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Mercury contamination in soils and process waters near artisanal gold mining sites in Chami, Mauritania

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ABSTRACT

Artisanal gold mining is a major economic activity in Chami, Mauritania, but its reliance on elemental mercury (Hg) for amalgamation raises concerns about environmental contamination. This study investigates the spatial distribution, concentration, and potential sources of Hg in soils and process waters surrounding the Chami gold processing site. During a field campaign, 30 soil samples and 9 water samples were collected from processing areas and nearby boreholes. Soil samples were analyzed using aqua regia digestion followed by ICP-AES, while water samples were assessed using the DMA-80 Direct Mercury Analyzer. Mercury concentrations in soils ranged from 1 to 133 ppm, with elevated levels observed near processing residues. Water samples also exhibited detectable Hg, particularly in process ponds (109.06 mg/l). Pollution indices (PI) and geo-accumulation indices (Igeo) revealed moderate to high contamination, highlighting the significant influence of anthropogenic sources. Spatial analysis indicated that tailings and effluent discharge points are the primary contributors to Hg enrichment in the environment. These findings demonstrate that Hg from artisanal gold mining accumulates in soils and waters of Chami, posing potential ecological and human health risks. The study provides essential baseline data for monitoring and developing mitigation strategies, and contributes to understanding Hg dynamics in arid ASGM-impacted regions where data remain scarce.

Keywords: mercury, gold mining, contamination and environment.

INTRODUCTION

Artisanal and small-scale gold mining (ASGM) is currently recognized as one of the fastest-growing extractive activities in developing countries and represents a major source of environmental mercury (Hg) release (Donald et al., 2025); Nkoa et al (2025) and Gumbo et Kapenge, (2025). In Mauritania, particularly in the town of Chami, the rapid expansion of gold panning activities has led to intensive use of elemental mercury for amalgamation, often in the absence of recovery systems or environmental safeguards. As a consequence, elevated Hg concentrations may accumulate in soils surrounding processing sites through direct spills, tailings disposal, and atmospheric deposition. However, mercury enrichment in soils may also result from natural geochemical processes, including pedogenesis and the weathering of Hg-bearing parent materials (Brabo et al., 2003). Distinguishing between anthropogenic and geogenic contributions therefore remains a critical scientific challenge in ASGM-impacted regions. Globally, ASGM is considered the largest anthropogenic source of mercury emissions, accounting for approximately 1,400 tons annually, or nearly 37% of total anthropogenic releases (Schmidt, 2012; UNEP, 2013). In tropical regions

such as the Amazon Basin, lateritic soils can temporarily retain mercury, delaying its transfer to aquatic systems. Nevertheless, several studies (Roulet and Lucotte, 1995; Guédron et al., 2009) have shown that erosion and disturbance of ferralitic soils may remobilize previously stored Hg. Anthropogenic pressures, including deforestation and vegetation fires, further enhance mercury mobilization into surface waters (Edmond et al (2024); McLagan et al; 2025; Veiga et al., 1994). However, most available studies focus on humid tropical environments, whereas considerably less attention has been paid to mercury dynamics in arid and semi-arid regions, where climatic conditions may strongly influence dispersion pathways. Mercury contamination is particularly concerning due to its persistence and resistance to biodegradation, allowing it to remain in the environment for several centuries. Through biogeochemical transformations, including methylation, Hg may increase in mobility and toxicity, thereby posing significant risks to ecosystems and human populations (Ray et al (2025); Thomas et al., 2002). Numerous studies have documented health risks associated with ASGM exposure (Tomude et al (2026); Burger et Gochfeld, 2006). Despite growing awareness of these risks, environmental monitoring data remain scarce across much of the African continent (Van Straaten, 2000; Adeniyi et al., 2008;), particularly in emerging mining hubs located in arid environments. Biomonitoring studies further confirm the widespread exposure associated with ASGM activities. For example, urine analyses conducted in Tanzanian mining communities showed that 37% of miners exceeded the World Health Organization guideline value of 50 μg Hg/g creatinine (Van Straaten, 2000). Similarly, elevated Hg concentrations were reported in populations residing near mining areas in Mongolia, including individuals not directly engaged in mining (Steckling et al., 2011). These findings highlight that mercury released during amalgamation processes contaminates surrounding environmental compartments and may affect broader populations through soil, dust, and water pathways. Owing to its capacity for long-range atmospheric transport, mercury is considered a global pollutant capable of dispersing even at low concentrations (Gumbo et Kapenege, (2025); Kruzhilko et al (2025); Boening, 2000).

The aim of this study is to assess the contamination by the mercure of soil and water compartments in the vicinity of the gold extraction in the Chami area. Also, this study compares the distribution of mercury in both compartments.

MATERIALS AND METHODS

Study area

The town of Chami (study area, Figure 1) 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 20° and 20°15′N and longitudes 16° and 16°15′W. The area is known for its intense industrial activities, particularly mining, as the majority of the inhabitants are gold miners or civil servants working in the mining sector. While this activity contributes significantly to job creation and the development of the mining area, it is also responsible for several direct or indirect discharges of toxic chemicals into the surrounding soils.

Sampling methods

Approximately 30 soil samples were collected during a field campaign in Chami (Figure 1). A hand auger was used to collect samples from the top 20 centimeters of soil, using a clockwise rotating motion. The geographical coordinates of each sampling point were recorded using a precision GPS (±3 m). The sampling points were chosen to ensure spatial representativeness and to reflect the heterogeneity of the site. Selection criteria included : proximity to the Chami gold processing site (with respective distances of 100 m, 200 m, and 300 m towards the Atlantic Ocean), prevailing wind direction (NW–SE), and local climatic conditions (arid and dry climate). The samples were placed in clean polyethylene bags, labeled with unique identifiers, and transported to the laboratory under ambient conditions, with a transport time of 24 hours in order to preserve the samples in the best possible condition. Upon arrival, the samples were air-dried, gently ground using an agate mortar, and then sieved through a 2 mm sieve to remove coarse debris. The homogenized samples were then packaged and sent to the ALS laboratory group in Dublin for mercury analysis.

During the field campaign, nine water samples were collected from treatment basins and

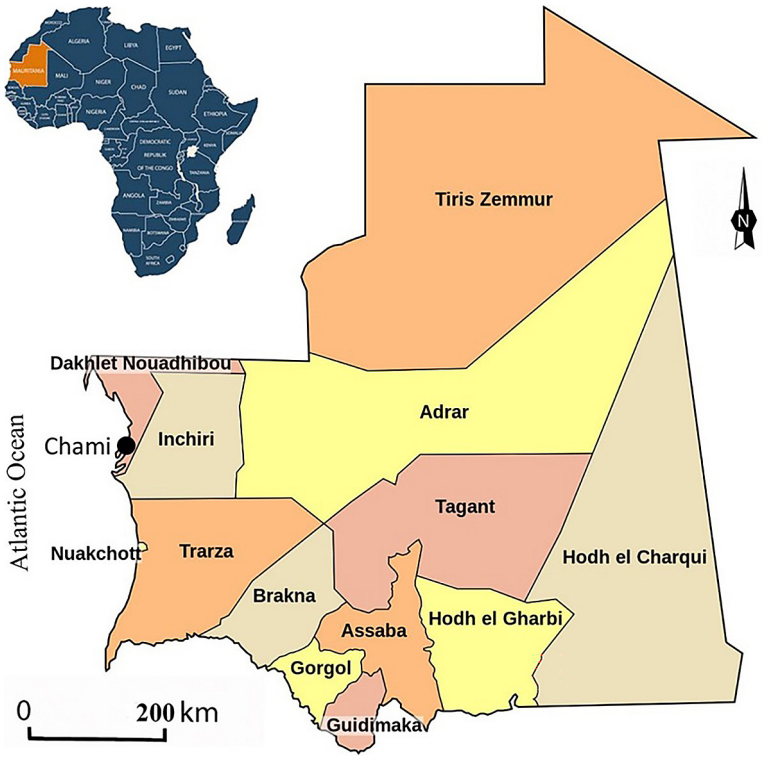

Figure 1. Location of the study area

boreholes likely to be affected by gold mining activities (Figure 2). The sampling points were chosen based on the presence of artisanal gold mining in Chami, the main source of mercury in the treatment water used at the Chami treatment center, as well as the risk of contamination at the boreholes. The samples were collected in sterile 100 mL polypropylene bottles, labeled, and stored at 4 °C until analysis. The geographical coordinates of each sampling point were recorded using a precision GPS (±3 m). The samples were then transported to the ONISPA laboratory in Nouakchott for mercury content determination.

Geochemical processing

Hg concentrations in soils and water samples were determined using standard laboratory protocols (ALS). For soils, ICP-AES was applied after digestion with aqua regia. For water, a DMA-80 Direct Mercury Analyzer was used for total Hg determination. All analytical procedures were performed in accordance with laboratory quality assurance guidelines.

Soil samples were first dried at digested with aqua regia (37% HCl + 65% HNO_3). For each analysis, 0.5 g of soil was placed in a digestion tube ("Digitube"), then 6 mL HCl and 2 mL HNO_3 were added. Tubes were heated at 95 °C for 45 minutes in a mineralization block. After cooling, the digest was diluted to 50 mL with deionized water and centrifuged at 2.000 rpm for 3 minutes. An aliquot of 12.5 mL was homogenized and analyzed using ICP-AES. Spectral interferences were corrected following the laboratory's standard protocol; calibration and regular verification, blanks to avoid contamination, spiked and control samples to verify accuracy (85–115% recovery), duplicates for precision, and dilution of samples that are too concentrated. [QC CERTIFICATE LR22196087 analysis limit method lower 1 ppm].

Water samples were analyzed for total Hg using the DMA-80 Direct Mercury Analyzer. Samples underwent thermal decomposition in an oxygen-rich environment, with mercury amalgamation on a gold trap, followed by thermal desorption. Hg concentration was determined by UV spectrometry at 253.7 nm, with measurements automatically switching between long and short path cells depending on absorbance. The detection limit of the method is 0.0058 mg/kg. QA/QC for mercury analysis by DMA-80 included verification of calibration using aqueous mercury standards, method blanks to monitor contamination, matrix-matched certified

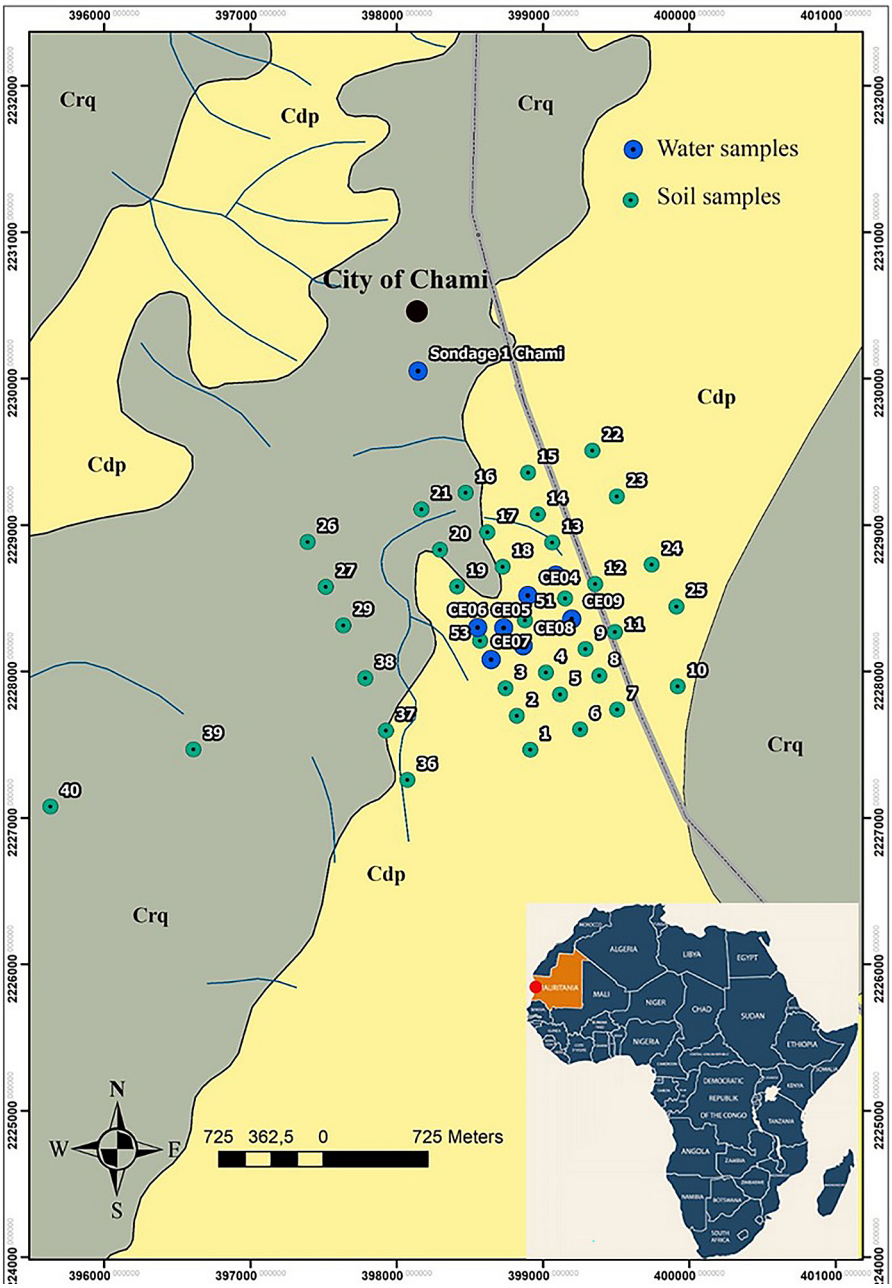

Figure 2. Map of sampling

reference materials (CRMs) to ensure accuracy, and duplicate samples to ensure accuracy, with data falling within accepted recovery tolerances. All procedures ensure accuracy and reliability of trace Hg measurements.

Pollution index

The pollution index (PI) reflects the relative enrichment of each metal compared to its natural geochemical background and allows identification of multi-element contamination (Chon et al., 1998; Smouni et al., 2010; Tankari Dan Badjo et al., 2013; Yehdhih et al., 2022). The *PI* for a given metal *x* is calculated as:

$$Pix = Bx/Cx \quad (1)$$

where: *Cx* is the concentration of metal *x* in the soil sample, and *Bx* is the background concentration of the same element.

A *PI* value greater than 1 indicates contamination relative to the background.

Geo-accumulation index

The geo-accumulation index (*Igeo*) was calculated to assess the degree of metal accumulation in soils, taking into account natural variations in background concentrations (Müller, 1969; Chassin et al., 1996). The formula is:

$$Igeo = \log2\ (Cn/1.5Bn) \quad (2)$$

where: Cn is the measured concentration of the element in the soil sample, Bn is the geochemical background value for the element (Muller, 1969), and 1.5 is a constant to account for natural fluctuations in element content and low-level anthropogenic influence.

The Igeo values were classified into seven pollution categories (Table 1), ranging from unpolluted (Igeo ≤ 0) to extremely polluted (Igeo > 5). This classification enables a quantitative assessment of soil contamination severity.

Statistical processing of results

Statistical analysis was conducted to describe the distribution of mercury concentrations and to identify relationships between variables. Descriptive statistics, including the mean, standard deviation, minimum, and maximum values, were calculated for each sample. All statistical calculations and graphical representations were generated using Microsoft Excel 2016, while spatial distribution maps were produced using ArcGIS 10.8 under the Universal Transverse Mercator (UTM) coordinate system in the Northern/Southern Hemisphere (Table 2).

Geological context

From a geological perspective, the study area belongs to the Senegalese–Mauritanian sedimentary basin, which is approximately 300 km wide and covers an area exceeding 160,000 km², of which about 100,000 km² lies offshores (Figure 2). This basin developed during the Permo-Triassic along the western part of a passive continental rift margin during the opening of the proto-Atlantic Ocean (Ritz and Bellion, 1990). The Tertiary formations are poorly exposed and occur mainly at the periphery of the basin, being mostly known from borehole data (Bellion et al., 1991). In contrast, Quaternary deposits are widely developed as superficial formations composed mainly of fine to coarse sands with clay intercalations (Ritz et al., 1989). These deposits correspond to transgressive and regressive formations that characterize the Senegal–Mauritanian sedimentary basin (Elouard et al., 1969; Riser, 1991).

Table 1. Müller's classification (1969)

Igeo value	Pollution class	Description
≤ 0	0	Unpolluted
0–1	1	Unpolluted to moderately polluted
1–2	2	Moderately polluted
2–3	3	Moderately to heavily polluted
3–4	4	Heavily polluted
4–5	5	Heavily to extremely polluted
> 5	6	Extremely polluted

RESULTS

Mercury concentration in soil

Soils have an average mercury concentration of 22.7 ppm, well above the upper continantal crust (UCC) geochemical background values (Taylor and McLennan, 1985), which are generally below 1 ppm in unaffected environments. The maximum concentration recorded was 22.2 ppm. The highest levels are observed in samples C001, C003, C013, C024, C028, C036, C037, C051, and C052, located in the immediate vicinity of the Chami processing site, suggesting a direct influence of mining activities on the contamination of surrounding soils. The relatively low median compared to the mean indicates an asymmetrical distribution, reflecting the presence of contamination hotspots. The coefficient of variation (CV = 1.6) confirms this spatial heterogeneity, which is typical of localized pollution linked to ore handling and processing areas (Table 3).

Mercury concentration in water

Process water presents an even more worrying situation. The average Hg concentration reaches 109.06 mg/L, which is extremely high and well above the international reference values set by the UCC for aquatic environments (≈ 0.06 mg/L). The high median indicates

Table 2. Mercury concentrations in the soil and water analyzed samples

Soil samples	Hg (ppm)	Water samples	Geographical coordinates	Hg (mg/L)
C001	59	EC1	402888.31 m E, 2215356.78 m N	0.0058
C002	1			
C003	70			
C004	13	EC2	398200.12 m E 2229448.39 m N	0.0058
C005	8			
C006	8			
C007	14	EC3	398685.06 m E, 2227774.43 m N	6.774
C008	10			
C009	2			
C010	1	EC4	398788.18 m E 2227527.35 m N	0.307
C011	1			
C012	1			
C013	33			
C014	1	EC5	399085.69 m E 2227647.56 m N	0.559
C015	1			
C017	1			
C019	1	EC6	399334.44 m E 2227729.57 m N	2.166
C020	1			
C022	3			
C023	1	EC7	398200.12 m E 2229448.39 m N	43.613
C024	5			
C025	1			
C026	<2	EC8	398960.50 m E, 2227899.60 m N	919.638
C027	2			
C028	<2			
C036	9	EC9	399153.60 m E, 2228040.79 m N	8.453
C037	6790			
C038	7			
C051	200			
C052	74			
UCC	1.5			

systematic contamination of all samples analyzed. The highest concentrations were found in samples EC6, EC7, EC8, and EC9, reflecting heterogeneous dispersion of mercury within the treatment system. The very high coefficient of variation (CV = 2.79) (Table 3) reflects extreme variability, probably linked to the variable intensity of amalgamation practices and effluent management methods.

Mercury environmental assessment in soil

The interpretation of pollution index values makes it possible to distinguish between different levels of environmental contamination. In general, a PI below 1 indicates no pollution or an acceptable level of contamination, while a PI between 1 and 3 indicates moderate pollution. Values between 3 and 6 indicate considerable pollution, while a PI above 6 reflects

Table 3. Statistical processing of results

Parameter	average	Median	Ecartypes	CV	Min	Max	IPMIN	IPMAX	UCC	IPM	Igeo min	Igeo max
Hg/soil	22.2	2.5	35.5	1.60	1	133	16.7	2216.7	0.06	370.6	-1	1
Hg/water	109.06	2.166	304.29	2.79	0.005	919.63	0.1	15327.30	0.06	1817.63		

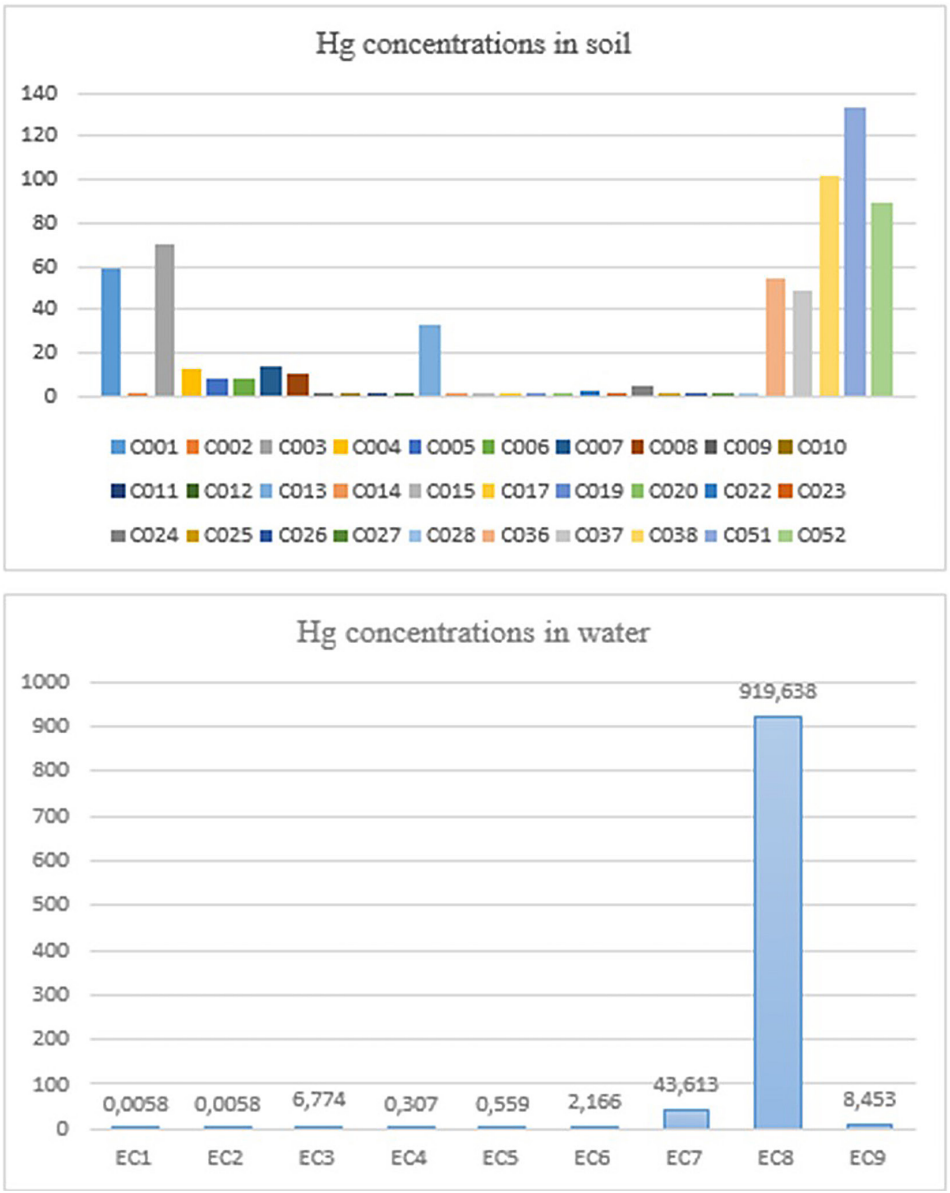

Figure 3. Mercury concentration in samples

very high pollution. The results obtained highlight marked spatial heterogeneity in mercury pollution indices. For soils, the highest indices were observed in samples C001, C003, C004, C005, C006, C013, C036, C037, C038, C051, and C052. In these samples, the index values far exceed unity, indicating significant mercury contamination and revealing, in some cases, moderate to high levels of pollution. Geo-accumulation index (Igeo) is used to assess the degree of mercury (Hg) enrichment in environmental matrices by comparing measured concentrations with geochemical background levels, with six classes ranging from 0 (no pollution) to 5 (extremely high pollution). For soil, the values range from −1 to 1, corresponding to classes ranging from unpolluted to moderately polluted (Figure 4).

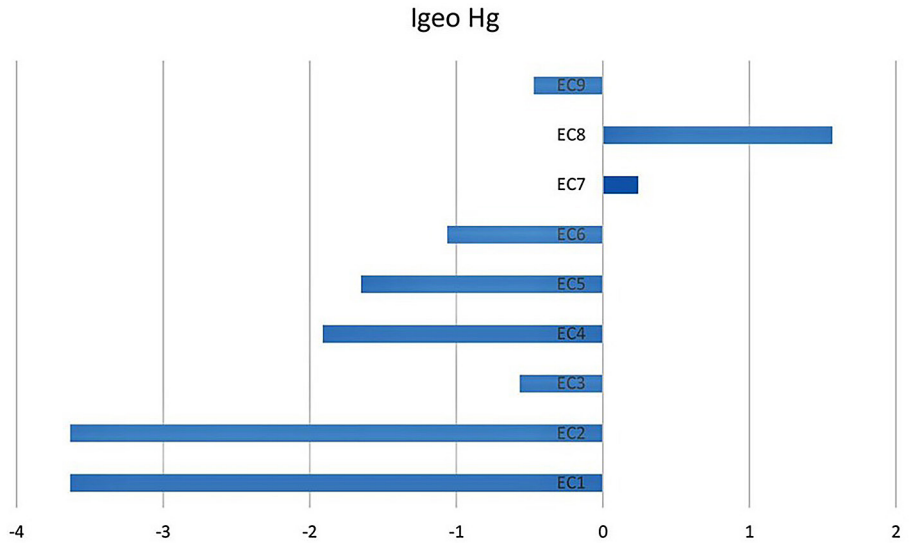

Figure 4. Geoaccumulation indices in analyzed samples

Mercury environmental assessment in water

With regard to process water, the calculated indices show particularly worrying Hg contamination, with values well above the critical threshold. This situation probably reflects the direct impact of discharges from artisanal gold mining activities, in which mercury is used for gold amalgamation. Overall, the critical threshold (IP > 1) exceeded in the majority of water analyzed samples indicates significant mercury contamination in the study area. In this study, the Igeo for water ranges from −3.63 to 1.57, reflecting situations ranging from unpolluted to heavily polluted and indicating significant spatial variability and occasional anthropogenic influence.

DISCUSSION

Similar studies conducted in Côte d'Ivoire (Gala Bi Trazie Jeremie, 2020) and Senegal (Niane, 2014) confirm that artisanal mining activities are a major source of local mercury contamination in soils.

It is also important to specify that heavy rainfall promotes the mobility of Hg by intensifying its vertical and lateral transfers (Dajade, 2020), leading to a risk of groundwater contamination through infiltration and atmospheric dispersion, a phenomenon also observed at gold mining sites in Tanzania and Zimbabwe (Straaten, 2000). In Chami, contaminated soils can be a source of Hg dispersion through wind action, which is characteristic of the region, or through rainwater leaching, which promotes its transport to lower topographical areas, particularly towards the Atlantic Ocean. Rainwater infiltration also increases the risk of groundwater contamination.

Due to its volatile nature (Veiga and Baker, 2004; Guédron et al., 2009), mercury can evaporate into the atmosphere and then redeposit on vegetation, soil, water resources, homes, and agricultural land (Grimaldi et al., 2015; Mallongi et al., 2017; Posthumus, 2019). In gold mining areas where mercury is used in smelting, an additional risk lies in atmospheric contamination linked to the volatilization of Hg from soils (Santos-Francés et al., 2011).

CONCLUSIONS

All soil and water analyzed samples contained detectable levels of Hg, with most soil samples exceeding established background concentrations (UCC), while process water samples showed Hg levels above environmental thresholds. Calculated pollution indices (PI > 1) and geo-accumulation indices (Igeo) indicate moderate to high contamination in both soils and process waters.

This comparison reveals that contamination is significantly more pronounced in water than in soil, illustrating the greater mobility of mercury in the aquatic system and highlighting the direct and continuous impact of gold mining activities on process water, while soil serves more as a

secondary reservoir where Hg accumulates in a more localized manner.

The coefficients of variation suggest that Hg distribution is primarily influenced by localized anthropogenic sources rather than natural variability. Spatial and proximity analyses show that the Chami gold processing site, including tailings deposits and treatment basins, is the main source of Hg accumulation in surrounding soils and waters.

The results demonstrate that artisanal gold mining in Chami has led to significant Hg accumulation in environmental compartments. These findings provide clear evidence linking the observed contamination to anthropogenic activities at the processing site and confirm the primary hypothesis that local gold processing is the main driver of environmental Hg contamination in the study area.

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