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Assessment of Heavy Metal Contamination in Soils Surrounding Bengote Open Cast Mines (East-Cameroon)

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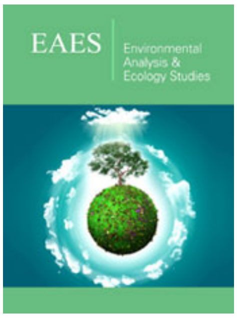

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Abstract

This study aims at assessing heavy metal contamination in Bangote, Gbafou and Nguesse soils around Bengote Open Cast Mining in Cameroon. In soil samples, heavy metals namely Iron (Fe), Chromium (Cr), Vanadium (V), Nickel (Ni), Copper (Cu), Mercury (Hg), Zinc (Zn), Lead (Pb), Arsenic (As), and radioactive elements Thorium (Th) and Uranium (U), contents were determined using ICP-MS techniques. The heavy metals average concentration in Upper Continental Crust (UCC) was considered background value. Average concentrations of heavy metals in both soils mixed with mining spoil lie above that of the world soil. Pb, V, As and U contents exceed the critical limit value of WHO specified standard.

The mean concentration of Cr, V, Ni, Cu, As, Hg, Pb, Th and U in studied soils are 245.00, 370.00, 8.27, 60, 90, 172.00, 0.18, 3640.00, 28.30, and 4.95mg/kg, respectively. The Enrichment Factor (EF), Contamination Factor (CF), Geoaccumulation Index (Igeo), Pollution Load Index (PLI) are the indices used to assess the contamination risk. The enrichment factor of all the studied metals for all sampling sites are in descending order Pb >V> Cr > As > Cu > Th > U> Ni > Cd. The contamination factor values revealed that Pb and V highly impacted the studied soils. The Pollution Load Index (PLI) values of most samples are >1, indicating the progressive deterioration of soils due to their contamination.

Keywords: Heavy metal; Contamination; Bengote; Pollution; Soil

Nomenclature: Fe: Iron; Cr: Chrome; V: Vanadium; Ni: Nickel; Cu: Copper; Hg: Mercury; Pb: Lead or Sinker; Th: Thorium; U: Uranium; WHO: World Health Organization; km2: Kilometer square; m: Meter; mm/year: Millimeter/year; cm: Centimeter; kg: Kilogram; mm: Millimeter; Log : Logarithm; mg/kg: Milligram/kilogram

Introduction

Global development has devoted a frantic race towards research, exploitation, processing of several types of metalliferous ores. This industry improves the quality of human life by creating jobs, lifespan, skills and knowledge, proper distribution of income, infrastructure, public health services and education [1]. The Cameroon mining industry creates economic growth at the national and regional levels. Mining industry is a human activity with negative impacts on the environment [2,3]. Some negative impacts are habitat destruction, loss of resources and biodiversity, deterioration of land and accumulation of pollutants in various ecosystems [4] as observed in heavy mechanized gold mining in Eastern and Adamawa Cameroon. In addition to acidic leachates and mining residues which cause deterioration of ecosystems, metallic trace elements (TMEs) cause even more harmful effects on the physiological functions of living organisms [5,6]. Therefore, environmental defenders and legislators investigate the impact of mining activity on the three indices of sustainable development: environment, social, and economy [7]. In high doses, metallic trace elements are toxic and can cause major functional complications and serious health problems. Furthermore, certain metals such as lead, mercury or arsenic are very toxic and are classified as pollutants known as “hazardous air pollutants” [8].

Soil is known as the innate action of forces for human beings and key receptor of pollutant hazardous elements (heavy metals and radioactive). Soil is that specific part of the earth's crust working as open dynamic system whose ability depends on the energetically flux received from the universe [9]. Soil pollution by hazardous elements is a major problem in the world. The abundance, toxicity, non-biodegradable and accumulative properties of these elements are of great concern in surrounding soils. Heavy metals from various sources including mine waste disposal, fossil fuel combustion and plastic waste can accumulate around the mine. They affect soils and plants and cause ecological risks [10]. The evaluation methods used to determine soil pollution by heavy metals are Enrichment Factor (EF), contamination factor (CF) and geo accumulation index. Their enrichment is compared with metal standard values. The methods also assess pollution in mining districts and provide basic information of environmental risks and pollution management in the mining area. They include poor disposal of mine waste, consumption of fossil fuels and occasional discharge of wastewater. The variations of heavy metals in different soil sampling sites were studied.

Experimental Methods

Study area

The study area is in the east region of Cameroon with a surface area of more than 2555km2 in three open cast gold mining, namely Bengote (4), Gbafou (3), Nguesse (3) and their surroundings. The geographical coordinates are between 4°25'59.84'' and 4°57'40.04'' North latitudes, and 14°22'00.49'' and 14°33'45.35'' East longitudes (Figure 1).

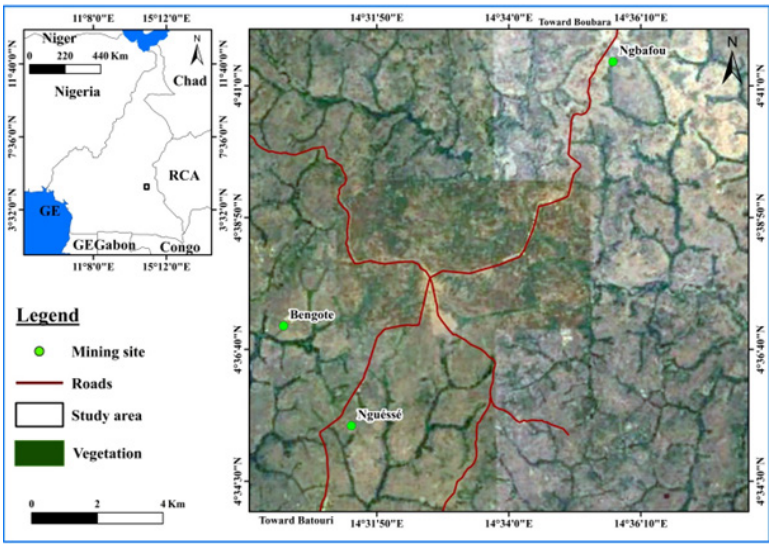


Figure 1: Location map showing the study area.

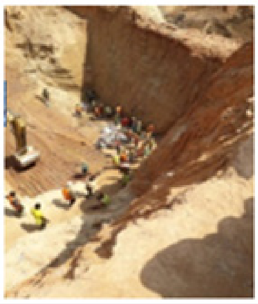
This study area is in the southern Cameroonian characterized by medium altitude (500-700)m and hilly landscape [11,12]. The climate is "Guinean sub-equatorial" with bimodal rainfall of four seasons. The annual precipitation exceeds 2000mm/year between the driest and wettest months. The summer average temperature ranges between 24 °C and 32 °C [13].

Geology and soil of surrounding areas

The study area belongs to the pan-African chain of Central Africa [14]. The geological context indicates Neoprotorozoic granitoids [15], boarded by the trans-Saharan Pan-African chain to the west and the Congo craton to the south. These granitoids intrude high-grade gneisses which represent a paleoprotorozoic basement, likely dismembered during the Pan-African assembly of western Gondwanaland [16,17]. In plutonic environments gold deposits consist of simple veins in second or third order structures such as fissures, linked to crustal discontinuities notably along shear zones in granitic rocks and associated metamorphic rocks [18]. Alterations associated with primary gold mineralization styles in eastern Cameroon include silification, sulphidation, seritization, k-feldspar alteration, with muscovite/sericite formation, haematization, carbonatization and pyritization [11,19]. Pyrite, arsenopyrite, galena, calcopyrite, specular haematite, and gold are primary ore mineral assemblage of quartz veins and veinlets [20]. The mine spoil is composed of weathered products of rocks in the study area (Table 1).

Table 1: Brief description of study area.

Location Name		Bengote	Gbafou	Nguesse
Latitude		4° 37' 6.13''	4° 41' 44.32''	4° 34' 59.71''
Longitude		14° 30' 16.47''	14°35' 42.79''	14° 31' 0.02''
Sample N°	soil mixed with mine spoil	4	3	3

Total area affected by open cast mine (hectare)	7	10	5
Dumping Method	overburden	overburden	overburden
Pictures of the different mining site	 (a)resources and biodiversity	 (b) Gbafou habitat	 (c) Nguesse biodiversity
Pictures of different sites after mining	 (d) Destruction of ressources, biodiversity	 (e) Deterioration of land	 (f) accumulation of pollutants in various ecosystems

Sample collection

At Bengote, samples in Gbafou, Bengot and Nguesse sites were collected at the top (0-60cm) soil using a Peterson mud sampler (XDB0201). One kilogram of the soil was sampled and stored in plastic packaging bags following the procedure used by [21]. These samples were dried at ambient temperature then ground in an agate mortar, sieved using a sieve of 0.080 mm to remove debris. All the samples were analyzed using the inductively coupled plasma mass spectrometry (ICP/MS) at the Geology Department of the University of Yaounde I. A total of 10 elements were analyzed and include Fe, Cr, V, Ni, Cu, Hg, Pb, As, Th and U of soil samples was obtained using the 'methods for chemical analysis of silicate' (AuME-ST43).

Heavy metals indices

The assessment of the levels of enrichment or contamination of the trace elements in soil was carried out using standard pollution measurement indices such as the Index of Geo-Accumulation (Igeo), Enrichment Factor (EF), Contamination Factor (CF) and the Pollution Load Index (PLI).

Geo-Accumulation Index (Igeo)

[22] introduced the geo-accumulation index (Igeo). Originally used with river bottom sediments, it was applied in the assessment of soil contamination (Müller, 1979). In this paper, the soils and debris Igeo of studied mine were computed using the following equation: $Igeo = Log2\ (Cn/1.5Bn)$ where, Where Cn is the measured concentration of the given heavy metal examined in the soil or sediment, Bn is the geochemical background value of the element, 1.5 is incorporated in the relationship to account for possible variation in background data owing to lithogenic effects, according to [23]. The geo-accumulation index, consist of seven grades (0 to 6) based on the increasing numerical value of the index and ranges from unpolluted to extremely polluted (Figure 2). The standard Igeo values are presented below (Table 2).

Table 2: Contamination categories based on Igeo.

Igeo Value	Grade	Classification
≤0	0	Unpolluted
0-1	1	Unpolluted to moderately polluted
1-2	2	Moderately polluted
2-3	3	Moderately to strongly polluted
3-4	4	Strongly polluted
4-5	5	Strongly to extremely polluted
>6	6	Extremely polluted

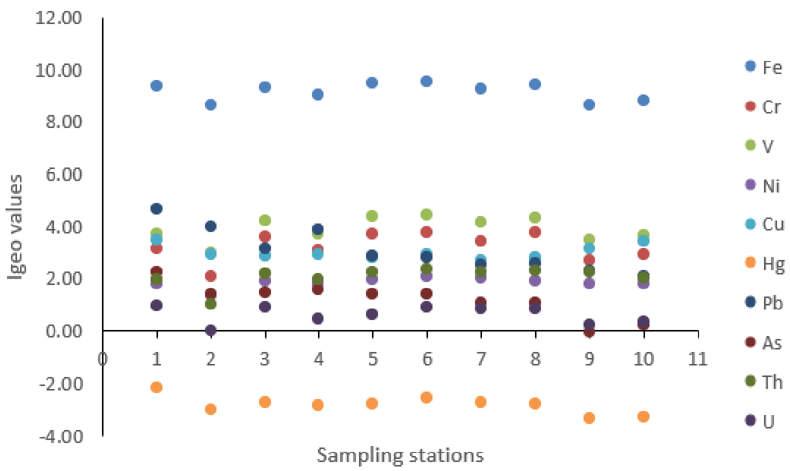


Figure 2: Igeo-accumulation indices of heavy metals in Bengote soils.

Enrichment Factor (EF)

To find probable source of elements in sediments, the enrichment factor was calculated for each element over the average shale background. Typically, the Enrichment Factor (EF) of elements is stated by the equation EF=(M/Fe) sample/(M/Fe) background, where M background and Fe background are the concentrations of the studied element and Fe in the background, M sample and Fe sample are the mean concentrations of the element and Fe, respectively. Fe is frequently used as a reference element. [24] suggested the use of regional background values which are constant while the contamination levels vary with time and areas. EF values ~1 indicate crust origin, EF < 1 suggest a possible mobilization or depletion of metals [25,26], EF >1 show anthropogenic origin. EFs >10 suggest non-crust source. On this basis there are five contamination categories (Table 3). The contribution of anthropogenic origins also increases with increasing EF values [27].

Table 3: Contamination categories based on EF.

EF Classes	Enrichment Level
EF< 3	minor or minimal enrichment
EF = 3-5	moderately enrichment
EF = 5-10	moderately severe enrichment
EF = 10-25	severe enrichment
EF = 25-50	very severe enrichment
EF > 50	extremely severe enrichment

Calculation of the Contamination Factor (CF) and Pollution Load Index (PLI)

The Pollution Load Index (PLI) of a single site is the root number (n) multiplied together by the Contamination Factor (CF) values expressed by the equation: PLI = n√ (CF1 × CF2 × CF3 × … … × CFn), where, n is the number of metals and CF the contamination factor. Harikumar et al. (2009) interpret the PLI values. PLI < 0 indicate unpolluted sediments; PLI=0 indicate perfection; PLI=1 indicate only baseline levels of pollutants, and PLI >1 would indicate progressive deterioration of site quality [28]. The CF and level of contamination advanced initially by [29] and modified by [30] and others are given in Table 4.

Table 4: Contamination levels based on CF.

Contamination Factor	Level of Contamination
CF< 1	Low contamination
1 ≤ CF< 3	Moderate contamination
3 ≥ CF< 6	Considerable contamination
CF > 6	Very high contamination

Results and Discussion

Concentration measurement in ETM in soils

The concentrations of each metal in soil samples, all sites combined are shown in Table 5 below reflects analytical selected heavy metals results and variation in contents according to the metal considered of the soils of the study area. The average concentration of Fe is 85.02g/kg, above UCC and averaging shale values. Under regional conditions of weathering, Fe concentration is important. The concentrations of Cr, V, Ni, Cu, Hg, Pb and As vary widely with an average value of 117.20, 167.63, 5.72, 25.35, 0.05, 582.44 and 34.46 mg/kg respectively. They are higher than UCC except Ni, Hg and U. Pb in all samples exceeds the critical limit of standard set by [31]. The soils, red and very rich in iron oxides, derive from weathering of preexisting rocks mainly granite and migmatite. High Concentrations of metals might occur due to reduction of Fe and Mn oxides and induced pH changes leading to their release from solid phases to the soil solution [31,32]. Except three samples, Pb in soils does not exceed its maximum allowable concentration (300mg/kg) in the whole area because under oxidizing conditions it is strongly sorbed than Cr and Ni [33,34]. The average concentration of other metals (Ni, Hg) is lower than the reference values from UCC [35]. The decreasing average concentration order is Fe > Pb >V> Cr > As > Cu > Th > U> Ni. We see a strong variability of major part of heavy metal concentrations. The analysis of from Table 5 clearly reveals that soils Bengote mines are richer in MTEs compared to soils in periphery of the mine and soils outside the mining area suggesting as well as artisanal gold mining in the Bengote area pollutes the soil by trace elements [4]. The concentrations of selected heavy metals content in soil samples prelevated from different area of study from Bengote Open Cast Mines present variations between 0.012ppm (Nguesse area) and 3640.00ppm (Bengote area). MTEs are having a very high mobility, and they are very easily absorbed by plants. Some of these higher values are considered as toxic [9].

Table 5: Heavy metal concentration in soils around Bengote Open Cast Mines.

	Fe (mg/kg)	Cr (mg/kg)	V (mg/kg)	Ni (mg/kg)	Cu (mg/kg)	Hg (mg/kg)	Pb (mg/kg)	As (mg/kg)	Th (mg/kg)	U (mg/kg)
1	108500	63.3	72.8	4.63	60.9	0.178	3640	172	13	4.95
2	20600	4.94	13.2	1.61	18.4	0.027	747	25.8	1.47	0.587
3	104500	170	234	6.14	15.4	0.05	106.5	31.5	21.6	4.45
4	52200	55.2	74.4	4.58	17.5	0.039	543	36.7	13.4	1.535
5	141500	222	336	7.03	13.1	0.044	55	24.9	24.1	2.32
6	162500	245	370	8.71	17.6	0.069	51.8	26.9	30.9	4.19
7	84000	120.5	194	8.27	10.3	0.048	25.7	11.5	24.2	3.69
8	122000	236	281	6.55	13.9	0.044	31	12.6	28.3	3.68
9	21200	21	41.1	4.62	29	0.012	15.75	0.94	23.8	0.87
10	33200	34.5	59.8	5.06	57.4	0.013	8.68	1.76	14.35	1.165
Ac	85020	117.244	167.63	5.72	25.35	0.0524	522.443	34.46	19.512	2.7437
UCC	30890	35	107	20	71	0.056	20	1.5	10.7	2.8
As	47200	90	130	68	45	0.4	20		12	3.7
WHO		185	-	50	100	1	1		-	0.3

Average concentration: AC; Average shale: As; Upper Continental Crust: UCC

Sampling stations : Bangote 1 (1), Bangote 2 (2), Bangote 3 (3), Bangote 4 (4), Gbafou 1(5), Gbafou 2(6), Gbafou 3(7), Nguesse 1(8), Nguesse 2 (9), Nguesse 3 (10).

Using the pollution indices for assessment

Contamination measurement indicators used for the assessment of soils in the study area include geo-accumulation index, enrichment factor, contamination factor and pollution load index. Average concentration of background values for world soil used in the various equations. Calculated pollution indices are presented in Tables 6-8.

Table 6: Igeo-accumulation indices of heavy metals in Bengote soils.

	Fe (mg/kg)	Cr (mg/kg)	V (mg/kg)	Ni (mg/kg)	Cu (mg/kg)	Hg (mg/kg)	Pb (mg/kg)	As (mg/kg)	Th (mg/kg)	U (mg/kg)
1	9.35	3.17	3.72	1.79	3.46	-2.18	4.69	2.24	1.97	0.97
2	8.63	2.06	2.97	1.33	2.94	-3	4	1.41	1.02	0.04
3	9.33	3.6	4.22	1.91	2.86	-2.73	3.15	1.5	2.19	0.92
4	9.03	3.11	3.72	1.79	2.92	-2.84	3.86	1.56	1.98	0.46
5	9.46	3.71	4.38	1.97	2.79	-2.78	2.87	1.4	2.24	0.64
6	9.52	3.76	4.42	2.06	2.92	-2.59	2.84	1.43	2.34	0.89
7	9.24	3.45	4.14	2.04	2.69	-2.75	2.53	1.06	2.24	0.84
8	9.4	3.74	4.3	1.94	2.82	-2.78	2.62	1.1	2.31	0.84
9	8.64	2.69	3.47	1.79	3.14	-3.35	2.32	-0.03	2.23	0.21
10	8.83	2.91	3.63	1.83	3.43	-3.31	2.06	0.25	2.01	0.34

Table 7: Enrichment Factor of heavy metals in Bengote soils.

	Fe (mg/kg)	Cr (mg/kg)	V (mg/kg)	Ni (mg/kg)	Cu (mg/kg)	Hg (mg/kg)	Pb (mg/kg)	As (mg/kg)	Th (mg/kg)	U (mg/kg)
1	1	0.51	0.19	0.07	0.24	0.9	51.82	32.65	0.35	0.5
2	0.19	0.04	0.04	0.02	0.07	0.14	10.63	4.9	0.04	0.06
3	0.96	1.38	0.62	0.09	0.06	0.25	1.52	5.98	0.57	0.45

4	0.48	0.45	0.2	0.07	0.07	0.2	7.73	6.97	0.36	0.16
5	1.3	1.81	0.89	0.1	0.05	0.22	0.78	4.73	0.64	0.24
6	1.5	1.99	0.98	0.12	0.07	0.35	0.74	5.11	0.82	0.43
7	0.77	0.98	0.52	0.12	0.04	0.24	0.37	2.18	0.64	0.38
8	1.12	1.92	0.75	0.09	0.06	0.22	0.44	2.39	0.75	0.37
9	0.2	0.17	0.11	0.07	0.12	0.06	0.22	0.18	0.63	0.09
10	0.31	0.28	0.16	0.07	0.23	0.07	0.12	0.33	0.38	0.12

Table 8: Contamination Factor (CF) and Pollution Load Index (PLI).

	Fe (mg/kg)	Cr (mg/kg)	V (mg/kg)	Ni (mg/kg)	Cu (mg/kg)	Hg (mg/kg)	Pb (mg/kg)	As (mg/kg)	PLI
1	3.51	1.81	0.68	0.23	0.86	3.18	182	114.67	3.23
2	0.67	0.14	0.12	0.08	0.26	0.48	37.35	17.2	0.54
3	3.38	4.86	2.19	0.31	0.22	0.89	5.33	21	1.94
4	1.69	1.58	0.7	0.23	0.25	0.7	27.15	24.47	1.42
5	4.58	6.34	3.14	0.35	0.18	0.79	2.75	16.6	1.82
6	5.26	7	3.46	0.44	0.25	1.23	2.59	17.93	2.25
7	2.72	3.44	1.81	0.41	0.15	0.86	1.29	7.67	1.38
8	3.95	6.74	2.63	0.33	0.2	0.79	1.55	8.4	1.66
9	0.69	0.6	0.38	0.23	0.41	0.21	0.79	0.63	0.51
10	1.07	0.99	0.56	0.25	0.81	0.23	0.43	1.17	0.62

Geo-Accumulation Index (Igeo)

The minimum and maximum values of Igeo for each metal are shown in Table 6 where, Calculated Igeo values are based on the UCC as background values. The mean values of Igeo decrease in the order of Fe>Pb>V>Cr>Cu>Th>As>Ni>U>Hg. The Pb and V Igeo values (4.7 and 4.06 respectively) indicate strongly to very strongly to extremely polluted, thus the most enriched heavy metals of the study area. For both soil types, Cr, Cu and V Igeo values fall in class 4 (Table 3) indicating strongly pollution. As and Th Igeo values (Figure 3) indicate moderately to strongly pollution. Ni and U Igeo values indicate moderately pollution and Hg falls in class 0 showing no contamination. This indicated that soils in the study area were contaminated by some metals mostly derived from overburden of spoil mine sources. The highest Igeo value for Pb and V in Native soil mixed with mine spoil could possibly be due to mine waste being dumped on open ground not far from the mine. This type of elimination introduces spreading of heavy metals on native soils as a result of weathering and runoff.

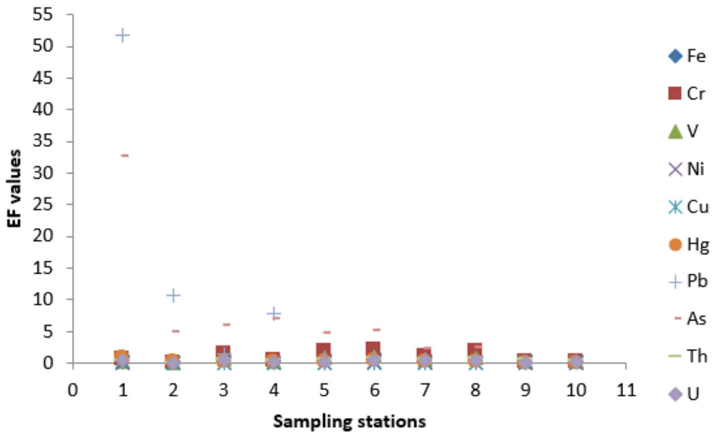


Figure 3: Enrichment Factor of heavy metals in Bengote soils.

Enrichment Factor (EF)

The Enrichment factor (EF) is a common tool to assess enrichment degree. Table 7 and Figure 4 shows the enrichment factors (EF) of the heavy metals in soils. The EF values in Table 7 show minimal enrichment in Cr, V, Ni, Cu, Hg, U and Th in both soils. They suggest a deficient source thus a little scope of enrichment. Trace elements assessment using EF at Bengote shows soils extremely enriched in Pb and As, with EF values of 51.82 and 32.65 respectively. However, Pb and As show high EF values (>4) in both major soils. Generally, the natural content of most elements in soils stems from parent rocks while high concentrations relate to mineralization. The higher concentration of Pb and As in major soil sample of the area may be attributed to the gold exploitation and waste storage process. Some studied metals of the area of study (V, Ni, Cu, Hg, Th and U) have EF<1, suggesting a possible leaching of heavy metals from mine waste.

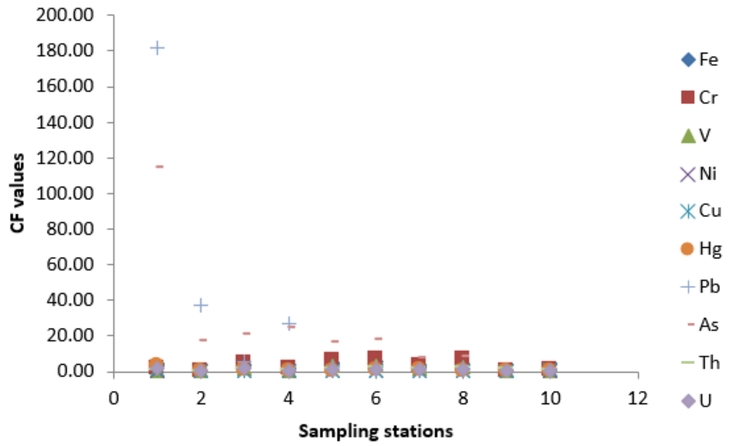


Figure 4: Contamination factor of heavy metals in Bengote soils.

Contamination Factor (Cf) and Pollution Load Index (PLI)

Both Cf and PLI values of elements in soils of the study area are significant (Figure 5) indicating heavy metals contamination. The CF values are presented in respect of Pb. As and Hg are higher than other heavy metals. Anthropogenic activities such as mining have released heavy metals from mining wastes, contributing to their high concentration in soils. Most samples show significant CF values of Pb and As. Pb concentration increase with the soil pH [36]. Calculated PLI using CF values shows moderately to strongly pollution (Table 8). Heavy metal contamination on soil surfaces, particularly at mining sites, is associated with a cocktail of contaminants rather than a single metal [37].

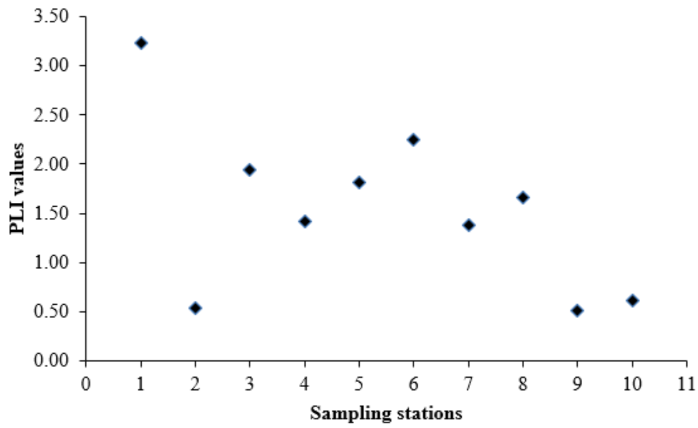


Figure 5: Pollution load index of heavy metals in Bengote soils.

A PLI > 1 in most sites (Table 5) indicates pollution. Ubiquitous mining activities characterized by indiscriminate dumping of mine wastes, tailings and other foreign materials, coupled with intense weathering, contributed to the release and redistribution of heavy metals in surrounding soils. This distribution by natural and anthropogenic processes can result in their deficiency or toxicity (such as Pb, As) to plants and animals. For example, Pb is toxic even at low exposure levels with acute and chronic effects on humans (neurological, renal gastrointestinal and reproductive effects) especially children and pregnant women [38,39] Long exposition to weathering of mine waste probably increased the release of heavy metal in the study area (surrounding soil-water environment). All Cf and PLI values of elements (Ni and Cu) in soil of the area of study are less than one (Figure 5). This indicates that there is no contamination by these elements. The situation of soil contamination in the study area analyzed from the geo-accumulation index, the enrichment factor, the contamination factor and the pollutant load index is recorded in Table 9.

Table 9: contamination's situation in the study area analyzed from pollution indices.

Igeo Value	Grade	Classification	Level Pollution by MTEs
≤0	0	Unpolluted	Hg, As,
0-1	1	Unpolluted to moderately polluted	As, U
1-2	2	Moderately polluted	Ni, As, Th,
2-3	3	Moderately to strongly polluted	Cr, V, Cu, Pb, As, Th
3-4	4	Strongly polluted	Cu, Pb,
4-5	5	Strongly to extremely polluted	V, Pb,
>6	6	Extremely polluted	Fe,
EF classes		**Enrichment level**	**Enrichment Level by MTEs**
EF< 3		minor or minimal enrichment	Fe, Cr, V, Cu, Hg, Ni, As, Th, U
EF=3-5		moderately enrichment	Pb, As,
EF=5-10		moderately severe enrichment	Pb, As,
EF=10-25		severe enrichment	Pb,
EF=25-50		very severe enrichment	As,
EF > 50		extremely severe enrichment	Pb,
Contamination Factor		**Level of Contamination**	**Contamination Level by MTEs**
Cf < 1		Low contamination	Fe, Cr, V, Ni, Cu, Hg, Pb, As, U
1 ≤ Cf < 3		Moderate contamination	Fe, Cr, V, Hg, Pb, As, Th, U
3 ≥ Cf < 6		Considerable contamination	Fe, Cr, V, Hg, Pb, As,
Cf > 6		Very high contamination	Cr, Pb, AS,
PLI Value		**Pollution Level**	**pollution Level by MTEs**
PLI< 0		Unpolluted	
PLI =0		Perfection	2,9,10
PLI=1		Base level of pollution	
PLI> 1		Progressive deterioration	1,3, 4, 5, 6, 7, 8

Conclusion

In summary, the evaluation of the degree of accumulation of heavy metals such as Pb, As, V, Cr etc., in the soil of the Bengote region, calculated using the Geoaccumulation Index (Igeo), the factor d The Enrichment (EF), Contamination (Cf) and Pollutant Load Index (PLI), shows that the soil in the area is heavily polluted by Pb, V, Cu, Cr, As and Th according to the geo index accumulation. Pb and As are also highly enriched in both media when EF is measured. In all indices measured, Ni, and Cu levels in soil remain below once, indicating that the supports are not contaminated by these elements.

The composition of soils in the study area reveals high MTEs levels. The elements must have remobilized from surrounding rocks, coupled with remobilization from widespread sulphides mineralization. Contamination measurement indicators used to assess soils in the study area include geo-accumulation index, enrichment factor, and contamination factor and pollution load indices. The combination of metals in soils is a potential source of toxicity for flora, fauna and inhabitants. In addition, this region experiences subsistence farming, pastoral activity and surface water consumption. These activities constitute another entry of MTEs in the food chain and thus increase the risk of contamination of the population in addition to destruction of ecosystems. The destruction of metallic species participates in the fixation of soil and lessens the diffusion of MTEs thus upsets the previous balance and accentuates the erosion effect. Some plants have adaptive processes to tolerate high MTEs levels in soil. They have significant potential for the development of mine site rehabilitation strategies using phytoremediation approaches.

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