

Environmental Assessment by Metallic Trace Elements of Gold Soils – Case of Chami (Dakhlet Nouadhibou, Mauritania)

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ABSTRACT

In the Inchiri region of northern Mauritania, the discovery of new artisanal methods for extracting gold has made the town of Chami a strategic location for gold miners and their mining operations. Despite the importance of this activity in the country's economy, to the significant revenues it provides, it is still likely to have a negative impact on the various environmental compartments. The objective of this study was to assess the environmental impact of trace metal elements (ETM) from gold panning in the soils of Chami area. For this purpose, forty soil samples were collected during a field mission in May 2022. The geochemical analyses of the ETM (As, Co, Cr, Cu, Hg, Pb, Ni and Zn) were carried out at the ALS laboratory in Dublin, using the inductively coupled plasma - atomic emission spectroscopy (ICP-AES) technique. The results show that the concentrations of ETM in soils differ according to the sampling station and the considered metal. These concentrations sometimes exceed the normal thresholds. The average value of the pollution index is higher than 1, revealing soil contamination by several elements (As, Cu, Hg and Pb). The geo-accumulation index varying between 0 and 4 shows a medium to high soil pollution class. The correlation matrix obtained shows positive correlations between the studied elements, which suggest that they have the same anthropic origin. These results show an accumulation of metals in soils that can persist in the environment, especially Hg, the most toxic element that is easy to diffuse and change speciation, in addition to being capable of causing risks to the environment and human health.

Keywords: gold mining, soils, pollution assessment, heavy metals, Chami, Mauritania.

INTRODUCTION

In several African countries, mining has become a major economic activity and a source of income for a significant number of the population (Hilson, 2002). However, the exploitation of these resources can be a source of environmental degradation, endangering certain environmental compartments (soil, water, atmosphere, etc.). Thus,

the exploitation of mining potential probably remains a source of contamination of soils by several harmful chemical substances, including trace metal elements (ETM). This contamination is due to the accumulation of metals resulting from industrialization, atmospheric deposition, mine tailings and coal, gasoline and fertilizer combustion. These metals released into the environment by human activities persist and are no longer degraded

(Aucejo et al., 1997). Also, high concentrations of metals in the soil can have negative consequences on human health and adverse effects on the environment (Bougherara et al., 2011).

In Mauritania, artisanal gold mining has become a booming activity in 2016, where the Mauritanian country has remarkably authorized the activity of gold panning, especially with the surge in gold prices and the discovery of artisanal mining methods of this type of deposit. Gold panning is practiced in several regions, including Chami, Zouérate, and Chegatt in the north of the country (Figure 1). The town of Chami is the closest to the region that hosts numerous gold deposits and showings. This is where Mauritania's main mineral resources are concentrated (Tasiast, Tijirite). However, this activity is considered a source of environmental pollution and human health deterioration (Driscoll et al. 2013) due to the use of toxic chemicals in the gold mining process. Among these chemicals, mercury (Hg) is the most commonly used in this process in Mauritania. It is used to separate the gold from the ore. During gold recovery, Hg is used in all stages of extraction. During this process, it can be lost directly to the environment through mining waste, or emitted to the atmosphere when amalgam is burned (Guedron et al., 2009). Gold panning is the largest source of Hg; it releases 1400 tons into the atmosphere, soil, and water (Schmidt,

2012). Once introduced into the environment, mercury can undergo speciation changes that are either physicochemical or biologically induced, resulting in changes in solubility, toxicity or bio-availability (Biester et al., 2002). At the Chami processing center, gold recovery activities are intense and continue day and night, with the extensive use of mercury in the various stages of gold extraction. These activities play an important role in the increase and release of mercury into the environment. This study, the first of its kind, allows assessing the impact of traces metallic elements and mercury use in gold panning on soil pollution in the town of Chami.

METHODS AND MATERIALS

Geographical context

The town of Chami (study area) is a department of the Dakhlet Nouadhibou region, located approximately 250 km from the capital city of Nouakchott, in the northern part of the Senegal-Mauritania basin in southwestern Mauritania between latitudes $-16^{\circ}0'$ and $-16^{\circ}15'W$ and longitudes 20° and $20^{\circ}15'N$ (Figure 1). This area is rich in industrial activities, particularly mining, since the majority of the inhabitants are gold miners and civil servants in the mining sector. This activity

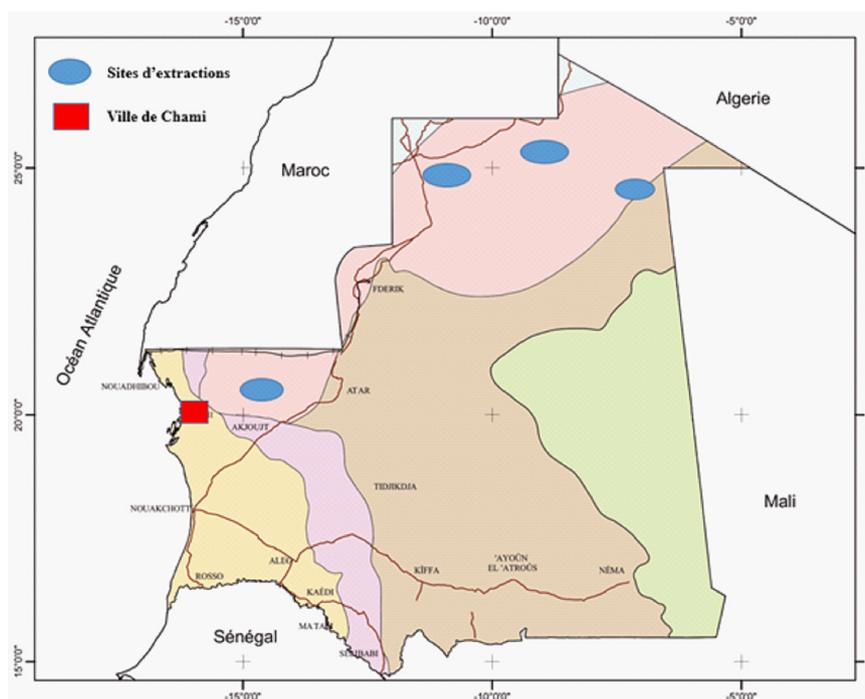


Figure 1. Location of the study area and extraction gold sites in Mauritania (Pitfield et al. 2004)

contributes intensively to the creation of jobs and the development of the mining area, but it is the source of several direct or indirect discharges of toxic chemicals into the surrounding soils.

Geological context

From a geological point of view, the study area belongs to the Senegalese-Mauritanian sedimentary basin which is about 300 km wide and extends over an area exceeding 160,000 km² of which 100,000 km² is offshore. This basin developed during the Permo-Triassic along the western part of a passive continental rift margin at the time of the proto-Atlantic opening (Ritz and Bellion, 1990). The Tertiary is poorly exposed, mainly at the periphery of the basin, and is mostly known only from boreholes (Bellion et al., 1991). The Quaternary, on the other hand, is largely developed in the superficial deposits, with detrital formations composed mainly of fine to coarse sands with clay intercalations (Ritz et al., 1989). These are transgressive and regressive formations that characterize the Senegal-Mauritanian sedimentary basin (Elouard et al., 1969; Riser, 1991).

Sampling

To determine the regional distribution of ETM and Hg in the surrounding soils at the

Chami processing site, approximately 40 samples were collected (Figure 2). Sampling was done by manually driving an auger 20 cm deep into the soil in a clockwise rotational motion. The geographic coordinates of the sampled points were determined using a GPS. The choice and distance between the sampled points were planned in order to guarantee heterogeneity of these points. The characteristics retained are the geographical position of the treatment site, source of mercury, and the climatic conditions of the study area. The samples were collected in polyethylene bags and transported to the laboratory.

Geochemical analysis method

The geochemical analysis of trace metals (As, Co, Cr, Cu, Hg, Pb, Ni and Zn) was carried out at the ALS laboratory in Dublin, using the Inductively Coupled Plasma - Atomic Emission Spectroscopy (ICP - AES) technique. According to the ALS standard, a prepared sample was digested with aqua regia, also called royal water. This water consists of one volume of 37% hydrochloric acid solution and one volume of 65% nitric acid solution. Royal water has the ability to dissolve all metals. The aqua regia digestion consisted of taking 0.5 grams of the dry solid sample and introducing it into a "Digitube" digestion tube. Then, 6 ml of a hydrochloric acid solution and 2

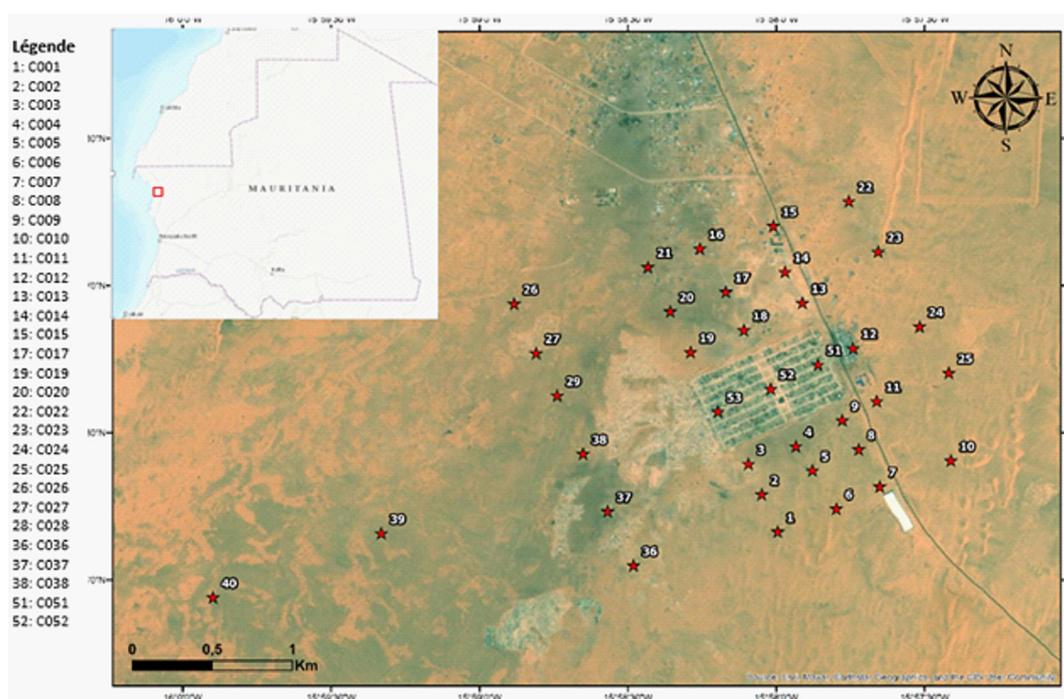


Figure 2. Location of sampling points

ml of nitric acid were added to the tube. Then, the sample was heated at 95°C for 45 minutes in the heating block digester. The resulting mineralizer was cooled to room temperature and subsequently volumetrically made up to 50 ml with deionized water and centrifuged at 2000 rpm for three minutes. After cooling, the resulting solution is diluted to 12.5 ml with ionized water, mixed and analyzed by inductively coupled plasma atomic emission spectrometry. The results of the analysis were corrected for spectral interferences between the elements (Table 1).

METALLIC TRACE ELEMENTS ASSESSMENT IN SOILS

Pollution index

Many authors have introduced the concept of the pollution index (PI) of soils in order to identify the multi-element contamination that is manifested by an increase in metal toxicity (Chon et al., 1998; Smouni et al., 2010; Tankari Dan Badjo et al., 2013, Yehdih et al., 2022). This index is a criterion for evaluating the overall toxicity of a contaminated soil. According to Chon et al. (1998), the determination of the PI is obtained from the average of the ratios of metal concentrations in soil samples to concentrations of the same element in the background. The formula for calculating this index is:

$$PI = Cx \text{ Sample} / Cx \text{ Background} \quad (1)$$

$IP > 1$ corresponds to a soil polluted by several metals.

Geo-accumulation index

Pollution is the phenomenon by which a compound accumulates in such a way that it can cause a danger to living organisms or compromise the ordinary use of the receiving environment (Chassin, et al., 1996). It is calculated by the equation of (Müller, 1969):

$$I_{geo} = \text{Log} (C_n / 1.5B_n) \quad (2)$$

where: C_n – concentration of the analyzed element; B_n – geochemical background for the same element and 1.5 – constant that associates the natural variations of the concentration of an element in an environment and the weak anthropogenic pressures.

The calculation of the intensity of pollution is done through the geo accumulation index (I_{geo}), composed of seven classes defining the degrees of pollution (Table 2). They oscillate from the natural content where there is no pollution to the most polluted values synonymous with contaminated soils.

Statistical analysis of the results

The calculation of the descriptive statistics and the correlation between the variables was carried out by means of Microsoft Excel software. Thus, the mean, standard deviation, maximum value and minimum value were determined for each chemical element analyzed. The graphs were established by means of the same software. As for the sampling map, it was made using Arc-Gis mapping software

RESULTS AND DISCUSSION

ETM concentrations in soil samples

Figure 3 shows the concentrations of trace metals (ETM) in the soil samples studied. It shows a variability of the concentrations according to the metals. The ETM values in soils indicated by (Table 1) are scattered and vary in different orders, from 2 to 6790 ppm for As; 1 to 82 ppm for Co; 11 to 216 ppm for Cr; 3 to 1055 ppm for Cu; 1 to 133 ppm for Hg; 2 to 468 ppm for Pb; 3 to 120 ppm for Ni and 4 to 206 ppm for Zn.

The statistical data for the trace elements studied in the soils are shown in Table 3. The mean values of metals are ranked in the following descending order: 468.4 ppm, 78.9 ppm, 36.5 ppm, 34.4 ppm, 31.3 ppm, 22.7 ppm, 22.2 ppm, and 9 ppm for As, Cu, Cr, Pb, Zn, Ni, Hg, and Co, respectively. The highest median values were recorded for Cu (10.5), Zn (10.5) and As (10) while Hg and Pb were characterized by the lowest, which means that the values of the contents for the latter were not high enough in all samples. The minimum concentrations recorded in decreasing order for the following elements Cr, Zn, Cu, Ni, As, Pb, Hg and Co. Their values are 11 ppm, 4 ppm, 3 ppm, 3 ppm, 2 ppm, 2 ppm, 1 ppm and 1 ppm, respectively. Comparing the median values and the minimum concentrations recorded with the corresponding background values of the upper crust (Taylor and Mc Lennon, 1995), it was

Table 1. Heavy metal concentrations (ppm)

Element (ppm)	As	Co	Cr	Hg	Ni	Pb	Zn
C001	23	14	26	59	17	28	126
C002	<2	6	19	1	9	4	10
C003	1660	20	45	70	32	468	206
C004	10	7	19	13	9	42	25
C005	21	4	17	8	8	40	27
C006	12	4	24	8	12	25	29
C007	14	7	24	14	13	39	23
C008	8	4	19	10	7	22	12
C009	4	2	14	2	5	12	7
C010	<2	2	16	1	5	2	5
C011	<2	3	15	1	5	3	7
C012	2	6	28	1	11	4	11
C013	56	18	139	33	109	164	127
C014	<2	1	14	1	4	2	4
C015	2	5	27	1	11	6	12
C017	<2	2	15	1	3	2	5
C019	<2	2	13	1	5	2	6
C020	<2	2	13	1	4	<2	5
C022	2	2	15	3	4	4	25
C023	<2	1	11	1	4	<2	4
C024	4	3	17	5	6	6	9
C025	<2	1	11	1	3	2	4
C026	<2	1	11	1	4	3	4
C027	2	10	22	1	17	5	10
C028	<2	2	11	1	5	2	7
C036	9	12	216	55	120	3	29
C037	6790	82	21	49	54	5	6
C038	7	6	17	102	5	6	116
C051	200	24	156	133	97	43	44
C052	74	18	101	89	94	19	35

Table 2. Classification of Müller (1969)

Classes	Geo-accumulation index	Pollution intensity
0	$I_{geo} \leq 0$	No pollution
1	$0 < I_{geo} < 1$	Not polluted to moderately polluted
2	$1 < I_{geo} < 2$	moderately polluted
3	$2 < I_{geo} < 3$	Moderately to heavily polluted
4	$3 < I_{geo} < 4$	Heavily polluted
5	$4 < I_{geo} < 5$	Heavily polluted to extremely polluted
6	$I_{geo} > 5$	Extremely polluted

found that Hg and As presented the highest concentrations. On the basis of the coefficient of variation (CV), the studied trace metal elements can be classified into two groups (Han et al. 2006 and Guo et al. 2012): a low CV group characterizing

the elements dominated by a natural source and a high CV group that reflects that the elements are affected by anthropogenic sources. In this study, the CV values are all high and above 1. They are listed in descending order, as follows: As 3.37;

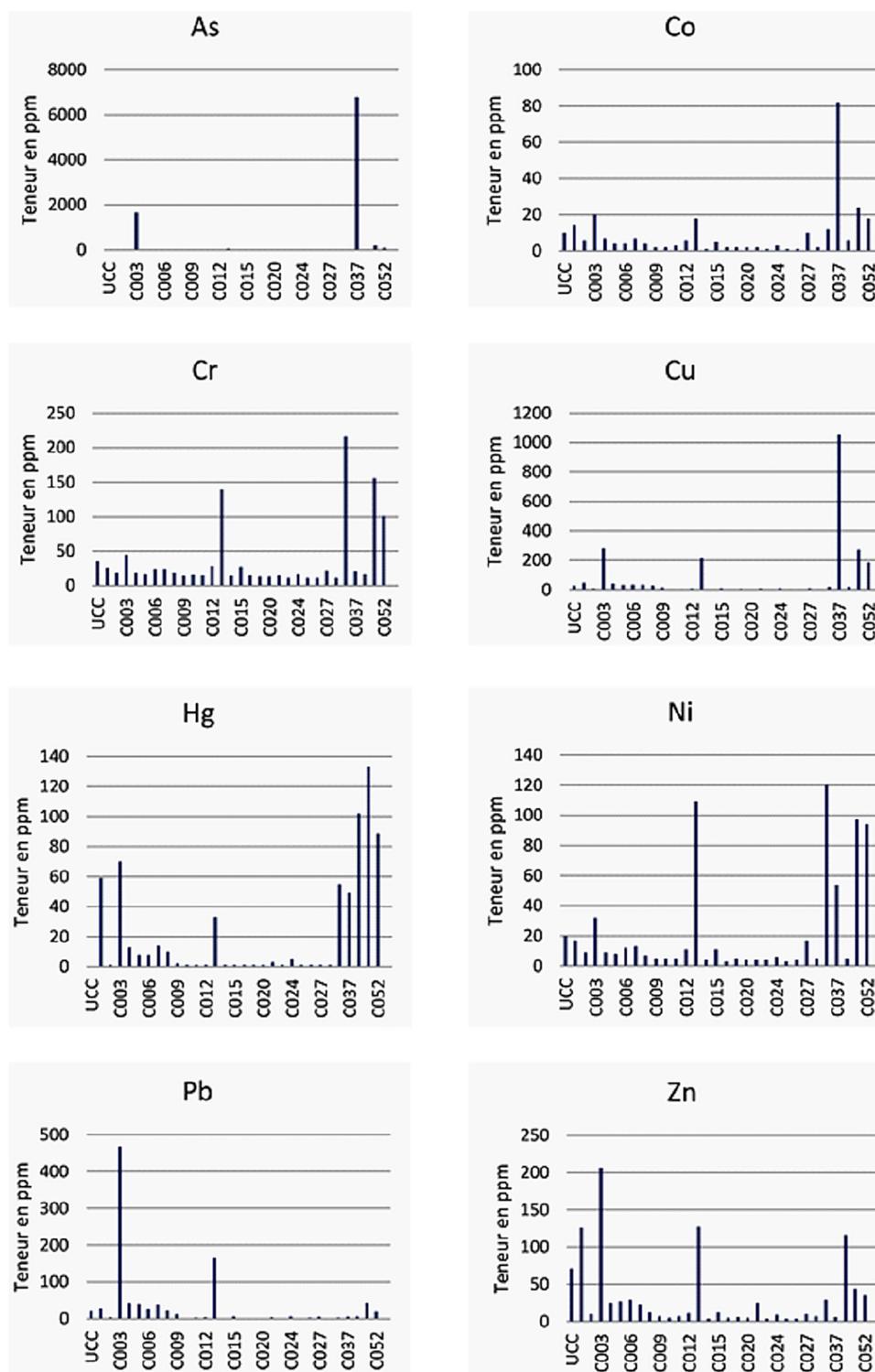


Figure 3. Distributions of ETM contents in soil samples

Pb 2.64; Cu 2.54; Co 1.68; Hg 1.60; Zn 1.53; Ni 1.52 and Cr 1.35. Graphical analysis of the trace metal element content distributions in the soil samples (Figure 4) shows the distribution of As, Co, Cr, Cu, Pb, Zn, Ni and Hg. The As levels in the analyzed samples ranged from below the detection limit to 6790 ppm. The majority of

samples showed levels above the world average for uncontaminated soils, which is set at 6 ppm (Bowen, 1979). The highest concentrations of As were obtained in samples C003 and C037. The Co concentrations obtained in the analyzed samples range from 1 to 82 ppm. The highest concentrations of these elements were recorded in samples

Table 3. Descriptive statistics of trace elements in the soils of Chami

Element	Mean	Median	Ecartypes	VC	Min	Max	PIMIN	PIMAX	UCC	PIM	Igéo min	Igéo max
As	468.4	10	1576.5	3.37	2	6790	1.3	4526.7	1.5	312.3	0	3.8
Co	9	4	15.1	1.68	1	82	0.1	8.2	10	0.9	0.8	2.7
Cr	36.5	18	49.4	1.35	11	216	0.3	6.2	35	1.0	2.4	3.7
Cu	78.9	10.5	200.8	2.54	3	1055	0.1	42.2	25	3.2	1.7	4.2
Hg	22.2	2.5	35.5	1.60	1	133	16.7	2216.7	0.06	370.6	-1	1
Pb	34.4	5.5	90.7	2.64	2	468	0.1	23.4	20	1.7	1.1	3.8
Ni	22.7	7.5	34.5	1.52	3	120	0.2	6	20	1.1	1.6	3.2
Zn	31.3	10.5	48	1.53	4	206	0.1	2.9	71	0.4	2.3	4

C003, C013, C037 and C051. For chromium, the content values in the samples range from 11 to 2016 ppm. The highest Cr concentrations were marked in samples C013, C036, and C51. Four of the samples exceeded the world average Cr value of 70 ppm (Bowen, 1979).

For all samples analyzed, Cu levels ranged from 3 to 1055 ppm. The highest concentrations were found in samples C003, C013, C037, C051 and C052. Ten samples had concentrations above the world average of uncontaminated soil for Cu (30ppm) (Bowen, 1979). Lead levels ranged from 2 to 468 ppm. The highest concentrations are recorded in samples C003, C013 and C051. Seven samples showed Pb levels above the world average for uncontaminated soils, set at 35 ppm. For Ni and Zn, the graphs display a variation in concentrations ranging from 3 to 120 ppm and from 4 to 206 ppm, respectively. The highest concentrations of Ni were noted in samples C03, C013, C036, C051, as well as in C001 C003 C013 C036 C0038 and C051 for Zn. Five samples had Ni levels above the world average value for Ni-free soil of 50 ppm. For Zn, four samples had higher levels compared to the world average value of Zn levels in uncontaminated soils 90 ppm. Hg concentrations in soil samples ranged from 1 to 133 ppm. It was noted that almost all exceed the world average value of 1 ppm (Bowen, 1979). The highest concentrations were found in samples C001, C003, C013, C024, C028, C036, C037, C051 and C052.

Pollution indices

In order to estimate the degree of soil pollution by trace metals, the pollution index (PI) is used. Thus, any soil with a higher pollution index for this metal is considered polluted by a metal. When the value of its pollution index exceeds 1, this indicates that the average concentration of the

metal in the analyzed soil exceeds the value of the standard and therefore the sample is polluted. The results of the pollution indices (Table 3) showed very diverse values for the trace elements: As, Co, Cr, Cu, Hg, Pb, Ni and Zn. The average pollution index values were all greater than 1 for all elements in descending order (Table 1): $Hg > As > Cu > Pb > Ni > Cr > Co > Zn$. The minimum index values were less than 1 for Co (0.1), Cr (0.3), Cu (0.1), Pb (0.1), Ni (0.2) and Zn (0.1). The degree of pollution was variable according to the metallic trace elements but it was more important in the samples C001, C003, C004, C005, C006, C013 C036, C037, C038, C051 and C052. Therefore, since the pollution index was greater than 1 in the majority of samples, it can be concluded that the soil is contaminated by several elements (As, Cr, Cu, Hg, Pb and Ni).

Geo-accumulation index

The geo accumulation index of Arsenic, Cobalt, Chromium, Copper, Mercury, Lead, Nickel and Zinc vary from 0 to 3.8; 0.8 to 2.7; 2.4 to 3.7; 1.7 to 4.2 and -1 to 1; 1.1 to 3.8; 1.6 to 3.2 and 2.3 to 4 respectively (Figure 5). These indices allow distinguishing six classes of pollution from class 0 synonymous with no pollution, passing to moderate pollution and arriving at class 5 characterizing the highest pollution. For As, Co, Cr, Pb, and Zinc, these indices varied from 0 to 3.8. For Cu and Zn, the indices of 1.7 to 4.2 and 2.3 to 4, respectively, show that the soil is moderately to heavily polluted. As for mercury, the value of the Igeo index varies from -1 to 1; indicating an unpolluted to moderately polluted soil. The analysis of correlations between elements allows determining the relationship between the studied metallic trace elements and their origin (Carpentier et al., 2002).

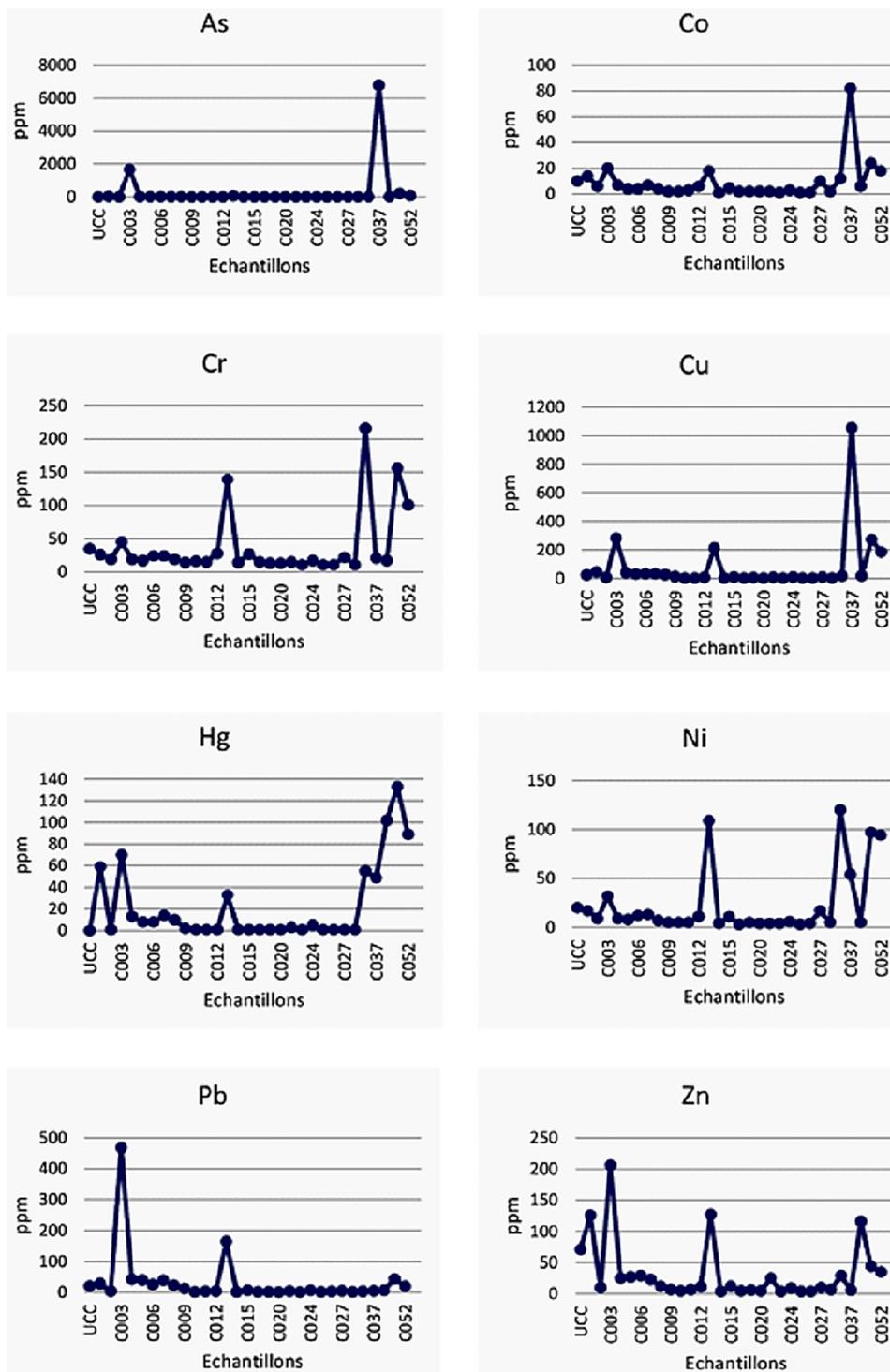


Figure 4. Spatial distribution of trace metals in the studied soil

The results of the correlation matrix obtained show positive correlations (Table 4). The most important correlations between the analyzed metals are: As; Co (0.93), As; Cu (0.95), Co; Cu (0.98), Cr; Hg (0.60), Cr; Ni (0.94), Hg; Zn (0.59), Hg; Ni (0.65) and Pb; Zn (0.80). This suggests that these elements have a common anthropogenic origin.

DISCUSSION

In this work, all samples displayed varying concentrations in studied ETM: As, Cu, Cr, Pb, Zn, Ni, Hg and Co with. This variation is related to both the position of the sample and the metallic element considered. For the elements As, Cr, Cu, and Hg, the average concentrations of ETM were



Figure 5. Geo accumulation index values for studied heavy metal elements in soil

Table 4. Correlation matrix of ETM in soil

Element	As	Co	Cr	Cu	Hg	Pb	Zn	Ni
As	1							
Co	0.93	1						
Cr	-0.03	0.24	1					
Cu	0.95	0.98	0.17	1				
Hg	0.22	0.46	0.60	0.41	1			
Pb	0.16	0.18	0.18	0.23	0.31	1		
Zn	0.07	0.18	0.28	0.17	0.59	0.80	1	
Ni	0.19	0.48	0.94	0.42	0.65	0.22	0.31	1

higher than the global normal concentrations of uncontaminated soil (Bowen 1979). The concentrations of these elements were in the range of 468.4 ppm 30 ppm 36.5 ppm and 22.2 ppm, respectively. The highest concentrations of these elements were recorded in samples: C001, C003, C013, C024, C028, C036, C037, C051 and C052. These samples were the closest to the Chami processing site, which means that the artisanal gold mining activity that takes place at the site, as well as the chemicals used for the separation of the mercury, could constitute a source of pollution of the soil surrounding the site. Indeed, if the Hg levels are a direct result of their use in the gold mining operation, the increase in concentrations of other metals could be explained by the fact that gold ores are often associated with several ores likely to contribute certain metals such as Cr and Cu, as shown by (Ibrahim et al., 2019) in Niger who explains the increase in Pb in the soil by the association of gold ores with sulfurous ores.

For mercury concentrations, similar studies in Côte d’Ivoire (Irié Bi et al., 2019) and Senegal (Niane et al., 2014) support authors’ observations on the source of mercury. They emphasized that the mine’s activities led to local soil

contamination with Hg. Moreover, the Hg levels recorded in the soils studied at Chami are higher than those reported by these authors. They exceed the critical levels defined by Kabata and Pendias (1992) which set between 3 and 5 ppm of mercury in the soil as a threshold for the protection of the environment and human health.

The main difference between these different contaminated sites and the study area is that mercury has been used for a much longer period of time (more than 10 years) in Senegal and Cote d’Ivoire (Niane et al. 2014). In Mauritania, however, gold panning activity began six years ago and has already begun to pollute the environment, which indicates the intensity of use of this element. The results show weak to strong positive correlations between the different MTEs as illustrated in the correlation table (Table 4). The highest correlations between the analyzed metals suggest that these elements have a common origin.

The degree of mercury pollution depends on its content in the soil and the conditions in which it is subjected. The polluted soils of Chami become a possible source of propagation of mercury in the environment, either through the wind, which characterizes the area, likely to diffuse the

mercury in all directions; or through rainwater, which is a source of leaching of polluted soils and their migration to lower altitudes (towards the Atlantic Ocean), especially since the area has a significant hydrographic network. In addition, rainwater presents risks of pollution of the groundwater by its infiltration into the soil.

Another risk is the contamination of the atmosphere by the vaporization flow of mercury from the soil (Santos-Francés et al., 2011). In addition to being a source of mercury, the gold panning activity in Chami could also be a source of its impact on the environment and human health of the population.

CONCLUSIONS

In this study, the distribution of trace metal elements in the soils of Chami area was examined. The analyzed samples revealed significant concentrations of the studied trace metal elements (As, Co, Cr, Cu, Hg, Pb, Zn and Ni) in soil. These concentrations decrease in the soil as one moves away from the Chami gold processing center towards other directions, notably NE -SW (major wind direction) towards the Atlantic Ocean, which is found over a distance of 30 km. The majority of these ETM levels were above the normal thresholds. The average pollution index was greater than 1, revealing soil contamination by the elements studied. As gold panning is the only use of Hg in the amalgamation area, it is directly responsible for the increase in concentration of this element in the Chami soil. The accumulation of this metal in the soil constitutes environmental and health risks for the population living in and around the Chami area, hence the importance of setting up a soil contamination monitoring plan and considering the clean-up of this soil.

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