ± 10.1 mg/kg (Maru) as against the Target and Intervention standards of 0.8 mg/kg and 12 mg/kg respectively (Table 9).

The concentrations of Pb observed in some of the soil samples were above the DPR Intervention value of 85 mg/kg and 530 mg/kg recording values in the range of 1.375 ± 0.078 mg/kg to 118.375 ± 11.9 mg/kg. Zinc concentrations detected in the soil sample of Maru (377.050 ± 21 mg/kg) and Bungudu (298.050 ± 17 mg/kg) zone of migration for intense ore-mining and processing site) had its values above both the Target (140 mg/kg) and Intervention (720 mg/kg) limits. Non-conformance with the regulatory standards was also recorded in similar sites for copper. Although Iron had relatively high concentrations in most of the soils in all areas, there were no available regulatory limit to compare the results with. The concentrations of the heavy metals analyzed from the contaminated locations varied significantly from the background at a probability level of 5%.

Table 9: Mean concentration of heavy metals in soil

Parameters, mg/kg	DPR target value	DPR Intervention value	Bukkuyum 1	Bukkuyum 2	Bukkuyum 3	Maru	Bungudu	Gusua	Tsafe (background (control)
Cadmium	0.8	12	0.320 ± 0.06	0.188 ± 0.024	0.75 ± 0.010	112.587 ± 10.1	89.545 ± 8.2	1.375 ± 0.061	0.11 ± 0.03
Lead	85	530	34.560 ± 3.2	1.375 ± 0.078	45.890 ± 4.6	118.375 ± 11.9	98.641 ± 6.9	1.884 ± 0.09	0.180 ± 0.02
Zinc	140	720	3.800 ± 0.19	1.525 ± 0.10	7.050 ± 0.92	377.050 ± 21	298.050 ± 17	29.700 ± 2.1	0.872 ± 0.038
Copper	36	190	3.725 ± 0.17	2.272 ± 0.12	6.975 ± 0.87	355.125 ± 24	258.782 ± 20	30.650 ± 2.1	0.640 ± 0.08

SD: standard deviation; N/A – Not available

3.3 Heavy metal contamination status in soils

Remediation of the soil was done by the Blacksmith Institute and other International bodies shortly after the dead of over 163 persons including children and the data still had high concentrations of metals in the soil matrix. Although, the current level of soil contamination was well below the assessment done approximately a decade ago by National and other International organizations, the results of this assessment showed that the polluted areas were still polluted with significant concentrations of heavy metals.

In appraising the contamination / pollution (C/P) level, a range of values between less than unity to greater than unity was reported for C/P, indicating very slight contamination to moderate contamination of the soils (Table 10). Severe contamination and excessive pollution index of 0.59 and 42.66 respectively was reported for lead and cadmium, while zinc was very severely contaminated with a C/P index of 0.85. Copper was moderately polluted with a C/P index value of 3.04 (Lacatusu, 2000).

The ontamination factor (CF) for the soils was greater than the highest factor of 6 for all metals, showing high contamination (Table 10). Using the rating depicted in Table 5, the degree of contamination was higher than the maximum index of 32, a value of 897.02 was obtained, indicating a high degree of contamination.

Similarly using the pollution load index in apprasing the state of pollution in the sampled areas, a value of 5.47 obtained for a n-root (4) revealed that the soils had intense perturbation (Table 10). Iron (Fe) had very high concentration levels, althogh Fe is regarded as being relatively abundant in nature, there was no standard value stipulated by Department of Petroleum Resources, hence, Fe could not be rated for the C/P pollution status (DPR, 2002).

The calculated values for geochemical accumulation (Igeo) and ecological risk factor (ERf) for Cd, Pb, Zn and Cu was (19.26, 0.27, 0.38, 1.37) and (1280, 2.95, 0.85, 15.2) respectively while the potential ecological risk index (ERi) was 1299, these values indicate that the soils were still perturbed (polluted). Geochemical accumulation (Igeo) varied from unpolluted to very strongly polluted, ERf had values from slightly enriched to extremely enriched with contaminants while ERi had index greater than 600 indicating very high ecological risk, signifying that the environment was still contaminated with heavy metals. The total metal load was calculated and appraised using Cd, Pb, Zn and Cu.

Table 10: Contamination status of heavy metals

Parameters	DPR target value	TRf	Pseudo-total metals levels (mg/kg)	Background levels	CF	C/P	DC = $\sum CF$	PLI = $\sqrt[n]{\pi CF}$	Igeo	ERf	ERi
Cd	0.8	30	34.128	0.11 ± 0.003	310.27	42.66			19.26	1280	
Pb	85	5	50.121 ± 4.1	0.180 ± 0.02	278.45	0.59	897.02	5.47	0.27	2.95	1299
Zn	140	1	119. 529 ± 23	0.872 ± 0.038	137.07	0.85			0.38	0.85	
Cu	36	5	109.588 ± 19	0.640 ± 0.08	171.23	3.04			1.37	15.2	

3.4 Spatial variation of total metals in soils

The results for total metals presented in Table 11 showed that there was spatial variation between the various contaminated locations for the total metal load, largely credited to the degree of mining activities in the areas. Maru and Bungudu had the highest concentration impact factor of 534.48 and 413.44 respectively (Table 11). There was also significant variation between the background and contaminated soils at a probability level of 5%, an indication that the control sites was not contaminated by anthropogenic mining and could be adjudged free of heavy metal pollution.

Table 11: Spatial variation of total metals in soils

Parameter	Background level (Control)	Bukkuyum 1	Bukkuyum 2	Bukkuyum 3	Maru	Bungudu	Gusau
Total metal (Cd+Pb+Zn+Cu)	1.802 ± 0.2	42.41 ± 5.2	5.36 ± 0.6	60.67 ± 2.1	963.137 ± 59	745.018 ± 34	63.609 ± 3.5
CF	1	23.53	2.97	33.67	534.48	413.44	35.30

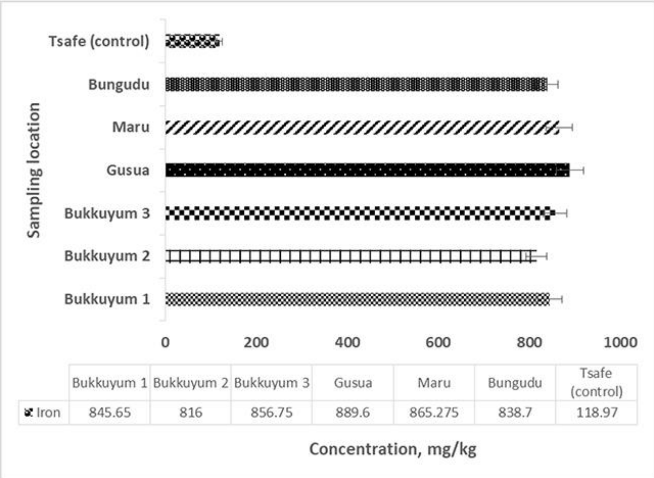

Figure 6: Iron levels in contaminated soils in comparison with the background

4. Discussion

Exposure of heavy metals have been in existence since man started attributing significant to the enhanced quality of different forms of metals – ornaments, alloys and the likes. Pure metals are replaced by electroplated metals, alloys and other types of metals to improve their quality in manufactured products. One precious metal in history is gold and due to its increasing daily value, the quest to own and increase wealth is the dream of both the rich and the poor. However, the poor and vulnerable are the ones to dig and mine areas suspected to contain such valuable precious stones. Couple with the poor living environment and condition, children are susceptible to such environment. Exposure to the dust, fume and skin contact of relatively large level of heavy metals in the environment could result in a myriad of health related issues (bone marrow malfunction, brain damage, cancer, anemia and blood related conditions etc.) (Dike *et al*., 2004; Patra *et al*., 2007; Musa *et al*., 2008).

The results of assessment approximately a decade after the saga showed that heavy metals are still present in relative large amount and have not been degraded appreciably. These concentrations are not likely to degrade in a hurry or be eliminated from the environment. Hassan *et al*., (2015), evaluated the levels of lead in drinking water of area in close proximity being affected by lead poisoning and found that the contamination factor of lead in waters around the affected region was greater than 6. A contamination factor of 6 and greater is considered very high and is an indication of severe pollution of the environmental media in question. Similarly, Boamponsem *et al*., (2010), recorded high concentrations of ten metals in water and sediment from streams within the vicinity of gold mining sites. The pollution index and other pollution factors used in their assessment were relatively higher than specified standards.

Ogeleka *et al*., (2016), considered the ecotoxicological evaluation of cadmium and lead exposure to soil dwelling receptors - snails (*Archachatina marginata*) and found the lethal concentration LC_{50} (concentration that would cause 50% of effects to organisms on exposure) of cadmium and lead after a 14-day exposure duration to be 2.052 and 2.734 mg/kg respectively. These metals were classified as extremely toxic in their assessment, although with a safe limit of 0.205 and 0.273 mg/kg in the above order. The Department of Petroleum Resources (DPR) recommended target and intervention limits for cadmium and lead in soils to be (0.8 and 12 mg/kg) and (85 mg/kg and 530 mg/kg) respectively. Concentrations obtained in the assessment indicated that these and other metals in the soils from the assessed areas were still polluted almost close to a decade of initial occurrence of poisoning in the area. Previously, soils in some of the affected areas in Zamfara State, Nigeria have lead concentrations above 100000 ppm. A level that is too high for the survival of most soil dwelling organisms and plants except very tolerant species (Ogeleka *et al*., 2016; Iwegbue, 2013). Not many would have forgotten the Zamfara mining saga, especially those that were worse hit in terming of losing their loved ones in the process. The impact of heavy metal poisoning can never be over emphasized since incidents over decades have revealed remarkable impacts and effects associated with the ingestion, contact and exposure to heavy metals in the environment. It has been known that poverty in the region have lead thousands of people to disregard the consequences these hazardous substances can cause in the quest for wealth thinking all that glitters is gold (Nuhu *et al*., 2014).

5. Conclusion

The deleterious consequences of environmental pollution of soils occasioned by gold mining in Zamfara State were investigated in this study approximately a decade of the lead poisoning saga that took the lives of over 163 persons. The results from this appraisal revealed that the soils in the mining areas were still contaminated when compared to those from the non-artisanal gold mining area. We conclude that there is the need to further remediate the contaminated soils within the artisanal gold mining region of the study area with periodic monitoring and evaluation so as to safe guard human lives from the harmful consequences of heavy metal effluence since they consume crops and animals from such environment.

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