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Assessment of Groundwater Contamination by Trace Metals in the Chami Gold Area (Mauritania)

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ABSTRACT

Artisanal gold mining in Chami is an important lever in the country economy, owing to the benefits it brings, but it is also likely to have a negative impact on various environmental compartments. Contamination of surface and ground water by trace metals elements (ETMs) was studied in the vicinity of the Chami gold processing center. The aim of the study was to assess the water contamination by trace metals (ETMs) in the town of Chami. Nine water samples (process and boreholes) were analyzed for (Co, Cr, Cu, Ni, Pb, Zn and Hg). The analysis was carried out by the DMA 80 technique for Hg at the ONISPA laboratory in Nouakchott and the other ETM at the Kenitra geosciences laboratory by the ICP-MS technique. The results of the analyses show that the ETM concentrations are high in process water samples and low in drilling water samples. Pollution indices and coefficients of variation indicate no contamination or anthropogenic traces in the borehole samples, but high levels of Hg and Ni in the process water. These results show the accumulation of metals in significant quantities in the process waters, especially Hg, proving that the waters of the mining waste basins at the Chami processing site are becoming sources of environmental pollution by mercury, which can be released into the environment by several pathways.

Keywords: artisanal mining, water, contamination, trace metals, Chami, Mauritania.

INTRODUCTION

The north of Mauritania has enormous mining potential, which can be a major lever for the country's economy. For the most part, these resources are exploited on an artisanal basis by gold miners. 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 the environment by several harmful chemical substances, notably trace metals (ETMs). These metals, released into the environment by human activities, persist and no longer degrade (Aucejo et al., 1997). High concentrations of metals in the environment can have negative consequences for human health and adverse effects on the environment (Bougherara et al., 2011). Artisanal gold mining, or orpaillage, is one of the major anthropogenic activities likely to degrade the quality of water resources, soils and the atmosphere, as well as impact the trophic chain (Driscoll et al., 2013). In the Chami area, where gold panning is concentrated at the processing center, the only

means of water supply is groundwater (wells and boreholes). Gold miners use mercury to process ore and separate the gold. During this process, mercury can be lost directly to the environment through mining waste, or emitted into the atmosphere when the amalgam is burned (Stéphane Guedron et al. 2009). This operation takes place close to drinking water sources (boreholes), increasing the risk of pollution of these water resources. The use of mercury for gold amalgamation, as well as effluent discharges from the washing of crushed ore (Fig. 3), are likely to deteriorate water quality through the mobilization and dispersion of heavy metals in the environment, particularly in groundwater through infiltration (Bamba et al., 2013). Environmental protection is not a priority concern for gold miners during processing activities, as they are not aware of the negative impacts that gold mining can have on the environment and on public health. The aim of this study, the first of its kind, was to analyze the effect of mercury use in gold panning on environmental pollution in the town of Chami, and the environmental assessment of groundwater in this area for toxic trace metals (Co, Cr, Cu, Ni, Pb, Zn and Hg).

DESCRIPTION OF THE STUDY SITE

The town of Chami is a Department (Moughataa) of the Dakhlet Nouadhibou Region. It is located about 250 km from the capital Nouakchott between latitudes -16°0’ and -16°15’W and longitudes 20° and 20°15’N (Fig. 1). The town is rich in industrial activity, particularly mining, since the majority of its inhabitants are gold miners and mining officials. This activity contributes significantly to job creation and the development of the mining sector, but is also responsible for the direct or indirect release of toxic chemicals, such as mercury, which can have a negative impact on the environment and public health, especially as the town of Chami is a crossing point of the N2 national highway and is located around 30 km from the Atlantic Ocean. The study area is characterized by generally flat terrain, with a low slope and an altitude range oscillating between 0 and 50 m. Moving in a NNE to SSW direction, these altitudes drop. This direction may play a role in the distribution of ETMs, as it is combined with wind direction. The presence of an extensive hydrographic network in the considered study

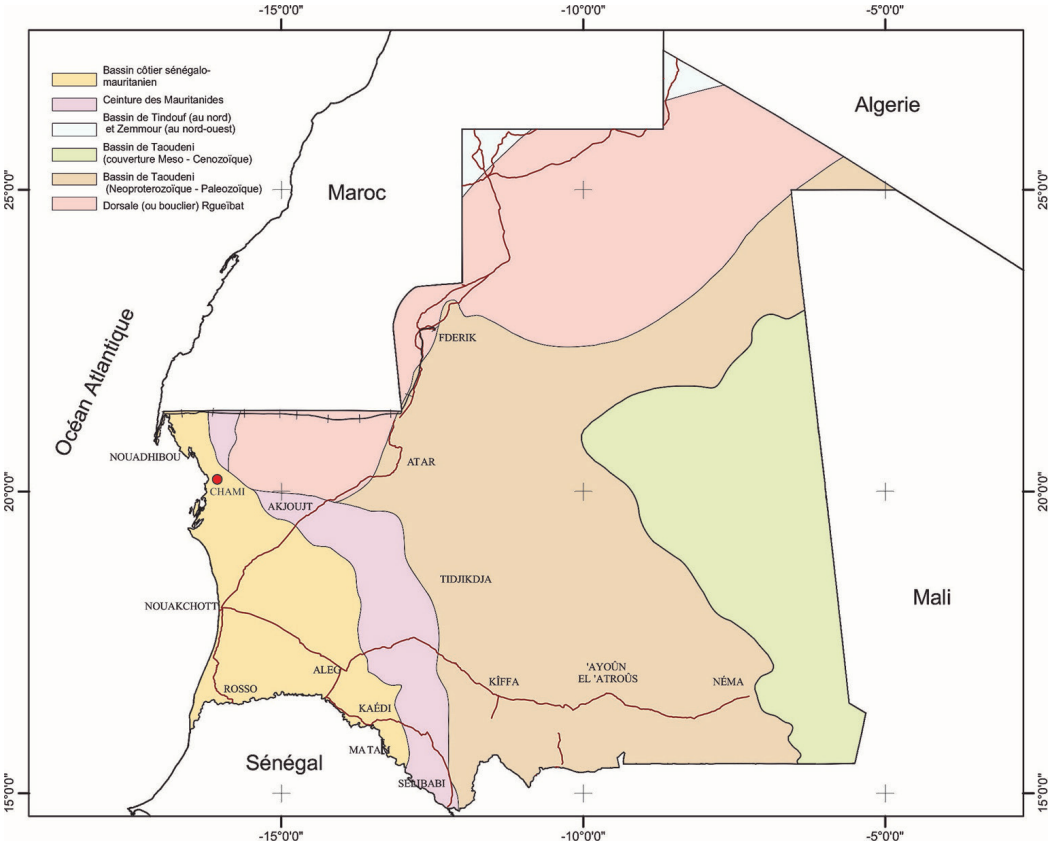

Fig. 1. Location of the study area (Pitfield et al., 2004)

area could also contribute to the infiltration of contaminated water into nearby groundwater. From a geological point of view, the study area belongs to the Senegal-Mauritania sedimentary basin, which is up to 300 km wide and covers an area of over 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, bounded to the north by the Mauritanian chain and the Rgueibat ridge and to the south-west by the Atlantic Ocean (Ritz and Bellion 1990). It is made up of mainly Tertiary and Quaternary geological formations (Bellion et al., 1991). The Tertiary is sparsely exposed, mainly on the periphery of the basin, and is mostly only known from boreholes. The Quaternary, on the other hand, is widely developed in superficial deposits, with detrital formations composed mainly of fine to coarse sands with clay intercalations (Ritz et al., 1989). These are the transgressive and regressive formations that characterize the Senegalo-Mauritanian sedimentary basin (Elouard et al., 1969; Riser, 1991).

METHODS AND MATERIALS

Sampling

Nine water samples were collected during a sampling mission in July, 2022. The geographical coordinates of the sampling points were determined using GPS. The sampling points were chosen on the basis of the presence of artisanal gold mining activity at Chami, a source of mercury in the process water used at the Chami processing center, and on the basis of water contamination at borehole level (Fig. 2). Samples are collected in sterile bottles and transported to the laboratory.

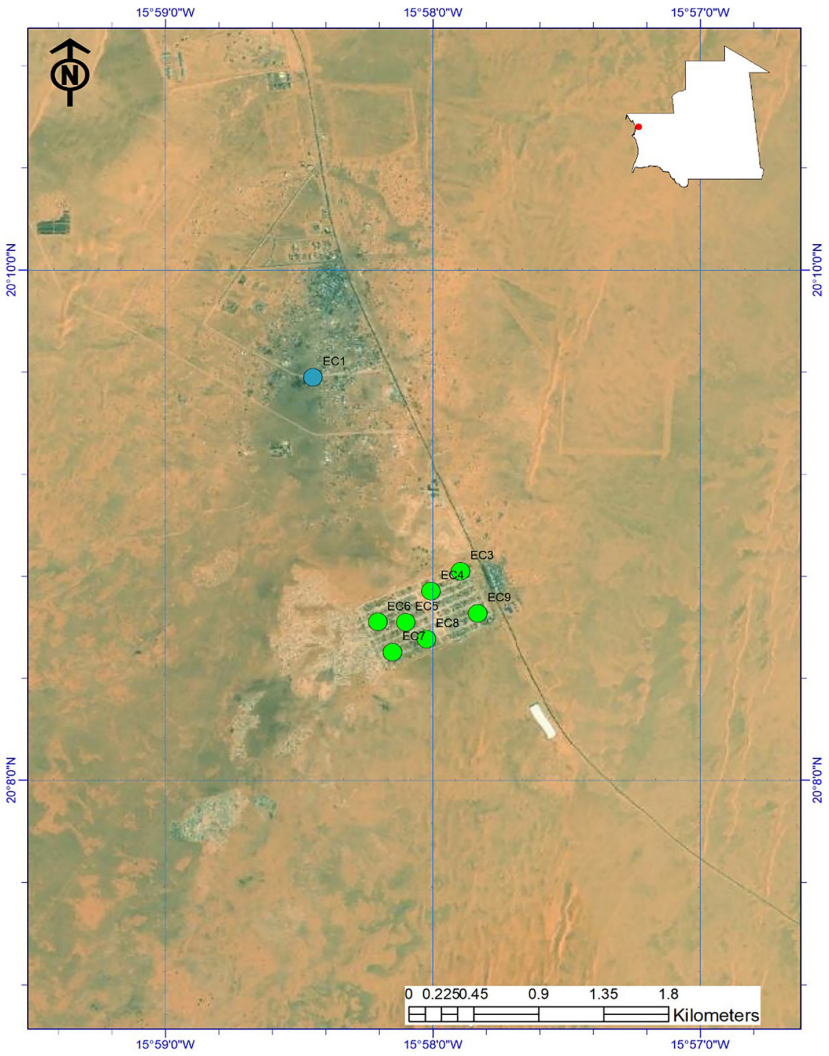

Fig. 2. Location of sampling

Fig. 3. Photos showing the process water basins in the treatment center

Geochemical analysis

The geochemical analysis of trace metals (Co, Cr, Cu, Ni, Pb, Zn) was carried out at the Geosciences Laboratory in Ibn Tofail University of Kenitra (Morocco), using the ICP (Inductively Coupled Plasma) emission spectrometry technique. Analysis by atomic emission spectrometry is based on the study of radiation emitted by atoms that have passed into an excited, generally ionized, and state. To dissociate the samples into their constituent elements, they are introduced into plasma at high temperatures (5,000 to 8,000°C), which causes total dissociation of the constituents. After sampling, the samples are acidified with 5 ml of concentrated nitric acid (d = 1.40) per liter of sample. Digestion is carried out with aqua regia (a mixture of two volumes of HCl and one volume of HNO_3). For each element, mass concentrations are given by the equipment data acquisition system, by reference to calibration solutions.

Mercury analysis

For Hg analysis, the samples were analyzed at the ONISPA laboratory in Nouakchott (Mauritania), using the DMA 80 method. They were thermally decomposed in a temperature-controlled furnace in the presence of oxygen. The combustion gases are then treated in a catalytic tube. Mercury was then amalgamated on a gold support. After desorption by heating, Hg is determined by UV spectrometry at 253.7 nm using two cells with different sensitivities placed in series. The signal is measured in each cell. The short-path cell is used to measure high mercury concentrations. When the absorbance in the long-path cell (low concentration) exceeds 0.8 absorbance units, the measurement is automatically performed with the short-path cell (high concentration).

Statistical analysis

Descriptive statistics and correlation between variables were calculated using Microsoft Excel. The mean, standard deviation, maximum and minimum values were determined. The same software was used to produce the graphs. The sampling map was produced using Arc-Gis mapping software.

Calculation of the pollution index

Many authors have introduced the concept of the pollution index (PI) of soils to identify multi-element contamination manifested by increased metal toxicity (Chon et al., 1998; Smouni et al., 2010; Tankari Dan Badjo et al., 2013). This index is a criterion for assessing the overall toxicity of a contaminated soil. According to Chon et al. (1998), the PI is determined by averaging the ratios of metal concentrations in soil samples to background concentrations of the same element. The formula for calculating this index is:

$$IP = Cx \text{ analyzed}/Cx \text{ background} \quad (1)$$

where: IP > 1 corresponds to soil polluted by several metals.

Geo-accumulation index

Pollution is the phenomenon by which a compound accumulates in such magnitude 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 Müller equation (1969):

$$Igeo = \text{Log } (Cn/1.5Bn) \quad (2)$$

where: Cn – concentration of the analyzed element, Bn – content of the geochemical

Table 1. ETM elements analysis table

Elements/samples in mg/l	Geographical coordinates	Co	Cr	Cu	Ni	Pb	Zn	Hg
EC1	402888.31 m E, 2215356.78 m N	0.017	0.011	0.949	0.002	0.005	0.527	0.0058
EC2	398200.12 m E 2229448.39 m N	0.02	0.022	14.34	0.036	0.164	4.738	0.0058
EC3	398685.06 m E, 2227774.43 m N	0.019	0.018	25.76	0.036	0.059	9.178	6.774
EC4	398788.18 m E 2227527.35 m N	0.032	0.024	4.882	0.046	0.058	1.754	0.307
EC5	399085.69 m E 2227647.56 m N	0.462	0.039	4.476	270	2.787	1.003	0.559
EC6	399334.44 m E 2227729.57 m N	0.047	0.02	0.037	54.56	0.056	0.016	2.166
EC7	398200.12 m E 2229448.39 m N	0.044	0.033	29.07	0.054	0.583	10.49	43.613
EC8	398960.50 m E, 2227899.60 m N	0.135	0.706	Abs	392.8	0.637	291.6	919.638
EC9	399153.60 m E, 2228040.79 m N	0.013	0.020	1.277	0.022	0.051	0.352	8.453

background for the same element and 1.5 – constant that associates natural variations in the concentration of an element in an environment and low anthropogenic pressures.

Pollution intensity is calculated using the geo-accumulation index (Igeo), composed of seven classes defining degrees of pollution (Table 2). These range from natural levels, where there is no pollution, to the most polluted values, synonymous with contaminated waters.

RESULTS AND DISCUSSION

ETM concentrations in water samples

The results of nine samples taken from the Chami area are presented in Table 1, and their distributions are plotted in Figure 4. Seven samples were taken from process water and two from borehole water. The distribution of ETMs in these water samples shows different concentrations depending on the sample and the metal. Figure 4 clearly shows the high presence of Hg and Ni in process water samples EC5, EC6, EC8 and EC9, with average to low concentrations of the other elements: Zi, Cu, Pb, Cr and Co in samples EC3, EC4 and EC7. For borehole water samples, only Cu shows the most remarkable concentration in sample EC2, while the other elements are low or even absent in both samples EC1 and EC2.

All the MTEs studied were detected in the borehole water samples, with the exception of mercury, the concentrations of which were below the detection limits set out in Table 3. Average concentrations of ETMs in borehole water samples ranged from 0.01 mg/l to 7.644 mg/l, with Cu, Zn, Pb, Co, Ni and Cr in decreasing order, at 7.644 mg/l, 2.632 mg/l, 0.084 mg/l, 0.068 mg/l, 0.019 mg/l, and 0.016 mg/l respectively. These data show that the only element with a higher concentration than the others is Cu with 7.644 mg/l, as this concentration is not critical but may

Table 2. Müller classification (1969)

Classes	Geo-accumulation index	Pollution intensity
0	Igeo ≤ 0	No pollution
1	0 < Igeo < 1	Not polluted to moderately polluted
2	1 < Igeo < 2	Moderately polluted
3	2 < Igeo < 3	Moderately to heavily polluted
4	3 < Igeo <4	Heavily polluted
5	4 < Igeo < 5	Heavily polluted to extremely polluted
6	Igeo > 5	Extremely polluted

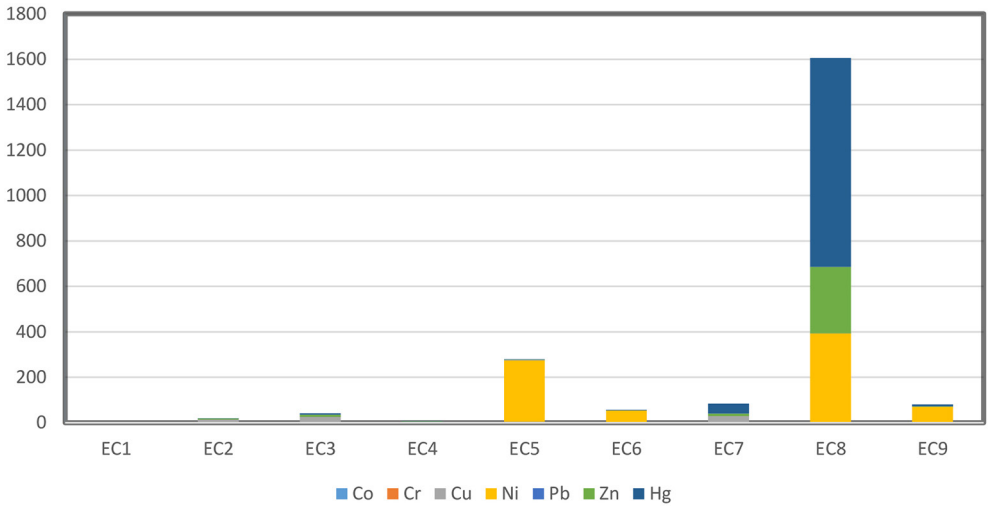

Fig. 4. ETM distribution in water samples

Table 3. Statistical parameters for ETM (mg/l) in process water and drilling water

Process water	Mean	Median	SD standard deviation	VC	Min	Max	PIM	PIMAX	UCC
Co	0.09	0.032	0.15	1.66	0.013	0.462	0.008	0.05	10
Cr	0.11	0.021	0.24	2.25	0.011	0.706	0.002	0.02	35
Cu	10.10	4.68	11.62	1.15	0.037	29.07	0.35	1.16	25
Ni	87.54	0.054	144.11	1.65	0.002	392.8	4.37	19.64	20
Pb	0.49	0.059	0.89	1.83	0.005	2.787	0.02	0.14	20
Zn	35.52	1.754	96.11	2.71	0.016	291.6	0 .5	4.11	71
Hg	109.06	2.166	304.29	2.79	0.005	919.63	1817.63	15327.30	0.06
Drilling water	Mean		SD	CV		PI			
Co	0.068		0.03	0.49		0.06			
Cr	0.016		0.004	0.26		0.01			
Cu	7.644		4.73	0.61		0.30			
Ni	0.019		0.012	0.63		0.01			
Pb	0.084		0.05	0.67		0.01			
Zn	2.632		1.48	0.56		0.03			

be due to the geological nature of the groundwater. The coefficients of variation (CV) are all less than 1, indicating that these trace metals are not affected by anthropogenic sources.

The statistical results for process water from the Chami treatment center show that the average concentrations of the ETMs studied are, in descending order, Hg >Ni >Zn > Cu > Pb > Cr > Co reaching 109.06 mg/l, 87.54 mg/l, 35.52 mg/l, 10.10 mg/l, 0.49 mg/l, 0.11 mg/l and 0.09 mg/l, respectively. These results show that all the ETM concentrations obtained in the process waters are below the UCC concentrations, with the exception of the mean concentrations of Hg and Ni, which exceed the UCC concentrations set at 0.06 for Hg and 71 for Ni. Median values are significant for Cu, Hg and Zn, showing their presence in all process water samples. The other metals Co, Cr, Ni and Pb are characterized by low median values. The coefficient of variation is characterized by values ranging from 1.15 to 2.79 for the trace metal elements studied; they are all greater than 1, suggesting that the elements are affected by anthropogenic sources (Han et al. 2006 and Guo et al. 2012). Values are in descending order; Hg 2.79, Zn 2.71, Cr 2.25, Pb 1.83, Co 1.66, and Cu 1.15. Mercury concentrations are explained by the intense gold panning activity that takes place in the center of Chami, where gold miners use mercury in the process. This use is responsible for the release of mercury directly into the environment through mining waste, similar arguments have

been reported by authors (Guedron et al. 2009). The element Ni shows a positive correlation with Hg in Table 4, suggesting that they have the same anthropogenic source, which is gold panning. The presence of a high concentration of this element can be explained by the primary nature of the mineralization exploited by miners during the artisanal gold mining process in the area.

The accumulation of mercury in mining waste basins at the Chami processing site, in critical concentrations and over a long period of time, may constitute the sources of mercury that can be released into the environment via several routes. Indeed, heavy rainfall increases mercury mobility by enhancing its vertical and lateral transfers (Dajade, 2020). Straaten (2000) has highlighted the risk of contaminating groundwater by infiltration and polluting the atmosphere with Hg at gold-mining sites in Tanzania and Zimbabwe. The mercury used to amalgamate gold is volatile (Veiga and Baker, 2004; Guedron et al., 2009). It can therefore evaporate into the atmosphere and be deposited on plant cover, house roofs, soil, uncovered water resources and wells, and arable land (Grimaldi et al., 2015; Mallongi et al., 2017; Posthumus, 2019).

Pollution indices

Various pollution index values are shown in Table 3. Analysis of this table reveals that borehole water is only slightly contaminated by the trace elements studied, with values not exceeding 0.3 recorded for Cu. This indicates that there is no pollution in these samples. On the other hand, for the process water samples, the pollution indices show high contamination by Hg (1817.63) and Ni

Table 4. Correlation

Element	Co	Cr	Cu	Ni	Pb	Zn	Hg
Co	1						
Cr	0.1489854	1					
Cu	-0.2093721	-0.28706205	1				
Ni	0.6697177	0.80828605	-0.43978733	1			
Pb	0.9840100	0.09164894	-0.07183768	0.60528426	1		
Zn	0.1128497	0.99882258	-0.25675598	0.78386188	0.05790253	1	
Hg	0.1148798	0.99894374	-0.26550266	0.78726854	0.06149611	0.99943682	1

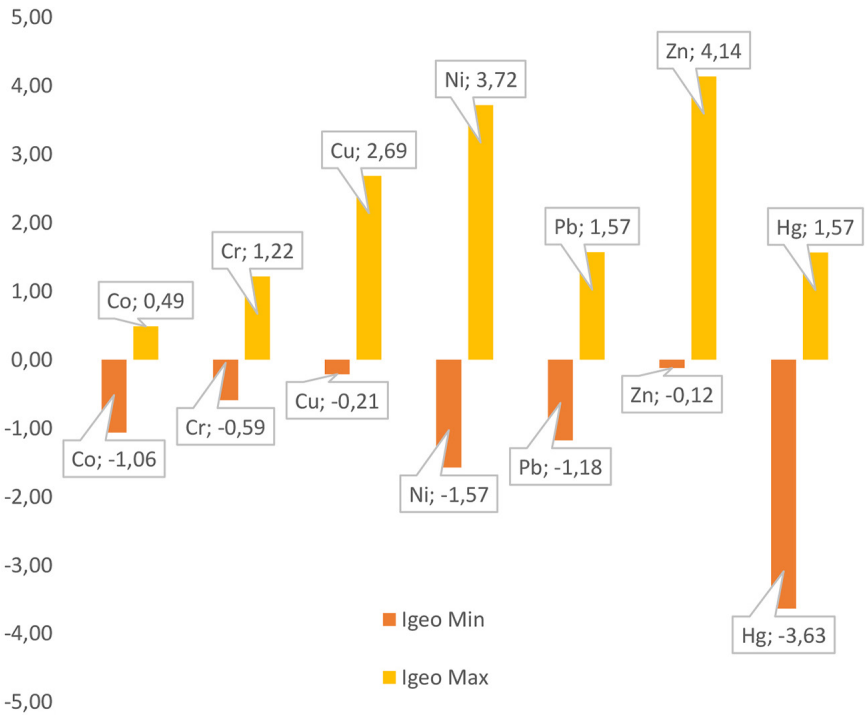

Fig. 5. Geoaccumulation index values for ETMs in process water samples

(4.37), and low contamination by the other metals: Zn (0.5), Cu (0.35), Pb (0.02), Cr (0.002) and Co (0.008). The degree of pollution is therefore well noted for mercury, which is justified by the effect of massive use of Hg during gold panning.

Geo-accumulation indices

In this study, the trace elements Cobalt, Chromium, Copper, Lead, Nickel, Zinc and Mercury show a variation in indices, reaching -1.0 to 0.49, -0.59 to 1.22, -0.21 to 2.69, -1.75 to 3.72, -1.18 to 1.57, -0.12 to 4.14 and -3.63 to 1.57, respectively (Figure 5). Cobalt, Chromium and Copper range from unpolluted to moderately polluted, while the element indices for Lead, Nickel, Zinc and Mercury vary from unpolluted to heavily polluted.

Correlation coefficient analysis

The origin and relationship between trace metals are determined using correlation parameters (Carpentier et al., 2002 a,b). Analysis of the correlation matrix data shows weak to strong positive correlations between the different ETMs studied (Table 4). The highest correlations between the analyzed metals are: Co; Ni (0.66), Cb; Pb (0.98), Cr; Ni (0.80), Cr; Zn (0.99), Cr; Hg (0.99), Ni; Zn (0.78), Ni; Hg (0.78), Zn; Hg (0.99). This confirms that these elements have a common origin.

CONCLUSIONS

In this study, the distribution of trace metals was examined in the waters of the Chami area (boreholes and processes). The analyzed samples revealed significant concentrations of trace metals (Co, Cr, Cu, Pb, Zn, Ni and Hg). Borehole water data show low concentrations of the studied elements. Pollution indices and coefficients of variation indicate no contamination or anthropogenic traces in these borehole samples, despite the intense mining activity. On the other hand, the results of the process water samples show ETM levels above normal thresholds, in the case of Hg and Ni. The average pollution index of all samples is greater than 1, revealing contamination of these waters by the elements covered by this study. The coefficients of variation indicate that the water has been affected by anthropogenic sources. The presence of mercury in significant quantities in the process samples suggests that the waters of the mine waste basins, at the Chami processing site are becoming sources of environmental pollution by mercury.

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