Original Research Article

Assessment of Metallic Contamination in Soils and Sediments in the Bétaré-Oya Gold Artisanal Mine District, East-Cameroon

ABSTRACT

Mining is an activity that involves the use of chemicals and results in unsustainable and dangerous conditions for the miners, their families, the community and the surrounding ecosystem. This study was done to assess metallic contamination of soils and sediments in the Bétaré-Oya gold artisanal mine district, East-Cameroon. A total of thirty (30) samples of exploited soils, control soils and sediments were taken from the mining sites of Lom, Mbal and Mali. The concentrations of heavy metals and metalloids (Fe, Sr, Cu, As, Pb and Zn) were determined by Inductive Plasma Ionisation Source Atomic Emission Spectrometry. The results show that in the sediments metals such as: As (1.82), Cu (24.22), Pb (18.04) and Zn (65.69) have average concentrations slightly higher than the UCC and Average Shale reference values. In the exploited soil As (1.93), Cu (16.86) and Zn (96.22) have average concentrations slightly higher than the UCC and Average Shale reference values.While in the cotrol soils only As (1.62) and Zn (59.72) shows an average concentration slightly above the UCC reference values. The average concentrations of the different heavy metals and metalloids were then used to calculate the intensity of contamination in soils and sediments. The results of this calculation indicate that the Enrichment Factor (EF) of As, Sr, Zn and Pb indicate an extremely high enrichment in these elements. The geo-accumulation Index (Igeo) (22.85-25), the Contamination (CF) (1.47), the low values of the ecological risk indices suggest a low potential ecological risk and Pollution load index (PLI) (0.67) indicates extreme contamination with these elements in the soils and sediments. However, only As indicates a slight contamination (class 1) in soils and sediments. Gold panning activities and untreated mine tailings discharges would be considered as the main sources of sediment and soil pollution in Bétaré-Oya.

Keywords: Bétaré-Oya, gold exploitation, metal contamination, sediments, soil, heavy metals.

1. INTRODUCTION

Heavy metals are naturally occurring metallic elements characterized by a high density, greater than 5g/cm^3 [1], which is the case for most transition metals. Metals are ubiquitous in surface waters, however, their concentrations are generally very low, which is why they are referred to as "trace metals" or "trace metal elements" (ETM). Unlike most organic contaminants, heavy metals are natural constituents in rocks and mineral deposits. These elements are present at low levels (in trace amounts, less than 0.1%) in soils, sediments, surface waters and living organisms [1]. These low concentrations of heavy metals form the geochemical background of a certain environment. Some metals are essential, that is to say indispensable for biological processes, but are toxic at high concentrations (Cu, Zn, Fe, and Cr). For example, zinc (Zn) at the concentration of one millimolar, is a trace element that is involved in many enzymatic reactions (dehydrogenases, proteinase, peptidases) and plays an important role in the metabolism of proteins, carbohydrates and lipids [2]. Others, however, are non-essential [lead (Pb), cadmium (Cd), arsenic (As), antimony (Sb) and tin (Sn)], meaning they have no metabolic function and are often toxic at a lower threshold than the essential elements. Arsenic, for instance, is regarded a human carcinogen from extremely low levels of exposure. Pb induces kidney tumours and disrupts the normal functioning of the kidneys, joints of the reproductive system and the human system.

The heavy metal contamination of soils, atmosphere, hydrosphere and sediments is a major environmental problem. These elements are of natural origin (weathering of rocks, volcanism, erosion, etc.) but they are also the result of anthropogenic activities such as mining. However, the mining sector is an essential component in the economic and social development of several countries and plays an important role in the economy. On the other hand, many researchers in Africa have shown that this activity is at the origin of serious environmental and human problems such as pollution and contamination of soils, plants, water, sediments, destruction of landscapes and even contamination of living beings. In Nigeria and South Africa, for example, mining has contributed significantly to the contamination and pollution of soils and sediments and a high ecological risk from heavy metals [3,4]. The arrondissement of Bétaré-Oya located in the East region specifically in the department of Lom and Djérem is part of one of the largest localities in Cameroon where artisanal gold mining takes place. It has more than a hundred mining sites in operation and abandoned without any rehabilitation project in order to preserve the ecosystem and the health of the populations. The sites are abandoned as they become unproductive, waste from gold washing is dumped directly into waterways and soils without prior treatment and gold miners use mercury in the gold washing process. Not far from these sites, and sometimes even on these mining sites, are the gold panners' villages and farmland. Soils, water, sediments, plants and even populations of this locality could be exposed to contamination by trace metal elements from these gold panning activities. The environmental problems caused by gold mining in Bétaré-Oya are often mentioned [5, 6, and 7]. This work reported the presence of heavy metals in water, sediments and soils of some active mining sites. However, the studies have demonstrated that the presence of heavy metals alone in an environment does not necessarily mean contamination and pollution [8]. In Ghana, for example, [9] reported that toxic metals such as Cu, Zn, Cd and Hg are associated with anthropogenic sources caused by mining activities in the Lower Pra Basin in Ghana (Africa), while As, Se and Pb could be linked to both anthropogenic and natural geochemical processes. Although [10, 11] have assessed the pollution at some sites, its work is insufficient for a locality that has about more than 100 gold mining sites, so it would be necessary to extend the study to other sites with more pollution assessment indices to determine whether gold mining is solely responsible for the metallic contamination in the sediments and soils of these sites.

The aim of this study is to determine the concentrations of certain heavy metals and metalloids and certain physico-chemical parameters (pH and EC) in the soils (exploited and control) and sediments of the sites of Mbal, Mali and Lom, then we will assess the degree of contamination based on pollution indices such as enrichment factor (EF), The Geo-accumulation Index (Igéo), the Contamination Factor (CF) and Pollution Load Index (PLI).

2. Materials and methods

2-1- Study area

The district of Bétaré-Oya is located between 5°30' and 5°45' North latitude and between 14°00' and 14°15' East longitude. It is located in the East Cameroon region, more precisely in the department of Lom and Djerem (Figure 1). It covers an area of 12600 km² with an estimated population of 63,882 inhabitants. The geology is mainly dominated by post- to late-tectonic granites, meta-sediments, metavolcanics, quartzites, mylonites, and gneisses, [12]. The soils encountered in the locality are ferralitic soils. Hydromorphic soils found in marshy valleys are also found here [6]. Bétaré-Oya is flavoured by the Lom River. This River receives water from an important network of small rivers, the most important of which are: Mbal, Mari Mboufana, Bédobo, Falls, Kokzara, Mbigala, Tigara, Kokzara, Lougere, Ndokayo etc (figure 1). These waters are turbid and have a grey colour. The hydrological regime of the Lom River is controlled by precipitation, with the lowest monthly flow observed in February (56 m3/ s), while the maximum flow is observed in October (328 m3/ s) [5]Gold mining in this locality began in the 1930s and was practised on the riverbanks in an artisanal mining manner by the natives [13]. The Environmental and Social Impact Evaluation of the Lom Pangar hydroelectric dam had identified 13 tons of gold at risk of being submerged. It is in this perspective that the operation of the more extensive mechanization of artisanal mining in Bétaré-Oya was born. From then on, the stampede for the precious metal intensified and several foreign mining companies arrived and set up operations. At present we have two types of exploitation in this locality: semi-mechanical exploitation practiced by mining companies and artisanal exploitation practiced by native populations. During exploitation, all the layers of soil are removed until they reach the gravel layer, which is then recuperated and washed to obtain gold. The residues of this washing are poured into the water and soil. These residues are composed of rock fragments. However, the native populations use only rudimentary equipment, while the companies use sophisticated and heavy machines. Mining methods are the same at all sites. Semi-mechanical mining produces more tons of tailings and physical impacts than mining by native people. No studies have yet been done to show the presence of DMA at the sites. Gold panning is the main activity practised by the populations and has always been carried out in an artisanal manner. The farms are alluvial and are practised on the banks and in the watercourses. The main sites studied are: Mbal (Mb), Mali (Ma) and Lom (Lm) (Figure 2). There are three types of operating sites in this locality: sites operated only by mining companies, sites operated only by native populations and sites operated by both native populations and companies. It is the latter type of site that was the subject of our study.

2.2. Sampling

The dry season was more favourable for sampling. The sites were selected according to their accessibility and the type of exploitation practised. Sampling was done randomly for soils and sediments (Figure 2). A total of thirty samples (n=30) were taken from the sites of Mbal, Lom and Mali. The distance between sampling points varied between 120 and 200 metres.

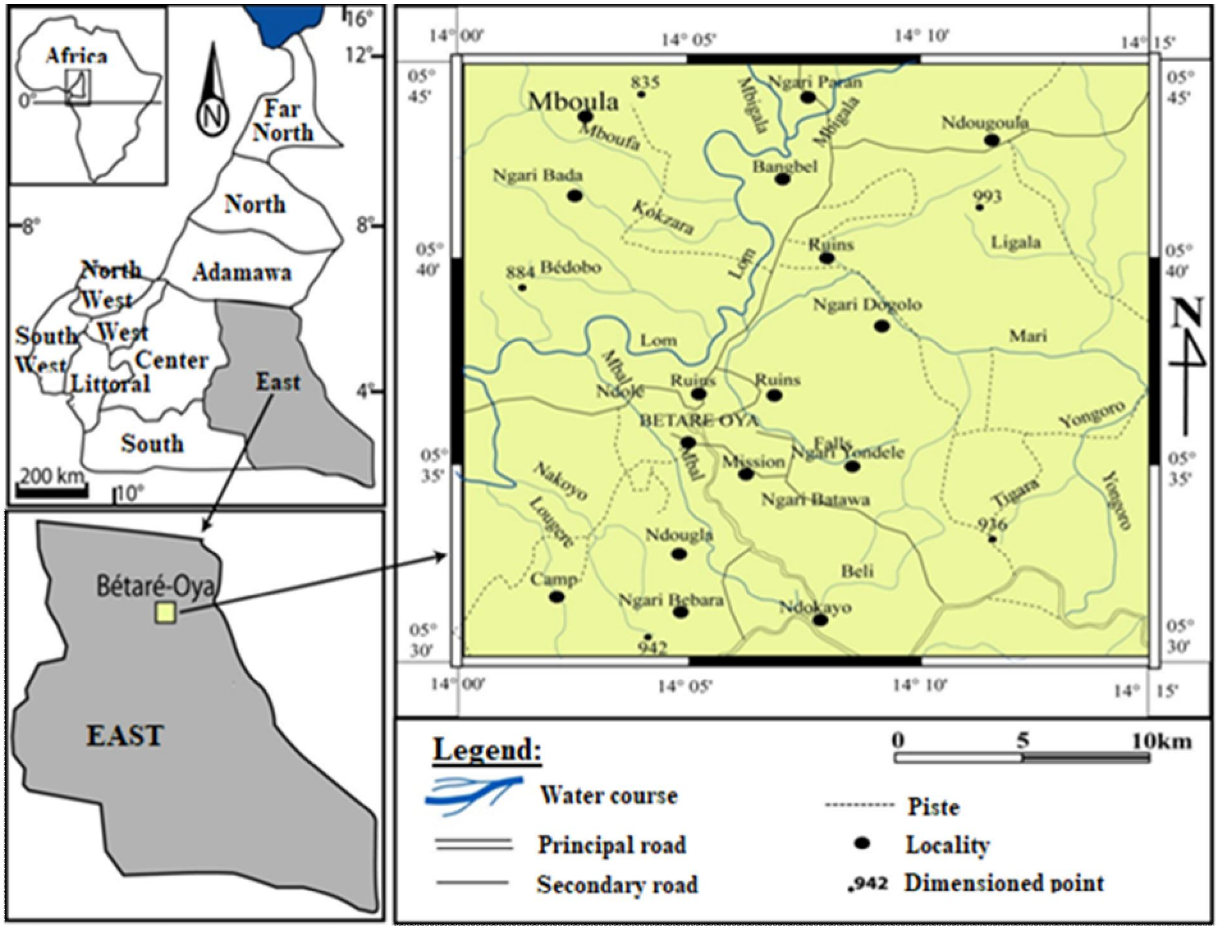

Figure1: **Localization map of the study area**

Soil sampling was carried out on exploited and control soils. The exploited soils are soils on which gold mining activities take place, while the control soils are soils on which no gold panning activities are carried out. A total of 21 soil samples (14 mined soil samples and 7 control soil samples) were taken approximately within the first 15 cm of the soil surface [14] demonstrated that metals always tend to accumulate in surface horizons rich in organic matter.

Surface sediments were collected along watercourses where mining takes place using a stainless steel spoon to avoid any type of contamination. Nine (09) samples of about 500 to 800 g were taken from the Mbal, Mali and Lom rivers.

Samples were kept in new plastic bags, labelled according to the watercourses and numbered in the order of collection and sent to the laboratory. The physico-chemical analyses (pH and EC) of the different soils and sediments were carried out at the Chemistry and Environment Laboratory of the University Institute of Technology (IUT) of the University of Ngaoundéré. Analyses of heavy metals in soils and sediments were carried out at the laboratory of Sejong University in South Korea. After drying, each soil and sediment sample was crushed and sieved. The fine fraction was chosen because metals associate more with it [15, 16 and 17]. A fraction of this sieve, greater than or equal to 10 grams, is analyzed for heavy metals. Soil and sediment pH was determined using the method described by [18]. This consists of putting 20 grams of the sieved soil and sediment into 50 ml of distilled water each. The mixtures are then stirred with a glass rod and left to stand before reading with the pH meter. According to [19] increasing pH promotes proton depletion and metal ion fixation, while acidic pH promotes proton fixation and dissolution of metal salts. With the same proportions in a beaker, the Electrical Conductivity was determined. The solutions were stirred and then filtered through filter paper and measured using a HANNA conductivity meter with a conductivity cell with automatic temperature correction. The levels of Trace Metal Elements (ETM) in soils and sediments were determined by inductively coupled plasma ionization source atomic emission spectrometry (ICP -AES).

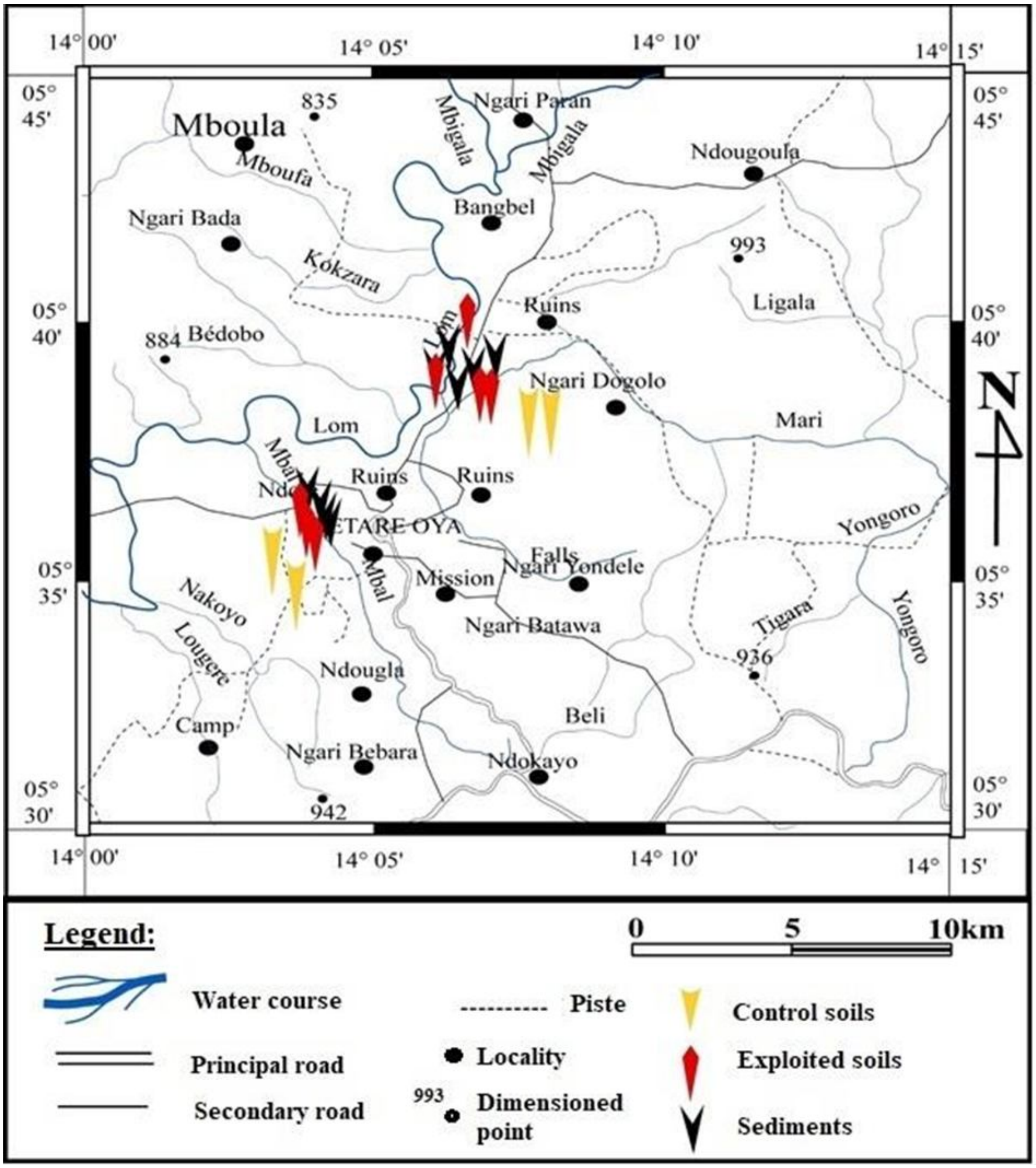

Figure 2: Sampling map

2.3. Estimation of the intensity of contamination

To estimate the intensity of contamination, indices were used. Their principle is based on the comparison of measured values with reference values such as averages of elemental contents in the earth's crust.

2.3.1. Enrichment Factor (EF)

The enrichment factor (EF) provides the number of times an element is enriched relative to the abundance of that element in the reference material. The reference materials used are those of the average shale defined by [20] Iron (Fe) was chosen as the immobile reference element for this calculation [21]. This choice is based on the fact that iron is naturally present in the sediments and soils of our study area. In addition, it is one of the reference materials widely used in the literature, [8, 22 and 23]. It is calculated according to the following formula:

$$EF= ([M]ech/[Fe]ech)/([M]RM/[Fe]RM)$$

Where: EF = enrichment factor; [M]ech= concentration of metal M in the sample; [Fe]ech= concentration of iron in the sample; [M]RM = concentration of metal M in the reference materials (RM) and [Fe]RM = concentration of iron in the reference materials (RM).

The EF values are grouped in five different categories: EF ≤ 2: absence to minimal enrichment; 2 < EF ≤ 5: moderate enrichment; 5 < EF ≤ 20: significant enrichment; 20 < EF ≤ 40: represent very high enrichment and EF > 40: extremely high enrichment [24].

2.3.2. The Geoaccumulation Index (Igeo)

The intensity of metal pollution is evaluated by a second criterion, which is [25] geoaccumulation index. The degree of contamination is estimated based on [26] continental crustal values. This empirical index compares a given concentration to a normalized geochemical background according to the following formula:

$$Igeo = Log2\ (Cn / 1.5\ Bn)$$

Where **Igeo** = geo-accumulation index; log2 = logarithm of base 2; n = element under consideration; C = measured concentration in the sample; **B = geochemical** background; 1.5 = geochemical background exaggeration factor, the function of which is to take account of the natural fluctuations of the geochemical background.

In addition, [25] defined a scale of values with six classes depending on the intensity of the pollution. This scale stipulates that: Igeo< 0 (class 0): no contamination; 0~1 (class 1): no to slight contamination; 1~2 (class 2): moderate contamination; 2~3 (class 3): moderate to heavy contamination; 3~4 (class 4): heavy contamination; 4~5 (class 5): heavy to extreme contamination and I-geo> 5 (class 6): indicates extreme contamination.

2.3.3. The contamination factor (CF) and Pollution load index (PLI)

Analysis of the Contamination Factor (CF) and Pollution Load Index (PLI) are other important tools for the assessment of heavy metal pollution. For the calculation of CF, elements such as Fe, Sr, As, Pb, Cu, and Zn are normalized using the corresponding mean values of metallic shales [20]. Indeed, the world average for shale is considered as a background value. The contamination factor (CF) was estimated using the following formula:

$$CF = \left(\frac{C_{metal}}{C_{background}}\right)$$

The CF can be classified as follows: FC < 1: low contamination, 1 ≤ **CF** < 3: moderate contamination, 3 ≤ **CF** < 6: considerable contamination and **CF** > 6: very high contamination [27]

The pollution load index (PLI) of a single site is the root of number (n) of multiplied together contamination factor (CF) values.

$$PLI = \sqrt[n]{(CF1 \times CF2 \times CF3 \times \ldots\ldots \times CFn}$$

Where, n is the number of metals and CF is the contamination factor. The pollution load index was interpreted after [28]. A PLI value under zero indicate unpolluted soils or sediments; zero indicates perfection; a value of one indicates the presence of only baseline levels of pollutants, and values above one would indicate progressive deterioration of the site quality [29, 30].

2.3.4. Ecological risk assessment (ERA)

The Ecological Risk Assesment is applied to evaluate heavy metal pollution in soil to associate ecological and environmental effects with their toxicology and the toxic-response factor. The ERA was carried out by potential ecological risk index (RI) for this study. The potential ecological risk index (RI) of the heavy metals is known as the sum of the risk factors, and it has been developed for six toxic metals using the equations of [27].

$$RI = \sum_1^n Er \qquad \text{and} \qquad Er = Tr \times CF$$

Where Er is the single index of ecological risk factor, and n is the amount of the heavy metal class, Tr toxic response factor suggested by [27] for six metals Cd (10), Pb (5), Hg (40), Cu (5), Ni (5), Zn (1). Er and RI express the potential ecological risk factor of individual and multiple metals respectively. The expressions and values used for the interpretation of the potential ecological risk factor [27] are indicated as follows: Er < 40: Low potential ecological risk; Er = 40- 80: Moderate potential ecological risk; Er:80- 160 Significant potential ecological risk; Er : 160- 320 High potential ecological risk; Er > 320: Very high potential ecological risk.RI < 150: Low ecological risk; RI: 150- 300 Moderate ecological risk; RI: 300- 600 Significant ecological risk; RI > 600: High ecological risk.

2.3.5. Statistical analyses

In order to determine the different correlations ($p < 0.05$) that exist between metals (Fe, Sr, As, Cu, Pb and Zn) studied on the one hand and between the latter and the physicochemical parameters on the other hand, Pearson correlation matrices have been established using software XLSTAT 2007 with the level of significance maintained at 95% for all tests.

3. RESULTS AND DISCUSSION

3.1. Physico-chemical parameters

Table I presents the results of pH and electrical conductivity (EC) measurements for sediments and soils. The pH varies for all samples from 5.01 to 8.34. The lowest value is recorded in sediments and the highest value in control soils. These pH values are similar to those obtained by [5] (5.40 to 8.84) in surface waters of the same locality. [31] also reports pH values between 5.5 and 7.8 in soils from a mining area in eastern Morocco. However, [32] found values between 4.20 and 7.70 in the exploited soils of Fel (kombo Laka-cameroon). The pH plays a very determining role in the behavior (mobility, bioavailability and solubility) of ETM [33]. These pH values would be related either to the geology of the locality dominated by the presence of metasedimentary rocks, volcano-sedimentary rocks and intrusive granites or to the gold mining activities practiced in the locality [5]. The EC gives values between 417 and 788 µS/cm for all samples. The lowest value is recorded in the control soils and the highest value in the mined soils. These conductivity values are greater than the values obtained by [32] in the Kombo Laka Mining Zone. These high conductivity values could be explained by the high positive charges of heavy metals contained in these samples, or by excessive mineralization attributed to leaching and runoff from mine tailings.

Table 1: Concentrations (mg/kg) of heavy metals and the physico-chemical analyses

Samples		**Fe**	**Sr**	**As**	**Cu**	**Pb**	**Zn**	**pH**	**CE**
Exploited soils (n=14)	**Min**	166.52	40.91	1.46	8.98	8.23	37.15	5.76	514
	Max	2089.97	397.62	2.68	32.21	9.57	216.83	8.11	788
	Mean	923.78	170.96	1.93	16.86	8.84	96.22		
Sediments (n=9)	**Min**	249.63	52.05	0.69	11.04	15.17	38.55	5.01	509
	Max	5664.9	121.63	2.81	36.92	25.91	113.85	8.05	737
	Mean	1993.62	84.96	1.82	24.2	18.04	65.69		
control soils (n=7)	**Min**	57.96	1.64	0.84	1.22	0.33	34,11	5.19	417
	Max	2796	374.41	3.75	18.05	1.83	182.04	8.34	669
	Mean	1257.45	73.48	1.62	11.67	1.01	59.72		
	UCC	46700	316	2	14	17	52		

	Average Shale	46700	300	1.3	45	20	95		

(n=numbers of samples)

3.2.The concentrations of heavy metals in the sediments and soils of Bétaré - Oya

Table 1 presents the results of trace elements concentrations in sediments, exploited soils and control soils. These results indicate the following values (in mg/kg):

In the sediment we have:

Fe: 249.63-5664.9 (mean 1993.62); Sr: 52.05-121.63 (mean 84.96); As: 0.69-2.81 (mean 1.82); Cu: 11.04-36.92 (mean 24.2); Pb: 15.17-25.91 (mean 18.04); Zn: 38.55-113.85 (mean 65.69).

In the exploited soils we have:

Fe: 166.52-2089.97 (mean 923.78); Sr: 40.91-397.62 (mean 170.96); As: 1.46 -2.68 (mean 1.93); Cu: 8.98-32.21 (mean 16.86); Pb: 8.23-9.57 (mean 8.84); Zn: 37.15-216.83 (mean 96.22).

In the control soils we have:

Fe: 57.96-2796 (mean 1295.12); Sr: 1.64-374.41 (mean 98.93); As: 0.84-3.75 (mean 1.77); Cu: 1.22-18.05 (mean 11.22); Pb: 0.33-1.83 (mean 1.02); Zn: 34.11-182.04 (mean 70.47).

These results show that in sediments, Fe, Cu and Pb have higher average heavy metal concentrations than in exploited and control soils, while Sr, As and Zn have slightly higher average concentrations in soils than in sediments. The concentration of ETM is higher in sediments than in control and exploited soils because sediments are often considered the site of heavy metal accumulation in the aquatic environment [34]. Sediment serves not only as a vector for the transport of pollutants, but also as a place for the storage and accumulation of heavy metals. In addition, tailings discharged to watercourses during operations can lead to a build-up of ETM in the sediment, which would subsequently act as a reservoir of ETM in the short or long term.

The sequences of ETM contents are: for sediments Fe >Sr> Zn > Cu >Pb> As; for exploited soils Fe >Sr> Zn > Cu > Pb > As and for control soils: Fe >Sr> Zn > Cu >As >Pb. These different sequences suggest that sediment and soil contamination depends on both the frequency and intensity of gold panning activities in the locality.

Comparison of the mean concentrations of the various heavy metals in this study shows that Fe has elevated concentrations in sediment (avg=1993.62 mg/kg), control soils (avg.=1295.12 mg/kg) and exploited soils (avg.=923.78 mg/kg) relative to other metals. These mean Fe levels (figure 3) obtained in the sediments are below the reference values for Average shale (46700 mg/kg) [20]; and UCC [26]. The different average concentrations obtained are lower than the average concentrations (16620 mg/kg) obtained by [7] on mine tailings discharges from the Mali Valley (Betare-Oya). The presence of iron in the analyzed sediments could be related either to its ubiquity in the samples and in the source rock, or to the oxidation of pyrite and sulphates in mine wastes that are rich in iron oxides, hydroxides and sulphides [34]. However, the decrease in Fe levels in soils relative to sediments could be explained by the possible migration of this element to the underlying horizons or by its leaching.

Sr is concentrated in both soils and sediments (figure 3). This would be attributed to both a natural source (bedrock) and leaching of this element from mine tailings into soils and streams that subsequently migrate to soils and sediments [11].

The mean concentration of Cu (figure 4) in sediment (24.2 mg/kg) is higher than that of exploited (16.86 mg/kg) and control soils (11.67). The high presence of this element in the sediments can be explained on the one hand by the fact that Cu is much more adsorbed in the sediment [36], and on the other hand by the oxidation of the chalcopyrite contained in the mine tailings. Indeed, [34] has also shown that the Cu present in the sediments of the Val de Milluni in Bolivia came from the oxidation of the chalcopyrite contained in mine tailings. The average Cu concentration in exploited soils is slightly higher than the maximum allowable limit for Cu concentrations (16mg/kg) in South African soils [37]. High soil concentrations are believed to be related to the high presence of organic matter in soils [36]. In fact, in the soils, the Cu is well distributed along the profiles and is preferentially fixed on the organic matter.

Figure 3: Variation in concentrations of Fe and Sr

The mean Pb (figure 4) content in sediment (24.2 mg/kg) is higher than the UCC reference value (14 mg/kg) [26] and the mean levels in exploited soils (8.84 mg/kg) and control soils (1.02 mg/kg). These levels are lower than the average concentration (35.49 µg/g) obtained by [38] in the stream sediments of the artisanal mining contamination in Ijero, southwest Nigeria. The presence of Pb in the sediments and exploited soils of the present study would be justified either by the oxidation of galena [34] or by the release of fuels and motor oils used in the operation of machinery and motor pumps used for gold panning. In addition, the mean Pb concentrations obtained in soils from this study are below the Canadian soil quality standard of 70 mg/kg [39].

The mean Zn concentration (figure 4) (96, 22 mg/kg) in exploited soils is higher than in sediment (65.69 mg/kg) and control soils (70.47 mg/kg), and these concentrations are above the UCC reference values (52 mg/kg) [26]. These high concentrations would result from the alteration of the different phases of sulphide minerals such as sphalerite which is the main ore of Zn contained in the source rock of the study area. Indeed, the work of [40, 41] noted the abundant presence of sphalerite, chalcopyrite and galena in the rocks of this locality. In addition, mining also contributes to the increase in this element through the direct discharge of mine tailings into watercourses and on land without vegetation cover. the average Zn concentrations in soils obtained in this study are higher than the average Zn concentration obtained by [4]in soils of the gold mining basin.

Figure 4 : Variation in concentrations of Cu, Pb and Zn

Mean As concentrations (figure 5) in exploited soils (1.93 mg/kg), sediments (1.82 mg/kg) and control soils (1.77 mg/kg) are above the reference values for Average Shale (1.3 mg/kg) and higher than the maximum allowable limit for As concentrations (1mg/kg) in Tanzanian soils [35]. For sediments and exploited soils, these high concentrations can be explained by gold panning activities. On the other hand for the control soils their values are higher than the abnormal because the gold mineralization is always accompanied by an enrichment in As these control soils abound in unexploited gold deposits. The As values in soils obtained in the present study are higher than those obtained by [3] in the soils of Anka artisanal gold mining area, Northwest Nigeria (0.64 µg/g. The high average As concentrations in contrôl soils may be due to alteration of the shales and granites that form part of the various lithological formations in this locality.

Figure 5: Variation in concentration of As

3.3. Estimating the intensity of site contamination

3.3.1. Enrichment factor (EF)

The calculation of the enrichment factor (EF) is an essential parameter to distinguish heavy metals of natural or anthropogenic origin [42]. The results of the soil and sediment EF for the study sites are presented in table 2. The variations of EF presented in figure 6 show that in exploited soils, Sr, As, and Zn show extremely high enrichment, Cu and Pb very high enrichment; however in sediments As and Pb extremely high enrichment, Cu and Zn show very high enrichment and Sr significant enrichment. In control soils As and Zn show extremely high enrichment, Cu and Pb significant enrichment and Sr enrichment represent very high enrichment. The enrichment of these various elements confirms the close relationship between the metallic contamination of sediments and soils and the gold mineralization, activities and gold panning methods practiced in this locality.

Table 2: Results of the EF calculation in exploited soils, sediments and control soils

	Samples	FE Sr	FE As	FE Cu	FE Pb	FE Zn
Exploited soils	Min	4.94	32.29	9.22	10.37	11.97
	Max	188.83	578.15	55.96	115.4	165.28
	Mean	49.03	163.88	26.53	39.18	79.53
Sediments	min	2.28	15.23	6.74	10.68	8.49
	Max	34.39	343.93	45.9	141.9	75.91
	Mean	13.32	92.53	21.37	45.39	31.34
control soils	Min	2.31	13.62	6.68	1.38	6.84
	Max	137.8	1066.04	23.28	32.23	327.68
	Mean	22.99	272.90	14.40	7.49	125.36

Figure 6: Variations of the Enrichment Factor (EF)

3.3.2 . Geoaccumulation Index (Igeo)

The results of the I-geo are presented in table 3. The variation of Igeo in exploited soils, sediments and control soils presented in figure 7 show that As indicates a slight contamination (class 1) in soils and sediments. however, Fe, Sr, Cu, Pb and Zn indicate an extreme contamination (class 6) of these elements in sediments and soils. The main sources of contamination of these elements in soils and sediments in this study would be gold panning activities and natural sources related to soil genetic processes (weathering of bedrock) that could also contribute to the contamination of these elements. It should be noted that the natural contamination is well expressed in the control soils.

Table 3: Results of the calculation of I-geo

	Samples	Igeo Fe	Igeo Sr	Igeo As	Igeo Cu	Igeo Pb	Igeo Zn
Exploited soils	Min	22.31	13.00	0.34	8.07	6.78	11.20
	Max	25.96	16.28	1.22	9.92	7.00	13.75
	Mean	24.78	15.06	0.74	8.98	6.88	12.57
Sediments	Min	22.89	13.35	-0.74	8.37	7.66	11.25

	Max	27.39	14.57	1.28	10.11	8.43	12.82
	Mean	25.89	14.05	0.66	9.50	7.91	12.02
control soils	Min	20.78	8.36	-0.46	5.19	2.14	11.08
	Max	26.38	16.19	1.70	9.08	4.61	13.49
	Mean	25.27	14.27	0.62	8.39	3.77	12.12

Figure 7: Variations of the Geo-accumulation Index (I-geo)

3.3.3 . Contamination Factor (CF) and Pollution Load Index (PLI)

The CF and PLI were used in this study to assess the sediment and soil environment of Bétaré-Oya and to understand the changes in the degree of sediment and soil contamination in the different samples. Table 4 and figure 8 present the results of the calculations and the variations in CF and PLI. It can be seen from this figures that in the exploited soils Fe, Cu and Pb are the metals with a CF<1 corresponding to an absence of contamination to a low contamination, on the other hand Sr, As and Zn have a 1≤CF≤3, which corresponds to a moderate contamination. In sediments Fe, Sr, and Cu show an absence of contamination to low contamination (CF<1); Pb, As, and Zn show moderate contamination (1≤CF≤3). In the control soils Fe, Cu and Pb also show an absence of contamination to moderate contamination. In exploited soils, As and Zn show moderate contamination. The PLI values in this study are greater than 0, which corresponds to low metal contamination. These various contaminations are said to be linked to gold panning, which is the main activity practised by the local population. Contamination in the control soils would be justified by natural inputs (weathering of bedrock and atmospheric deposition, etc.).

Table 4: Calculation results for CF and PLI

	Samples	CF Fe	CF Sr	CF As	CF Cu	CF Pb	CF Zn	PLI
exploited soils	Min	0.004	0.14	1.12	0.2	0.41	0.39	0.18
	Max	0.045	1.33	2.06	0.72	0.48	2.28	0.56
	Mean	0.019	0.54	1.47	0.365	0.44	0.96	0.37
Sediments	min	0.005	0.17	0.53	0.25	0.76	0.41	0.17
	Max	0.121	0.41	2.16	0.82	1.3	1.2	0.67
	Mean	0.038	0.28	1.58	0.54	0.87	0.66	0.42
control soils	Min	0.0012	0.005	0.65	0.03	0.02	0.36	0.03
	Max	0.06	1.248	2.88	0.4	0.09	1.92	0.22
	Mean	0.027	0.24	1.24	0.26	0.05	0.63	0.26

Figure 8: Variations of the contamination factor (CF) and Pollution load index (PLI)

3.3.4. Ecological risk assessment (ERA)

The Er and RI for heavy metals (Cu, Pb and Zn) at the study sites are shown in Table 5. Er in soils and sediments showed a low potential ecological risk factor (Er < 40) and a low ecological risk (RI<150) for Pb, Zn and Cu. According to the ecological risk assessment, the study area is a low ecological risk and therefore has no impact on living beings.

Table 5: potential ecological risk index (RI) potential ecological risk factor (Er)

	Samples	**Er Cu**	**Er Pb**	**Er Zn**	**RI**
Exploited soils	Min	1	2,05	0,39	3,44
	Max	3,6	2,4	2,28	8,28
	Mean	1,825	2,2	0,96	4,985
Sediments	min	1,25	3,8	0,41	5,46
	Max	4,1	6,5	1,2	11,8
	Mean	2,7	4,35	0,66	7,71
Control soils	Min	0,15	0,1	0,36	0,61
	Max	2	0,45	1,92	4,37
	Mean	1,3	0,25	0,63	2,18

3.4. Correlations between heavy metals and physico-chemical parameters

Pearson correlation coefficients *(r)* were calculated using XLSTAT software (Addinsoft 2013) to examine the correlation $(p < 0.05)$ between metal concentrations in different parameters (tables 6, 7 and 8). The Pearson Correlation Matrix has proven useful in providing a reliable classification of metals and physicochemical properties of soils and sediments. This approach has been widely used in the classification of study sites in geochemical and water quality analyses [32, 36, 43 and 44].

In sediments (table 6), there is a positive and very significant correlation between: Fe/Pb, (0.934 to 0.998); positive and moderately significant correlations are observed between: As/Zn and Pb/Zn (0.748 - 0.881) and positive and moderately significant correlations are observed between: As/Pb, Fe/Zn and pH/CE (0.598 to 0.655).

Table 6: Pearson correlation matrix between physico-chemical parameters and heavy metals in sediments

Variables	**Fe**	**Sr**	**As**	**Cu**	**Pb**	**Zn**	**pH**	**CE**
Fe	**1**							
Sr	0.145	**1**						
As	0.434	-0.109	**1**					
Cu	0.188	-0.005	-0.359	**1**				
Pb	**0.968**	0.055	**0.613**	0.042	**1**			

Zn	**0.655**	0.444	**0.733**	-0.237	**0.748**	**1**		
pH	0.111	-0.102	-0.028	0.178	0.018	-0.082	**1**	
CE	0.417	0.124	0.101	**0.532**	0.336	0.167	**0.598**	**1**

In the exploited soils (table 7) there is a positive and very significant correlation observed between: Sr/Zn (0.935 - 0.924); a positive and moderately significant correlation: Fe/Cu, (0.704 - 0.816), positive and moderately significant correlations: Fe/Pb, Cu/CE and Pb/CE (0.502 - 0.660) and a negative and moderately significant correlation between: As/Pb (-0.561).

In the control soils, the analysis of table 8 shows that positive and highly significant correlations are observed between: Fe/Pb and Sr/Zn (0.900 - 0.998); positive and moderately significant correlations are observed between : Fe/Cu and Cu/Pb, (0.704 to 0.885); positive and moderately significant correlations between: Cu/ pH and Fe/pH (0.545 to 0.693) and negative and moderately significant correlations between: pH/CE, Zn/CE, Cu/CE and Sr/CE (-0.668 to -0.525)

Table 7: Pearson correlation matrix between physico-chemical parameters and heavy metals in exploited soils

Variables	**Fe**	**Sr**	**AS**	**Cu**	**Pb**	**Zn**	**pH**	**CE**
Fe	**1**							
Sr	-0.166	**1**						
AS	-0.378	-0.100	**1**					
Cu	**0.762**	-0.446	-0.452	**1**				
Pb	**0.619**	0.375	**-0.561**	0.420	**1**			
Zn	-0.063	**0.935**	-0.263	-0.317	0.497	**1**		
pH	0.066	0.137	-0.152	-0.144	0.056	0.275	**1**	
CE	0.419	-0.141	-0.468	**0.582**	**0.516**	-0.030	0.111	**1**

Tables 8: Pearson correlation matrix between physico-chemical parameters and heavy metals in control soils

Variables	**Fe**	**Sr**	**As**	**Cu**	**Pb**	**Zn**	**pH**	**CE**
Fe	**1**							
Sr	-0.222	**1**						
As	-0.069	-0.351	**1**					
Cu	**0.885**	-0.025	0.228	**1**				
Pb	**0.902**	-0.062	-0.277	**0.709**	**1**			
Zn	-0.382	**0.981**	-0.329	-0.183	-0.231	**1**		
pH	**0.693**	0.199	-0.222	**0.699**	0.494	0.122	**1**	
CE	-0.387	**-0.668**	0.056	**-0.525**	-0.425	**-0.587**	**-0.627**	**1**

The positive and significant correlations observed between most of the metals studied could be explained by a possible common origin or could have the same chemical properties; on the other hand, the negative correlations could evoke either different origins between these elements or also the fact that an increase in the concentration of one element could lead to a decrease in the concentration of the other. The positive and very significant correlations observed between Pb, Zn and Cu can be explained by the fact that Pb is readily associated in nature with zinc, silver and copper ores. Fe is positively correlated with most metals at the sampling sites, and this may be explained by the fact that in soils, iron oxides and hydroxides promote the concentration of these metals (Cu, Pb, Zn, As and Sr) [45]. The fact that most of the metals studied (Zn, Pb, Cu, etc.) are from the chalcophiles family could also explain these correlations.

4. CONCLUSION

The objective of this study was to study the impact of gold mining on the metallic contamination of sediments and soils in the locality of Bétaré-Oya. For this purpose, sediment and soil samples were taken to determine the pollution level of heavy metals (Fe, Sr, As, Cu, Pb and Zn). The results obtained show that in As, Cu, Pb and Zn sediments have mean concentrations slightly higher than the UCC reference values. However, in exploited soils only Zn shows an average concentration slightly higher than the UCC reference values. Calculations of the enrichment factor, contamination factor,

geoaccumulation index, the ecological risk and PLI showed high contamination for Sr, As, Pb, Cu and Zn in sediments and soils with these elements. The main source of this contamination is believed to be gold mining activities and techniques. This study revealed that gold mining contributes to the pollution of the sediments and soils of Bétaré-Oya. However, contamination in the control soils would be justified by natural inputs (weathering of bedrock and atmospheric deposition). This pollution is a risk on the one hand for the populations who use these soils for crops and these waters for domestic activities. On the other hand, groundwater contamination by these ETM is possible. At the end of this study we suggest the restoration of the sites after exploitation and the respect of the environmental rules during and after the exploitation for the reduction of the impacts of this activity and the pollution in this locality.

REFERENCES

[1]. CALLENDER, E., HEAVY METALS IN THE ENVIRONMENT-HISTORICAL TRENDS. IN: B.S. LOLLAR (ED.), ENVIRONMENTAL GEOCHEMISTRY. TREATISE ON GEOCHEMISTRY. ELSERVIER-PERGAMON, OXFORD, PP. 67-105. (2003).

[2]. KABATA-PENDIAS A. AND PENDIAS H. TRACE ELEMENTS IN SOILS AND PLANTS. BOCA RATON, THIRD ED. CRC PRESS, BOCA RATON, FLORIDA. FL:CRC PRESS. 2001. ISBN: 0849315751. 413P.

[3]. ADEWUMI AJ, LANIYAN TA. CONTAMINATION, SOURCES AND RISK ASSESSMENTS OF METALS IN MEDIA FROM ANKA ARTISANAL GOLD MINING AREA, NORTHWEST NIGERIA. THE SCIENCE OF THE TOTAL ENVIRONMENT. 2020 MAY;718:137235. DOI: 10.1016/J.SCITOTENV.2020.137235.

[4]. KAMUNDA C, MATHUTHU M, MADHUKU M. HEALTH RISK ASSESSMENT OF HEAVY METALS IN SOILS FROM WITWATERSRAND GOLD MINING BASIN, SOUTH AFRICA. INT J ENVIRON RES PUBLIC HEALTH. 2016;13(7):663. PUBLISHED 2016 JUN 30. DOI: 10.3390/IJERPH13070663.

[5]. RAKOTONDRABE F, NGOUPAYOU, JRN, MFONKA Z, RASOLOMANANA EH, ABOLO AJN,

ASONE BL, AKO AA, RAKOTONDRABE MHASSESSMENT OF SURFACE WATER QUALITY OF BETARE-OYA GOLD MINING AREA (EAST-CAMEROON). JOURNAL OF WATER RESOURCE AND PROTECTION (2017), 9, 960-984. HTTPS://DOI.ORG/10.4236/JWARP.2017.98064

[6]. TEHNA N, NGUENE FD, ETAME J, MEDZA EKODO JM, NOA TS, SUH CE, BILONG P

IMPENDING POLLUTION OF BETARE OYA OPENCAST MINING ENVIRONMENT (EASTERN CAMEROON). J ENVIRON SCI ENG 4:37–46 (2015). HTTPS://DOI.ORG10.17265/2162-5263/2015.01.006.

[7]. PAHIMI H, PANDA CR, NGASSOUM MB, TCHAMENI R ENVIRONMENTAL IMPACTS OF MINING IN THE VOLCANO-SEDIMENTARY BASINS OF CAMEROON: CASE STUDY OF ARTISANAL GOLD MINE TAILINGS (BETARE OYA, EAST-CAMEROON). INTERNATIONAL JOURNAL OF ENERGY, SUSTAINABILITY AND ENVIRONMENTAL ENGINEERING, 2: 5-15. VOL. 2 (1), SEPTEMBER 2015, PP. 5-15

[8]. EKOA BESSA AZ, YASSER A. EL-AMIER, EDJENGTE DOUMO EP, NGUEUTCHOUA G (2018): ASSESSMENT OF SEDIMENTS POLLUTION BY TRACE METALS IN THE MOLOUNDOU SWAMP, SOUTHEAST CAMEROON. ANNUAL RESEARCH & REVIEW IN BIOLOGY 30(1)2018: 1-13.

[9]. CHABUKDHARA M, GUPTA SK, KOTECHA Y, NEMA AK GROUNDWATER QUALITY IN GHAZIABAD DISTRICT, UTTAR PRADESH, INDIA: MULTIVARIATE AND HEALTH RISK ASSESSMENT. CHEMOSPHERE 179:167–178. (2017)

[10] TEHNA, N., SABABA, E., BESSA, A.Z.E., ETAME, J. MINE WASTE AND HEAVY METAL POLLUTION IN BETARE-OYA MINING AREA (EASTERN CAMEROON). ENVIRONMENTAL AND EARTH SCIENCES RESEARCH JOURNAL, VOL. 6, NO. 4, 2019 PP. 167-176. HTTPS://DOI.ORG10.18280/EESRJ.060404

[11]. VÉRONICA EM, NCHANG NG, SUH EC ENVIRONMENTAL GEOCHEMISTRY OF MINE TAILINGS SOILS IN THE ARTISANAL GOLD MINING DISTRICT OF BÉTARÉ -OYA, CAMEROON. EP.CCSENET.ORG ENVIRONMENT AND POLLUTION; VOL. 6, NO. 1; 2017 ISSN 1927-0909 E-ISSN 1927-0917 PUBLISHED BY CANADIAN CENTER OF SCIENCE AND EDUCATION HTTPS://DOI.ORG/10.5539/EP.V6N1P52

[12]. TOTEU S, PENAYE J, DELOULE E, VAN SCHMUS WR, TCHAMENI R DIACHRONOUS

EVOLUTION OF VOLCANO-SEDIMENTARY BASINS NORTH OF THE CONGO CRATON: INSIGHTS FROM UŔPB ION

MICROPROBE DATING OF ZIRCONS FROM THE POLI, LOM AND YAOUNDE´ GROUPS (CAMEROON) 429 P. (2006) HTTPS://DOI.ORG/10.1016/J.JAFREARSCI.2005.11.011

[13]. CAPAM: CENTRE D'APPUI ET DE PROMOTION DES ACTIVITÉS MINIÈRES ENVIRONMENTAL MONITORING MISSION OF ARTISANAL MINING SITES IN THE EAST AND ADAMAWA REGIONS. (2016) 44 P.

[14] KOUAME IK , GONE DL, SAVANE I , KOUASSI E A , KOFFI K , GOULA BTA ET 18. DIALLO M. MOBILITE RELATIVE DES METAUX LOURDS ISSUS DE LA DECHARGE D’AKOUEDO ET RISQUE DE CONTAMINATION DE LA NAPPE DU CONTINENTAL TERMINAL (ABIDJAN - COTE D’IVOIRE). 2006 10.4314 / AFSCI.V2I1.61133

[15]. KOUAKOU K. STUDY OF TRACE METALS (CD, CU, PB, ZN, NI) IN SOILS AND GROUNDWATER.

DOCTORATE, UNIVERSITY OF ABOBODJAME, ABIDJAN, 2009 126P.

[16]. TOURE N.,YAO A., ALUI K. A., GUETY T. P. EVALUATION EN ELEMENTS MAJEURS ET TRACES METALLIQUES D’UN ENVIRONNEMENT DE PRODUCTION AGRICOLE DANS LA VALLEE DU NIEKI AU SUD-EST DE LA COTE D’IVOIRE. JOURNAL OF APPLIED BIOSCIENCES (34), PP. 2134-2144. VOL. 34, 2010, PP. 2134-2144. HTTP://WWW.AJOL.INFO/INDEX.PHP/JAB/INDEX

[17]. KEUMEAN K, SIAKA B, GBOMBELÉ S, NAGNIN S, BERNAD S, METONGO. CONCENTRATION OF HEAVY METALS IN THE SEDIMENTS OF THE COMOÉ RIVER ESTUARY AT GRAND-BASSAM (SOUTH-EAST CÔTE D'IVOIRE). JOURNAL OF APPLIED BIOSCIENCES (61) (2013), 4530-4539.

[18]. MATHIEU C AND PIELTAIN F ANALYSE CHIMIQUE DES SOLS METHODES CHOISIES. EDITIONS TEC ET DOC/LAVOISIER, PARIS, (2003) 408 P.

[19]. PICKERING WF METAL ION SPECIATION- SOILS AND SEDIMENTS. ORE GEOLOGY REVIEWS 1, 83-146. (1986)

[20]. TUREKIAN KK, WEDEPOHL KH. DISTRIBUTION OF THE ELEMENTS IN SOME MAJOR UNITS OF THE EARTH'S CRUST. GEOLOGICAL SOCIETY OF AMERICA BULLETIN, 72(2): 175-19 HTTP://DX.DOI.ORG/10.1130/0016- 7606(1961)72%5B175:DOTEIS%5D2.0.CO;2

[21]. AGUNBIADE FO, FAWALE AT. USE OF SIAM WEED BIOMARKER IN ASSESSING HEAVY METAL CONTAMINATIONS IN TRAFFIC AND SOLID WASTE POLLUTED AREAS, INTERNATIONAL JOURNAL ENVIRONMENT SCIENCES TECHNOLOGY. 6 (2), 267-276. (2009)

[22. LIU W, ZHAO J, OUYANG Z, SODERLUND L, LIU G IMPACTS OF SEWAGE IRRIGATION ON HEAVY METAL DISTRIBUTION AND CONTAMINATION IN BEIJING, CHINA. ENVIRONMENT INTERNATIONAL, 31, 805-812 (2005) . HTTP://DX.DOI.ORG/10.1016/J.ENVINT.2005.05.042

[23]. FANG TH, HWANG JS, HSIAO SH, CHEN HY. TRACE METALS IN SEAWATER AND

COPEPODS IN THE OCEAN OUTFALL AREA OFF THE NORTHERN TAIWAN COAST. MARINE ENVIRONMENTAL RESEARCH, 61, 224-243 (2006) . HTTP://DX.DOI.ORG/10.1016/J.MARENVRES.2005.10.002

[24]. LOSKA K, CEBULA J, PELCZAR J. USE OF ENRICHMENT, AND CONTAMINATION FACTORS TOGETHER WITH GEOACCUMULATION INDEXES TO EVALUATE THE CONTENT OF CD, CU, AND NI IN

THE RYBNIK WATER RESERVOIR IN POLAND. WATER, AIR, & SOIL POLLUTION 93, 347–365 (1997) HTTPS://DOI.ORG/10.1023/A:1022121615949

[25]. MULLER G. INDEX OF GEOACCUMULATION IN SEDIMENTS OF THE RHINE RIVER. GEOJOURNAL, 2(3): 108-118. (1969).

[26]. WEDEPOHL K. THE COMPOSITION OF THE CONTINENTAL CRUST. GEOCHEMICA AND COSMOCHIMICA ACTA, 59, PP. 1217-1232. (1995)

[27]. HAKANSON L. ECOLOGICAL RISK INDEX FOR AQUATIC POLLUTION CONTROL. A SEDIMENTOLOGICAL APPROACH. WATER RESEARCH, 14, 5, 975-1001. (1980)

[28]. HARIKUMAR PS, NASIR UP, RAHMAN MM. DISTRIBUTION OF HEAVY METALS IN THE CORE SEDIMENTS OF A TROPICAL WETLAND SYSTEM. INTERNATIONAL JOURNAL OF ENVIRONMENTAL SCIENCE & TECHNOLOGY, 6(2): 225-232 (2009). HTTP://DX.DOI.ORG/10.1007/BF03327626.

[29]. TOMLINSON DL, WILSON JG, HARRIS CR, EFFREY DW. PROBLEMS IN THE ASSESSMENT OF HEAVY-METAL LEVELS IN ESTUARIES AND THE FORMATION OF A POLLUTION INDEX. HELGOLÄNDER MEERESUNTERSUCHUNGEN.1980; 33(1):566.

[30]. SESHAN BRR, NATESAN U, DEEPTHI K. GEOCHEMICAL AND STATISTICAL APPROACH FOR EVALUATION OF HEAVY METAL POLLUTION IN CORE SEDIMENTS IN SOUTHEAST COAST OF INDIA. INTERNATIONAL

JOURNAL OF ENVIRONMENTAL SCIENCE & TECHNOLOGY, 7(2): 291 - 306(2010) HTTP://DX.DOI.ORG/10.1007/BF03326139

[31]. ABDELAZIZ SMOUNI, MOHAMMED ATER, FLORENCE AUGUY, LAURENT LAPLAZE, MOHAMMED EL MZIBRI, FATIHA BERHADA, ABDELKARIM FILALI-MALTOUF, PATRICKDOUMAS . ÉVALUATION DE LA CONTAMINATION PAR LES ELEMENTS-TRACES METALLIQUES DANS UNE ZONE MINIERE DU MAROC ORIENTAL. CAHIERS AGRICULTURES, EDP SCIENCES, 2010, 19 (4), PP.273-279. <10.1684/AGR.2010.0413> <HAL-01219555>.

[32]. EKENGÉLÉ NL, SABINE DD, PHILÉMON ZZ, JUNG MC PHYSICAL AND METALS IMPACT OF TRADITIONAL GOLD MINING ON SOILS IN KOMBO-LAKA AREA (MEIGANGA, CAMEROON). INTERNATIONAL JOURNAL OF GEOSCIENCES, 7, 1102-1121(2016). HTTP://DX.DOI.ORG/10.4236/IJG.2016.79084

[33]. JEAN-BAPTISTE SIRVEN. DETECTION DE METAUX LOURDS DANS LES SOLS PAR SPECTROSCOPIE D'EMISSION SUR PLASMA INDUIT PAR LASER (LIBS). PHYSIQUE ATOMIQUE [PHYSICS.ATOM-PH]. UNIVERSITE SCIENCES ET TECHNOLOGIES - BORDEAUX I, 2006. FRANÇAIS. FFTEL-00122546F HTTPS://TEL.ARCHIVES-OUVERTES.FR/TEL-00122546

[34]. MATIAS MIGUEL SALVARREDY ARANGUREN. CONTAMINATION EN METAUX LOURDS DES EAUX DE SURFACE ET DES SEDIMENTS DU VAL DE MILLUNI (ANDES BOLIVIENNES) PAR DES DECHETS MINIERS APPROCHES GEOCHIMIQUE, MINERALOGIQUE ET HYDROCHIMIQUE. PLANETE ET UNIVERS [PHYSICS]. UNIVERSITE PAUL SABATIER - TOULOUSE III, 2008. FRANÇAIS. FFTEL-00277431F. HAL ID: TEL-00277431 HTTPS://TEL.ARCHIVES-OUVERTES.FR/TEL-00277431

[35]. HE, Z.; SHENTU, J.; YAN, X.; BALIGAR, V.C.; ZHANG, T.; STOFFELLA, P.J. HEAVY METAL CONTAMINATION OF SOILS: SOURCES, INDICATORS, AND ASSESSMENT. J. ENVIRON. INDIC. 2015, 9, 17–18

[36] EKENGELE LN, BLAISE A, JUNG M. ACCUMULATION OF HEAVY METALS IN SURFACE SEDIMENTS OF LERE LAKE, CHAD. GEOSCI J 21, 305– 315 (2017). HTTPS://DOI.ORG/10.1007/S12303-016-0047-4

[37]. DEPARTEMENT OF ENVIRONMENT AFFAIRS. THE FRAMEWORK FOR THE MANAGEMENT OF CONTAMINATE LAND, SOUTH AFRICA. AVAILABLE ONLINE:

HTTP://SAWIC.ENVIRONMENT.GOV.ZA/DOCUMENTS/52 PDF (ACCESSED ON 5 FEBRUARY 2016).

[38]. TEMITOPE AYODEJI LANIYAN & ADENIYI JOHNPAUL ADEWUMI: POTENTIAL

ECOLOGICAL AND HEALTH RISKS OF TOXIC METALS ASSOCIATED WITH ARTISANAL MINING CONTAMINATION

IN IJERO, SOUTHWEST NIGERIA, JOURNAL OF ENVIRONMENTAL SCIENCE AND HEALTH, (2020) PART A, DOI:

10.1080/10934529.2020.1751504 HTTPS://DOI.ORG/10.1080/10934529.2020.1751504.

[39]. CCME CANADIAN SOIL QUALITY GUIDELINES FOR THE PROTECTION OF ENVIRONMENT AND HUMAN HEALTH. CANADIAN COUNCIL OF MINISTERS OF THE ENVIRONMENT. (2006) HTTP://WWW.CCME.CA/OURWORK/SOIL.HTML

[40]. FON AF, BIH VC, CHEO ES. APPLICATION OF ELECTRICAL RESISTIVITY AND CHARGEABILITY DATA ON A GIS PLATFORM IN DELINEATING AURIFEROUS STRUCTURES IN A DEEPLY WEATHERED LATERITIC TERRAIN, EASTERN CAMEROON. INTERNATIONAL JOURNAL OF GEOSCIENCES , 2, 960-971. (2012) HTTPS://DOI.ORG/10.4236/IJG.2012.325097.

[41]. MIMBA ME, OHBA T, FILS SCN, NFORBA MT, NUMANAMI N, BAFON TG, SUH CE. REGIONAL GEOCHEMICAL BASELINE CONCENTRATION OF POTENTIALLY TOXIC TRACE METALS IN THE MINERALIZED LOM BASIN, EAST CAMEROON: A TOOL FOR CONTAMINATION ASSESSMENT. GEOCHEMICAL TRANSACTIONS, 19(1)2018: 11. HTTP://DX.DOI.ORG/10.1186/S12932-018-0056-5

[42]. PRAVEENA SM, ARIS AZ AND RADOJEVIC M. HEAVY METALS DYANAMICS AND SOURCE IN

INTERTIDAL MANGROVE SEDIMENT OF SABAH BORNEO ISLAND. ENVIRONMENT ASIA, 3, 79-83.

[43]. BAM PKE, AKITI TT, OSEA DS, GANYAGLO YS.AND GIBRILLA A. MULTIVARIATE CLUSTER ANALYSIS OF SOME MAJOR AND TRACE ELEMENTS DISTRIBUTION IN AN UNSATURATED ZONE PROFILE, DENSU RIVER BASIN, GHANA. AFRICAN JOURNAL OF ENVIRONMENTAL SCIENCE AND TECHNOLOGY, 5, 155-167. (2011. HTTP://WWW.ACADEMICJOURNALS.ORG/AJEST

[44]. BHUIYAN MAH, PARVEZ L, ISLAM MA, DAMPARE SB, SUZUKI S HEAVY METAL POLLUTION OF COAL MINE AFFECTED AGRICULTURAL SOILS IN THE NORTHERN PART OF BANGLADESH.

JOURNAL OF HAZARDOUS MATERIALS, 173, 384-392. (2010)

[45]. EKENGELE NL, MABREY S , ZO’O ZAME P. EVALUATION DE LA CONTAMINATION METALLIQUE DES SOLS EXPOSES A L’INCINERATION DES PNEUS D’AUTOMOBILES DANS LA VILLE DE NGAOUNDERE (CAMEROUN) J. MATER. ENVIRON. SCI. 7 (12) (2016) 4633-4645.