Research Article

Ecological risk assessment of heavy metal-contaminated soils of selected villages in Zamfara State, Nigeria

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Abstract

The incidence of heavy metal contamination in Zamfara State, northern Nigeria, due to artisanal mining in some villages has resulted in the pollution of a vast area of land and water. This study evaluated the extent of environmental risks caused by heavy metals. It involved five (5) villages (Bagega, Dareta, Sunke, Tunga, and Abare) where mining activities were taking place and Anka town with no record of mining activities served as control. In each of the five villages, three sites (3) were identified as a mining site, processing site, and village making a total of sixteen (16) sites. Bulked soil samples were collected in triplicate and analyzed for iron, lead, cadmium, chromium, zinc, and nickel using flame atomic absorption spectrophotometry. Measured concentrations of the heavy metals in soils were then used to calculate the pollution and ecological risk pose by heavy metals. Their concentrations were in the order Fe > Pb > Cr > Zn > Cd > Ni, with Pb and Cd having a concentration higher than permissible levels for soils and accounted for 98.64% of the total potential ecological risk. Also, all the different pollution indices examined showed that all the sites were polluted with Cd, and all the processing sites were polluted with Pb. This reveals that processing sites pose more risk to heavy metal contamination. Correlation analysis showed a highly significant ($p < 0.001$) positive correlation between Pb and Zn, Cr and Ni, and a significant ($p < 0.01$) positive correlation between Fe and Pb, Zn and Cr. The principal component analysis suggested that Pb, Zn, Cr, and Ni likely originated from the same source, i.e., mining activities, and Fe and Cd originated from the abundant parent material in the study area.

Keywords Contaminated soils · Ecological risk assessment · Heavy metals · Zamfara State · Nigeria

1 Introduction

Heavy metal persistence and toxicity present a devastating environmental problem in our world today. The heavy metals are accumulated in our environment as a result of natural and anthropogenic activities from illegal mining and intense mineral exploration in mining areas. This results in the production of a large amount of waste material, leading to the release of toxic elements to the environment [44] particularly heavy metals [4]. This illegal and intense mineral exploration produces substantial waste material accumulating on tailings and heaps [38], and without proper management, the minerals on the heaps and tailing serve as the source of contaminants, which are often washed out by water and can eventually pollute the environment [34, 35]. Besides, the degree and extent of heavy metal contamination are determined by the geochemical characteristics of both the ore and the bedrock [29].

Soils are a rich ecosystem, consisting of both living and non-living matter with varying levels of interaction between them. It is also a critical component due to its

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ability to accumulate pollutants produced by natural and anthropogenic activities such as from agriculture, industry, mining and vehicular movement. Different processes interact together to aid the movements of heavy metals in soil, and this includes processes of biological, chemical, and physical nature [57]. These polluted soils serve as the source of dispersal of heavy metals in the environment and may enter the food chain and food web [25]. The biggest problems of the heavy metals are persistent and non-degradable, their presence in soil is stable and long-term [36], and these pose risks to public health and the environment [61].

Incidence of heavy metal contamination in Zamfara State, Nigeria, in 2010 [32] captured a lot of attention, and many kinds of research have been carried out to assess the levels of the heavy metals in the affected areas [4, 40, 44, 47, 48]. However, to the best of our knowledge, little or no study has been carried out or reported on the ecological risk of these contaminated areas. Long-term, low-level exposure to common pollutants like heavy metals is detrimental to health [11]; therefore, there is the need to assess the levels of this pollutant not only in contaminated soils but also in the soils of our environments, to provide information on the level of risks for proper management. This research was therefore design to determine the status and assess the ecological risk posed by heavy metal pollution in arable lands in the selected villages of Zamfara State, Nigeria.

2 Materials and methods

2.1 Study area, soil samples collection and preparation

The soil samples for the study were collected from six (6) locations, i.e., Abare, Sunke, Tungar Kudaku (Tunga), Bagega, Dareta, and Anka town (Fig. 1, Table 1), all from Anka Local Government of Zamfara State, Nigeria. According to Jurgen et al. [32], Abare and Sunke are confirmed heavy metal-contaminated area, Bagega is suspected, and Dareta is a remediated area. Anka with no record of heavy metal contamination served as our control.

The soil samples were sampled from six (6) different villages/locations. In each of the locations, apart from Anka town (i.e., control site), sampling was done from the processing site, mining site, and the villages, while only one sample was collected from Anka. At each sampling site, five subsamples were randomly collected at depth of 0–30 cm to make a composite sample. A total of sixteen (16) sampling sites were obtained as shown in Table 1. Each soil sample was placed inside a polythene bag. The samples were taken to the laboratory, spread, and air-dried, some portions were used for the chemical and physical analyses, while the remaining were stored at room temperature and used for heavy metal analysis.

2.2 Routine soil analysis

The soil samples were dried and sieved through a 2.0 mm sieve. Total nitrogen, organic carbon, available phosphorus, exchangeable cations, exchangeable acidity, effective cation exchange capacity, soil pH, and electrical conductivity were carried out on the 2.0 mm soil samples.

The pH and conductivity meters were used to measure the pH and electrical conductivity, respectively, in the soil suspension (1:2.5 w/v dilutions) [31]. Organic carbon was determined by Walkley and Black method [41]. The hydrometer method was used for the determination of particle size distribution [24]. Total nitrogen was determined using the Kjeldahl method [13], and available phosphorus by Bray 1 extraction method [16], exchangeable cation by extraction with 1 N NH_4OAc solution [49], exchangeable acidity by leaching the soil sample with 1 N KCl solution [7] and effective cation exchange capacity by summation method.

2.3 Determination of total heavy metal concentration

The air-dried soil sample was finely ground in stainless steel, 1 g of each sample was placed in a conical flask, and a mixture of concentrated HNO_3:$HClO_4$:HF in the ratio 3:1:3 was added [45]. The mixtures were then heated to 80^0C for 3 h. The digests were filtered into a 100-ml standard plastic bottle and made to 100 ml with deionized water.

The heavy metal concentrations in the samples were measured using flame atomic absorption spectrophotometry (Varian model-AA240FS) in the Ahmadu Bello University Multi-User Laboratory. The heavy metals determined include: iron (Fe), cadmium (Cd), lead (Pb), chromium (Cr) zinc (Zn), and nickel (Ni).

2.4 Determination of pollution indices

Pollution indices are very useful in processing, analyzing, and conveying raw environmental information to the public and decision-makers [18]. Geoaccumulation index, contamination factor, pollution load index, and enrichment factor were the indices used to measure the extent of heavy metal pollution, while the ecological risk index was used to assess the ecological risk associated with the heavy metals' pollution in the study area.

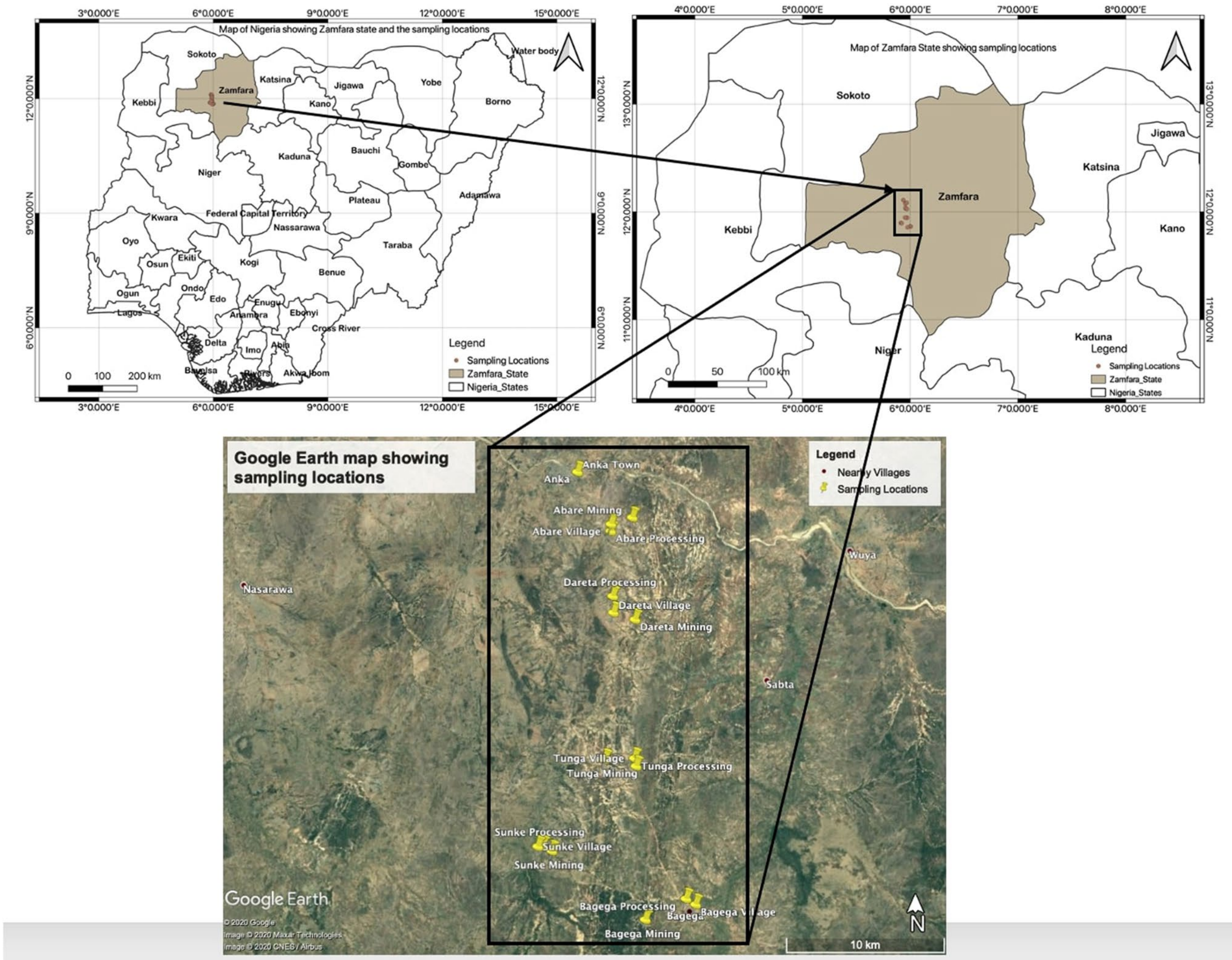

Fig. 1 Maps showing Nigeria, Zamfara State and the sampling locations

2.4.1 Enrichment factor (EF)

The enrichment factor is the index used to determine the amount of metal added to soil compared to the average occurrence of that metal in the Earth's crust [37]. It was calculated based on Eq. (1) using Fe as a reference element due to its abundance in soil [46].

$$EF = \frac{\left(\frac{Msample}{\text{Resample}}\right)}{\left(\frac{Mref}{\text{Reref}}\right)} \tag{1}$$

where EF is enrichment factor, Msample and Resample are the concentrations of the metal and the reference metal, respectively, in the contaminated soil and Mref and Reref are concentrations of the metal and the reference metal in the reference soil, respectively [2, 3, 5].

Five contamination categories are classified based on enrichment factors [55]. These include: < 2, deficient to minimal enrichment; 2 < 5, moderate enrichment; 5 < 20, significant enrichment; 20 < 40, very high enrichment; and ≥ 40, extremely high enrichment.

2.4.2 Geoaccumulation index (I_{geo})

An index of geoaccumulation was used to define and determine metal contamination in the soils. This was done, by comparing current concentrations with pre-contamination levels. It was computed using Eq. (2) [43].

$$I_{geo} = \log_2 \left[\frac{Cn}{1.5Bn}\right] \tag{2}$$

Cn stands for measured concentration of the examined metal n in the soil and Bn stands for reference value

Table 1 Coordinates and altitudes of the soil sampling sites

Sampling site	Locations	GPS coordination		Altitudes (m.a.s.l.) (m)
		Latitudes	Longitudes	
1	Bagega mining	11°51.494[1] N	5°56.299[1]E	386
2	Bagega processing	11°51.874[1] N	5°59.760[1]E	393
3	Bagega village	11°51.486[1] N	5°54.394[1]E	390
4	Dareta mining	11°59.196[1] N	5°59.507[1]E	386
5	Dareta processing	12°02.331[1] N	5°57.391[1]E	358
6	Dareta village	12°02.322[1] N	5°57.320[1]E	349
7	Sunke mining	11°53.180[1] N	5°56.656[1]E	389
8	Sunke processing	11°53.865[1] N	5°55.185[1]E	371
9	Sunke village	11°53.718[1] N	5°55.339[1]E	366
10	Tunga mining	11°57.303[1] N	5°57.419[1]E	375
11	Tunga processing	11°53.865[1] N	5°55.185[1]E	371
12	Tunga village	11°56.932[1] N	5°57.989[1]E	385
13	Abare mining	12°05.280[1] N	5°57.216[1]E	363
14	Abare processing	12°04.355[1] N	5°57.324[1]E	347
15	Abare village	12°04.696[1] N	5°57.324[1]E	349
16	Anka town	12°06.648[1] N	5°56.443[1]E	318

m. a. s. l., meter above sea level

or geochemical background concentration of the metal n (mg/kg) in the soil. Factor 1.5 was used to take into account the possible variations in background values for a given metal in the environment and the small anthropogenic influences [2, 3, 30].

Seven classes of geoaccumulation index (I_{geo}) were identified [17]; these are: ≤ 0 as Class 0 , i.e., unpolluted; 0.1–1.0 as Class 1, i.e., unpolluted to moderately polluted; 1.1–2.0 as Class 2, i.e., moderately polluted; 2.1–3.0 as Class 3, i.e., moderately to strongly polluted; 3.1–4.0 as Class 4, i.e., strongly polluted; 4.1–5.0 as Class 5, i.e., strongly to extremely polluted; and > 5 as Class 6, i.e., extremely polluted.

2.4.3 Contamination factor (CF)

The contamination factor is an index used to define the contamination or pollution range of a certain metal. It was calculated by employing the model set by [33].

$$CF = \frac{\text{Concentration of the metal in the soil}}{\text{Target (Background)Value}} \quad (3)$$

The background/target value is a reference value for the maximum allowable concentration of metals in the Nigerian soil [19]. Values less than one define the contamination range, while values greater than one define the pollution range.

Ten contamination categories are recognized based on contamination factor (CF) [33], and these are: < 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; and > 16 excessive pollution.

2.4.4 The pollution load index (PLI)

This is the geometric mean of CFs of the heavy metals under study, proposed by Tomlinson et al. [56]. It gives an estimate of the combined metal contamination status and the necessary action that should be taken. It was computed using Eq. (4).

$$PLI = (CF1 \times CF2 \times CF3 \times CF4 \ldots \ldots \times CFn)^{1/n} \quad (4)$$

where n stands for the number of metals studied and CF is the contamination factor calculated from Eq. (3).

The value of PLI was divided into four groups [58], i.e., < 1 – no pollution, 1.0 < 2—moderate pollution, 2.0 < 3—heavy pollution, and ≥ 3.0—extreme pollution.

2.4.5 Ecological risk factor (ErF)

This is an index that quantitatively expresses the potential ecological risk associated with a given single contaminant [26], calculated as:

$$\mathrm{ErF} = \mathrm{Tr}^i \times \mathrm{CF}^i \quad (5)$$

where Tr^i is toxic response factor of a metal (Pb = 5, Zn = 1, Cd = 30, Cr = 2, Ni = 5) and CF^i is the contamination factor.

Five terminologies are used to define ecological risks based on Hakanson [26]. These are < 40, low potential ecological risk; 40 < 80, moderate potential ecological risk; 80 < 160, considerable potential ecological risk; 160 < 320, high potential ecological risk; and ≥ 320, very high ecological risk.

2.4.6 Potential ecological risk index (RI)

This index is the sum of all the ecological risk factors of the metals under study, taking into account the cumulative effects of the metals under study [26]. It is calculated thus:

$$\mathrm{RI} = (\mathrm{ErF1} + \mathrm{ErF2} + \mathrm{ErF3} \ldots + \mathrm{ErF}n) \quad (6)$$

where ErF is the ecological risk factor and n is the number of elements studied. The following terminologies have been used for the potential ecological risk index [26]: < 150, low ecological risk; 150 < 300, moderate ecological risk; 300 < 600, considerable ecological risk; and ≥ 600, very high ecological risk.

2.5 Statistical analyses

Each soil sample collected was made into triplicate before analysis, and the data collected were analyzed using SAS 9.0 [53] and Microsoft Excel (version 2016), where there are significant differences, and Duncan multiple range technique (DMRT) tests were used to separate the means. Correlation analysis was employed to compare relationships between variables. Principal component (PC) analysis was done on the variables to check the possible factors that contribute toward the metal concentrations and source apportionment. The selection of the number of significant principal components was based on varimax orthogonal rotation with Kaiser normalization at eigenvalues greater than 1.

3 Results and discussion

3.1 Physical and chemical properties of the experimental soil

The physical and chemical properties of the experimental soils are shown in Table 2. According to the USDA soil classification system, the textural classes of the soils at the plowing depth were majorly sandy loam, few are loam, and only one falls under silt loam. The presence of loam in all the soils indicates that the soils of the region are suitable for agriculture, as most crops thrive best on loam textured soils [15]. The pH (H_2O) values recorded for these soils ranged from 6.2 to 7.7, 18.75% fall under slightly acidic, 68.75% under neutral, and 12.5% are slightly alkaline [42]. The values are in agreement with those reported by Raji et al. [51] in some soils of the Nigerian savanna and are within the optimum pH range for most plants' growth. Electrical conductivity ranged from 0.10 to 0.35 dSm^{-1}; these indicate that no salt/salinity problem would be encountered in the soils [28]. The cation exchange capacity recorded for the soil units ranged from 3.97 to 14.89 $cmol_{(+)}kg^{-1}$, and these according to the ratings of Hazelton and Murphy [27] ranged from low to moderate which indicates that the soils would have low to moderate nutrient retention capacity [14]. Organic carbon ranged from 0.20 to 1.22 gkg^{-1}, these can be classified as very low (≤ 2%) based on Sigarf et al. [54] ratings, and this could be due to the lower amount of organic matter because of lower vegetation. The available phosphorus ranges from 1.58 to 17.68 mg/kg and is rated low to medium according to the rating of the Federal Ministry of Agriculture and Natural Resources of Nigeria [21]. Total nitrogen content of all the soils ranged from 0.7 to 2.8 gkg^{-1} and rated very low to low according to Sigarf et al. [54]. This could be due to lower organic matter contents of the soil [12], and this indicates nitrogen deficiency in the soils, which is typical of savanna soils.

3.2 Amounts of heavy metals in the soils

The spatial distribution of heavy metals studied in the soils from all the study locations is depicted in Table 3. The average concentrations of the heavy metals varied significantly ($p < 0.001$) and decreased in the following order Fe > Pb > Cr > Zn > Cd > Ni. Iron (Fe) has the highest average concentration compared with other metals studied. These agree with many reports indicating natural soils containing a significant amount of Fe [2, 3, 6, 9, 20]. From the coefficient of variation of Fe (0.316), it suggests that less variability exists in the different sites, which reflects the homogenous spatial distribution of Fe in the area. These reveal that a high concentration of Fe in the soils cannot be conclusively attributed to mining alone, but other sources of Fe must be put into consideration. Besides, Fe has been reported to be the most abundant heavy metal in Nigerian soil [10]. The average Pb concentrations from all the processing sites of the study locations exceeded the international threshold of 300 mg/kg for Pb in arable soils [1], and they also exceeded the maximum allowable concentration of 85 mg/kg in the Nigerian soils as set by Department of Petroleum Resources of Nigeria [19]. The Pb concentration of Anka (control site) together

Table 2 Experimental soil physical and chemical parameters

Locations	pH		EC	OC	Available P	Total N	Ca	Mg	K	Na	EA	ECEC	Clay	Silt	Sand	Textural
	(H_2O)	($CaCl_2$)	(dSm^{-1})	(gkg^{-1})	(mg/kg)	(gkg^{-1})	($cmol_{(+)}\ kg^{-1}$)						(%)			Classes
Bagega mining	7.2	6.7	0.14	0.26	3.50	**2.8**	7.78	0.62	0.39	0.26	0.40	9.45	14	28	58	SL
Bagega processing	7.4	6.8	0.13	0.42	1.58	2.5	7.92	1.32	0.42	0.64	0.40	10.69	16	18	66	SL
Bagega village	**7.7**	6.7	0.12	0.66	2.98	1.4	4.71	0.65	0.34	0.00	0.60	6.30	10	42	48	L
Dareta mining	6.6	5.2	0.13	0.52	2.63	1.8	3.69	0.57	0.25	0.02	0.40	4.92	16	28	56	SL
Dareta processing	**6.2**	5.5	0.30	0.08	2.28	1.4	6.01	1.12	0.19	0.19	0.40	7.90	6	40	54	SL
Dareta village	7.1	5.8	**0.10**	0.62	2.63	1.4	7.51	1.07	0.24	0.30	0.60	9.71	10	40	50	L
Sunke mining	6.9	5.8	0.12	0.80	2.10	2.1	3.20	0.15	0.20	0.02	0.40	**3.97**	10	42	48	L
Sunke processing	6.6	6.1	**0.35**	**0.20**	2.10	2.1	5.09	0.37	0.77	0.51	0.40	7.13	10	22	68	SL
Sunke village	7.2	6.5	0.17	**1.22**	3.15	2.1	9.63	0.28	0.37	0.00	0.40	10.68	10	52	38	SiL
Tunga mining	6.5	6.0	0.14	0.30	2.45	1.4	11.70	1.53	0.24	0.00	0.60	14.07	16	24	60	SL
Tunga processing	6.4	6.3	0.31	0.22	2.10	**0.7**	9.63	1.03	0.23	0.28	0.40	11.57	10	22	68	SL
Tunga village	7.0	6.2	0.12	0.80	7.88	1.4	10.30	1.48	0.44	0.00	0.40	12.62	12	46	42	L
Abare mining	6.8	6.2	0.14	0.80	1.78	1.8	7.23	0.88	0.32	0.00	0.40	8.83	6	24	70	SL
Abare processing	7.1	6.3	0.18	0.26	4.38	1.4	7.64	0.92	0.32	0.14	0.60	9.62	8	40	52	L
Abare village	7.2	6.4	0.19	0.32	3.85	1.1	10.00	0.80	0.24	0.11	0.40	11.55	8	30	62	SL
Anka town	7.2	6.6	0.18	0.32	4.20	1.4	12.00	2.00	0.29	0.00	0.60	**14.89**	6	22	72	SL

Textural class key: SL, Sandy Loam; SiL, Silt Loam; L, Loam

Table 3 Mean concentrations of heavy metals in soils from all the study locations of Anka Local Government, Zamfara State (mg/kg)

Location	Site	Fe	Pb	Cd	Cr	Zn	Ni
Bagega	Mining	18,331.20	449.80	1.23	119.90	48.40	8.30
	Processing	31,141.90	559.60	1.40	74.70	24.10	3.00
	Village	22,205.10	0.00	1.40	48.70	3.90	0.00
Dareta	Mining	22,489.80	0.00	1.77	47.80	0.00	0.00
	Processing	29,190.30	533.50	1.63	41.50	35.20	4.50
	Village	13,177.10	0.00	1.80	32.90	0.00	0.00
Sunke	Mining	42,018.70	0.00	2.20	51.50	21.70	0.00
	Processing	20,383.90	325.50	2.10	31.60	26.90	0.00
	Village	14,507.40	0.00	1.70	15.80	1.50	0.00
Tunga	Mining	17,732.30	0.00	1.60	52.30	8.60	0.00
	Processing	20,383.90	322.50	1.90	32.20	27.80	0.00
	Village	16,735.20	0.00	1.70	24.30	11.70	0.00
Abare	Mining	10,902.20	0.00	1.40	0.00	16.70	0.00
	Processing	22,498.70	311.80	1.50	7.30	12.50	0.00
	Village	23,642.80	320.80	1.40	0.00	11.60	0.00
Anka	Village	11,576.80	0.00	1.20	0.00	0.00	0.00
SE		38.45	2.89	0.28	0.78	0.76	0.15

with most of the mining sites and the villages is low. Only the Bagega mining site has a considerable amount of Pb (449.8 mg/kg), and this may be due to some element of grinding of the metal ores taking place around the mining sites. Therefore, this is a clear indication of Pb contamination from the processing of the metal ores.

Cadmium concentrations in all the study sites are greater than the maximum allowable concentration of 0.8 mg/kg in the Nigerian soils as set by the Department of Petroleum Resources of Nigeria [19]. Only Anka (control site) with a concentration of 1.2 mg/kg has a value less than the international threshold of Cd (1.4–19.5 mg/kg) as set by different countries [1]. This shows that the soils of all the study locations apart from Anka (control site) are contaminated with Cd. This agrees with the study of Mohammed and Abdu [40] of Dareta soils, Salisu et al. [52] of Bagega soils, and Abdu and Yusuf [4] of Abare soils. Zinc and Ni concentrations in all the study sites are less than the maximum allowable concentration of 140 mg/kg and 35 mg/kg, respectively, in the Nigerian soils, as set by the Department of Petroleum Resources of Nigeria [19]. They also have concentrations less than the international threshold of Zn (200–1400 mg/kg) and Ni (50–210 mg/kg), respectively, in arable soil set by different countries [1]. Although the concentrations are less than the maximum allowable concentrations, the significant differences ($p < 0.001$) observed between the locations indicate that mining activities have a great influence on the variations, as Anka (control site) have the lowest concentrations of Zn and Ni, and statistically lower than all the mining and processing sites of the study locations. All the Cr concentrations except Anka, Abare village, and Abare mining site, exceeded the 6.4 mg/kg set as a threshold by the UK, but are less than the other international threshold values set by other countries [1]. Statistical analysis result reveals a significant difference ($p < 0.0001$) between the sites and locations, with Anka (control site) having a value less than all the international threshold and less than the maximum allowable concentration formulated by DPR, and statistically lower than all other locations. This indicates that mining activities may have a contribution to the Cr contaminations.

3.3 Correlation and principal component analysis

To elucidate the relationship that exists between the heavy metals under study, and to identify the potential sources of the heavy metals' pollution, principal component analysis and correlation analysis were carried out. Table 4 shows that 3 principal components (PCs) account for 87% of the total variation. PC1 explained 58% of the total variation and mainly included Ni, Cr, Zn, and Pb, whose variance values were, 0.917, 0.807, 0.850, and 0.798, respectively. PC2 explained 17% of the total variation and mainly included Fe and Cd with a variance value of 0.669 and 0.564, respectively. PC3 explained 13% of the total variation and mainly included Fe, with a variance value of 0.581. The correlation matrix indicates there is a significant positive correlation between Pb, Zn, Cr, and Ni; Zn with Cr and Ni; and Cr with Ni; and also between Fe, Pb, Zn, and Cr (Table 4).

The principal component analysis result was following those of the correlation analysis. These significant correlations that exist between many of the heavy metals may suggest their common origin [22, 39, 50]. Thus, Pb, Zn, Cr,

Table 4 Principal component analysis (PCA) and correlation coefficients of heavy metals in Anka soils

Metal	PCA			Metal	Pearson's correlation coefficient					
	PC1	PC2	PC3		Fe	Pb	Cd	Zn	Cr	Ni
Fe	0.453	0.669	0.581	Fe	1					
Pb	0.798	0.255	−0.294	Pb	0.368**	1				
Cd	−0.628	0.564	−0.371	Cd	0.224	−0.09	1			
Zn	0.850	0.280	−0.360	Zn	0.359**	0.757***	0.031	1		
Cr	0.807	−0.191	0.249	Cr	0.345**	0.375***	−0.02	0.582***	1	
Ni	0.917	−0.258	−0.171	Ni	0.156	0.652***	−0.21	0.771***	0.754***	1
Eigenvalue	3.450	1.013	0.783							
Variability (%)	57.504	16.875	13.048							
Cumulative (%)	57.504	74.379	87.428							

***Correlation is significant at the 0.001 level;

**Correlation is significant at the 0.01 level

and Ni likely originated from the same sources, i.e., mining activities, since it is the dominant anthropogenic activity taking place in the study area. The sources of Fe and Cd with the same principal component may likely be from the parent material of the area, as Anka (control site) has also recorded a significant amount of Cd, and for Fe, as reported earlier is the most abundant element in Nigerian soil [10].

3.4 Pollution assessment of heavy metals in the soils

3.4.1 Enrichment of heavy metals in soil

The accumulation of heavy metals in the soil of the study area was evaluated using the enrichment factor (Table 5). Lead enrichment evaluation shows that three sites (Bagega mining, Bagega processing, and Dareta processing) have extremely high enrichment, four sites (Sunke processing, Tunga processing, Abare processing, and Abare village) have very high enrichment, while the remaining nine sites including Anka (control site) have a deficient to minimal enrichment. It was observed that all the processing sites (Table 5) fell under very high enrichment to extremely high

Table 5 Enrichment factor of the heavy metals in soils from all the study locations in Anka Local Government, Zamfara State

Locations	Pb		Cd		Zn		Cr		Ni	
Bagega mining	57.91	E	10.59	S	1.31	D	3.43	M	0.31	D
Bagega processing	42.41	E	7.07	S	0.38	D	1.26	D	0.07	D
Bagega village	0.00	D	9.92	S	0.09	D	1.15	D	0.00	D
Dareta mining	0.00	D	12.36	S	0.00	D	1.11	D	0.00	D
Dareta processing	43.13	E	8.80	S	0.60	D	0.75	D	0.11	D
Dareta village	0.00	D	21.49	V	0.00	D	1.31	D	0.00	D
Sunke mining	0.00	D	8.24	M	0.26	D	0.64	D	0.00	D
Sunke processing	37.69	V	16.21	S	0.66	D	0.81	D	0.00	D
Sunke village	0.00	D	18.44	S	0.05	D	0.57	D	0.00	D
Tunga mining	0.00	D	14.20	S	0.24	D	1.55	D	0.00	D
Tunga processing	37.34	V	14.67	S	0.68	D	0.83	D	0.00	D
Tunga village	0.00	D	15.98	S	0.35	D	0.76	D	0.00	D
Abare mining	0.00	D	20.20	V	0.76	D	0.00	D	0.00	D
Abare processing	32.71	V	10.49	S	0.28	D	0.17	D	0.00	D
Abare village	32.02	V	9.32	M	0.24	D	0.00	D	0.00	D
Anka town	0.00	D	16.31	S	0.00	D	0.00	D	0.00	D

Enrichment factor categories: D, deficient to minimal enrichment; M, moderate enrichment; S, significant enrichment; V, very high enrichment; E, extremely high enrichment

enrichment of Pb. This gives a clear indication that the processing of the metal ores was the major anthropogenic activities leading to the accumulation of Pb in the study areas. This is to say by grinding the ore, the Pb compounds are exposed to the air, and hence, they can be transported through the processes of physical, chemical, and biological nature [57] to different locations to cause accumulation. It was also observed for Cd that two sites (Dareta village and Anka mining) have very high enrichment, two sites (Sunke mining and Abare village) have moderate enrichment, and all the remaining twelve sites including Anka (control site) have significant enrichment of Cd. Since Anka (control site) also has a significant enrichment of Cd, we cannot conclude generally that the accumulation of Cd is due to mining activities alone, but other sources of Cd must be taken into consideration. Mohammed and Abdu [40] confirmed that the enrichment of Cd in the area was due to anthropogenic activities in which mining is inclusive. For Zn, Cr, and Ni, all the sites have a deficiency to minimal enrichment of the three metals, except Bagega mining sites that have moderate enrichment of Cr (Table 5). This indicates that mining activities did not impact any significant accumulation of Zn, Cr, and Ni with the natural background levels in the study areas.

3.4.2 Geoaccumulation (Igeo) of heavy metals in soils

The calculated Igeo for the soils of this study ranged from -16.31 to 4.22 for Pb, 1.46 to 2.29 for Cd, − 16.31 to − 0.17 for Cr, − 2.70 to − 0.75 for Fe, − 18.71 to − 1.56 for Zn, and − 18.22 to − 3.62 for Ni (Table 6). This revealed that all the sites studied in respect to Cr, Zn, Fe, and Ni fell into class 0 (unpolluted), while Pb ranged from class 0 (unpolluted) to class 5 (strongly to extremely polluted), and Cd ranged from class 2 (moderately polluted) to class 3 (moderately to strongly polluted). Like the result of the enrichment factor (Table 5) Igeo confirms that all the processing sites were strongly to extremely polluted with Pb, and all the study sites were moderately polluted with Cd. This also confirms that the processing of the metal ores is the major anthropogenic activity leading to the pollution of the study areas with Pb. However, the reference values used for assessing soil heavy metals vary greatly. Some used the pre-industrial reference level, the average crust level, background level, average content of shale heavy metals, etc. [26, 59]. For this study, average content of shale heavy metals was used. The reference values could lead to a discrepancy in assessment, but still [40] used the background level as the reference in one of the study locations and observed that Pb was strongly/extremely polluted, Cd was extremely polluted and Zn is unpolluted. This confirms that despite the different reference values used, the study locations were polluted with Pb and Cd.

3.4.3 Pollution load indices and contamination assessment of heavy metals in the soils

The soil contamination assessment was based on contamination factor (Table 7) calculated for each heavy metal and each study site using the values from standard

Table 6 Geoaccumulation index of heavy metals in soils from all the study locations of Anka Local Government, Zamfara State

Locations	Pb		Cd		Cr		Fe		Zn		Ni	
Bagega mining	3.91	SP	1.46	MP	− 0.17	UP	− 1.95	UP	− 1.56	UP	− 3.62	UP
Bagega processing	4.22	SEP	1.64	MP	− 0.85	UP	− 1.18	UP	− 2.56	UP	− 5.09	UP
Bagega village	− 16.5	UN	1.64	MP	− 1.47	UP	− 1.67	UP	− 5.19	UP	− 15.1	UP
Dareta mining	− 16.5	UN	1.97	MP	− 1.5	UP	− 1.65	UP	− 16.7	UP	− 18.2	UP
Dareta processing	4.15	SEP	1.86	MP	− 1.7	UP	− 1.28	UP	− 2.02	UP	− 4.5	UP
Dareta village	− 15.5	UP	2	MP	− 2.04	UP	− 2.43	UP	− 17.7	UP	− 16.6	UP
Sunke mining	− 16.5	UP	2.29	MSP	− 1.39	UP	− 0.75	UP	− 2.72	UP	− 15.6	UP
Sunke processing	3.44	SP	2.22	MSP	− 2.09	UP	− 1.8	UP	− 2.41	UP	− 15.9	UP
Sunke village	− 15.5	UP	1.92	MP	− 3.09	UP	− 2.29	UP	− 6.57	UP	− 17.2	UP
Tunga mining	− 16.5	UP	1.83	MP	− 1.37	UP	− 2	UP	− 4.05	UP	− 15.2	UP
Tunga processing	3.43	SP	2.08	MSP	− 2.07	UP	− 1.8	UP	− 2.36	UP	− 16.6	UP
Tunga village	− 15.5	UP	1.92	MP	− 2.47	UP	− 2.08	UP	− 3.61	UP	− 16.6	UP
Abare mining	− 16.5	UP	1.64	MP	− 16.6	UP	− 2.7	UP	− 3.09	UP	− 17.2	UP
Abare processing	3.38	SP	1.74	MP	− 4.21	UP	− 1.65	UP	− 3.51	UP	− 18.2	UP
Abare village	3.42	SP	1.64	MP	− 17.6	UP	− 1.58	UP	− 3.62	UP	− 17.2	UP
Anka village	− 15.5	UP	1.42	MP	− 16.3	UP	− 2.61	UP	− 18.7	UP	− 15.6	UP

Geoaccumulation index classes: UP, unpolluted; UMP, unpolluted to moderately polluted; MP, moderately polluted; MSP, moderately to strongly polluted, SP, strongly polluted; SEP, strongly to extremely polluted; EP, extremely polluted

Table 7 Contamination factor of heavy metals in soils from all the study locations of Anka Local Government, Zamfara State

Locations	Fe		Zn		Ni		Pb		Cd		Cr	
Bagega mining	3.67	MP	0.35	MC	0.24	SIC	5.29	SeP	1.54	SIP	1.2	SIC
Bagega processing	6.23	SeP	0.17	SIC	0.09	VSIC	6.58	SeP	1.75	SIP	0.75	VSIC
Bagega village	4.44	SeP	0.03	VSIC	0	VSIC	0	VSIC	1.75	SIP	0.49	VSIC
Dareta mining	4.5	SeP	0	VSIC	0	VSIC	0	VSIC	2.21	MP	0.48	VSIC
Dareta processing	5.84	SeP	0.25	SIC	0.13	SIC	6.28	SeP	2.04	MP	0.42	SIC
Dareta village	2.64	MC	0	VSIC	0	VSIC	0	VSIC	2.25	MP	0.33	VSIC
Sunke mining	8.4	Vsep	0.16	SIC	0	VSIC	0	VSIC	2.75	MP	0.52	VSIC
Sunke processing	4.08	Sep	0.19	SIC	0	VSIC	3.83	MP	2.63	MP	0.32	VSIC
Sunke village	2.9	MP	0.01	VSIC	0	VSIC	0	VSIC	2.13	MP	0.16	VSIC
Tunga mining	3.55	MP	0.06	VSIC	0	VSIC	0	VSIC	2	SIP	0.52	VSIC
Tunga processing	4.08	SeP	0.2	SIC	0	VSIC	3.79	MP	2.38	MP	0.32	VSIC
Tunga village	3.35	MP	0.08	VSIC	0	VSIC	0	VSIC	2.13	MP	0.24	VSIC
Abare mining	2.18	MP	0.12	SIC	0	VSIC	0	VSIC	1.75	SIP	0	VSIC
Abare processing	4.5	SeP	0.09	VSIC	0	VSIC	3.67	MP	1.88	SIP	0.07	VSIC
Abare village	4.73	SeP	0.08	VSIC	0	VSIC	3.77	MP	1.75	SIP	0	VSIC
Anka town	2.32	MP	0	VSIC	0	VSIC	0	VSIC	1.5	SIP	0	VSIC

Contamination factor categories: VSIC, very slightly contamination; SIC, slight contamination; MC, moderate contamination; SeC, severe contamination; VSeC, very severe contamination; SIP, slight pollution; MP, moderate pollution; SeP, severe pollution; VSeP, very severe pollution; EP, excessive pollution

table formulated by the Department of Petroleum Resources of Nigeria [19] as target/background reference value for Nigerian soil. Based on the values of the contamination factor calculated, the soils were generally classified as very slightly contaminated with Zn, Ni, and Cr. All the processing sites were moderate to severely polluted with Pb and Fe. And all the sites were slight to moderately polluted with Cd. It was also observed that very slight contamination was recorded for Pb in Anka (control site), Bagega village, Dareta village, Sunke village, and Tunga village. The pollution of the area with Pb and Cd is evident to be from the mining activities, while Fe is based on the abundance of the element in the earth crust as reported by Amusan et al. [10]. These results also confirm that mining activities led to pollution of the study areas with heavy metals, as several researchers have earlier reported that the Nigerian savanna soils are generally non-polluted [2, 3, 8, 51].

The pollution load index value (Fig. 1, maps showing Nigeria, Zamfara State, and the sampling locations, Fig. 2) indicates that there is no pollution load in all the study sites (PLI < 1) apart from Bagega mining, Sunke processing, and Tunga processing that have moderate pollution. There is increasing potential for rising pollution levels in virtually all the study sites apart from the control site (Anka town), this called for remediation and control of illegal mining in all the study sites.

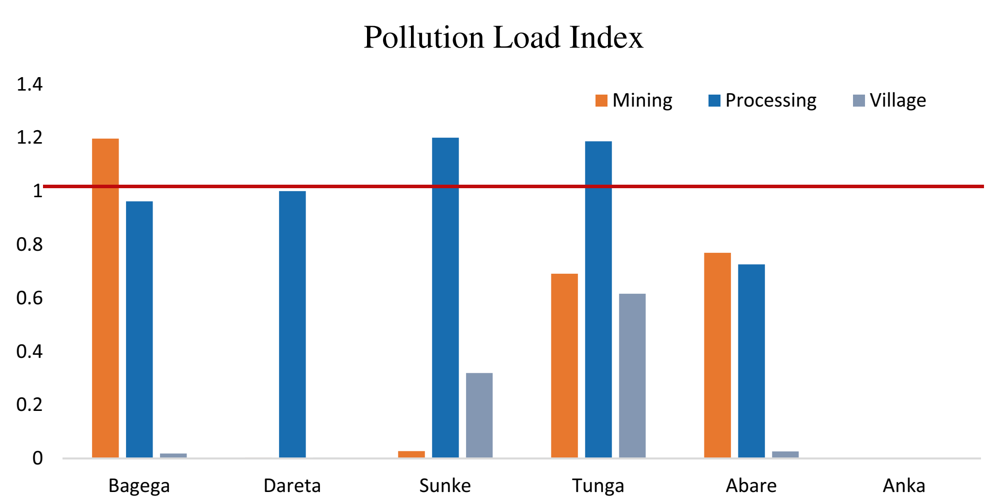

Fig. 2 Pollution load index of the heavy metals in soils from all the study locations of Anka Local Government, Zamfara State

Table 8 Ecological risk factor of the heavy metals in soils from all the study locations of Anka Local Government, Zamfara State

Locations	Pb		Cd		Cr		Zn		Ni		PERI
Bagega mining	26	LP	46	MP	2.4	LP	0.4	LP	1.2	LP	76.64
Bagega processing	33	LP	53	MP	1.5	LP	0.2	LP	0.4	LP	87.51
Bagega village	0	LP	53	MP	1	LP	0	LP	0	LP	53.50
Dareta mining	0	LP	66	MP	1	LP	0	LP	0	LP	67.21
Dareta processing	31	LP	61	MP	0.8	LP	0.3	LP	0.6	LP	94.36
Dareta village	0	LP	68	MP	0.7	LP	0	LP	0	LP	68.15
Sunke mining	0	LP	83	MP	1	LP	0.2	LP	0	LP	83.69
Sunke processing	19	LP	79	MP	0.6	LP	0.2	LP	0	LP	98.72
Sunke village	0	LP	64	MP	0.3	LP	0	LP	0	LP	64.08
Tunga mining	0	LP	60	MP	1.1	LP	0.1	LP	0	LP	61.12
Tunga processing	19	LP	71	MP	0.6	LP	0.2	LP	0	LP	91.06
Tunga village	0	LP	64	MP	0.5	LP	0.1	LP	0	LP	64.32
Abare mining	0	LP	53	MP	0	LP	0.1	LP	0	LP	52.62
Abare processing	18	LP	56	MP	0.2	LP	0.1	LP	0	LP	74.83
Abare village	19	LP	53	MP	0	LP	0.1	LP	0	LP	71.45
Anka town	0	LP	45	MP	0	LP	0	LP	0	LP	45.00

Ecological risk factor terminologies: LP, low potential ecological risk; MP, moderate potential ecological risk; PERI, Potential ecological risk index

3.4.4 Ecological risk assessment of heavy metals in the soils

The ecological risk assessment results are summarized in Table 8. It was found that ecological risk factors for Pb, Cr, Zn, and Ni were below 40, thus indicating low potential ecological risk. Cadmium was all within the moderate potential ecological risk. To quantify the overall potential ecological risk of observed metals in the study sites, the risk index (RI) was calculated as the sum of all the five risk factors (Fig. 3). Risk index could characterize the sensitivity of the local ecosystem to the toxic metals and represent ecological risk result from the overall contamination. The contribution to the overall potentially ecological risk shows that Cd contributed 84.25% and Pb contributed 14.39% of the total potentially ecological risk, this means that the two metals combined account for 98.64% of the total risk. This result is similar to what was reported by Fan et al. [23] in contaminated soil of three mining areas in Central China in which Cd accounted for almost 99.77% of the total risk. Wu et al. [60] also reported a similar result where Cd accounted for 70.6% of the total risk. The different pollution indices examined in this study (EF, Igeo, CF, and ErF) showed that all sites were polluted with Cd, and all the processing sites were polluted with Pb and are the main constraint to ecological risk.

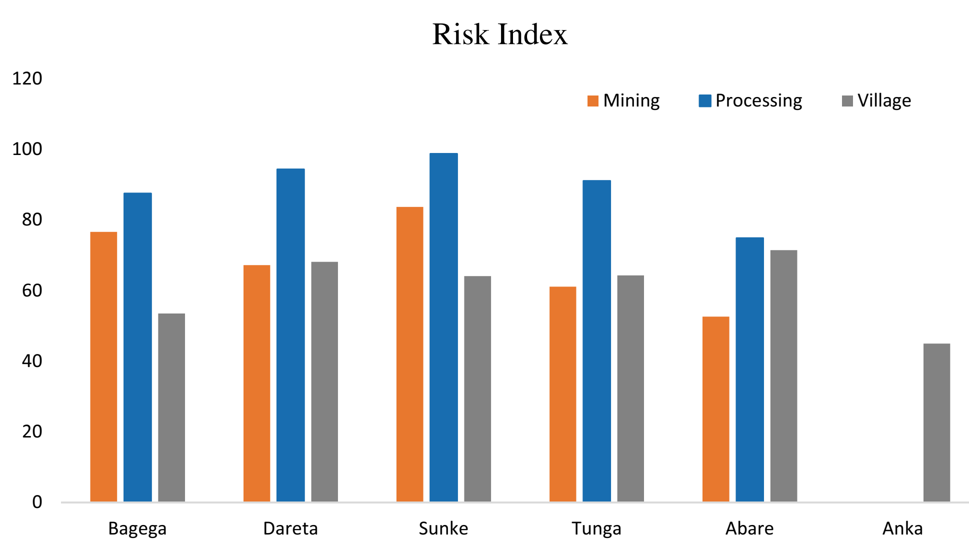

Fig. 3 Potential ecological risk index of the heavy metals in soils from all the study locations of Anka Local Government, Zamfara State

4 Conclusion and recommendation

In conclusion, the principal component analysis suggested that Pb, Zn, Cr, and Ni with the same principal component likely originated from the same source, i.e., mining activities, and Fe and Cd also with the same principal component originated from the abundant parent material in the study area. The results of this research revealed that processing sites pose more risk to heavy metal contamination as compared to mining sites and the farmlands around the villages, this is due to the grinding of the metal ores that releases the metals into the environment. It also revealed that Pb and Cd have the highest enrichment with most of the values greater than the maximum allowable limits set by different countries, and they virtually accounted (98.64%) of all the total potential ecological risk in the study areas. This quantitative evidence demonstrates the critical need to put in place mining regulations to protect the environment and residents, especially children, from heavy metal pollution in the area, and remediation of the contaminated areas is highly recommended.

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Author contributions Sharhabil comes up with the idea and designed the research, carried out the studies, and wrote the manuscript. Nafiu and Fatima studied the analysis of soil samples and carried out the studies of other sections. Sharhabil and Nafiu generated all the figures and tables in the manuscript and draft the manuscript. All authors read and approved the final manuscript.

Availability of data and materials Data sharing applies to this article as data sets were generated and analyzed during the current study.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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