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Article

Keywords: mercury, contamination, pollution, Chami, Mauritania

Posted Date: April 7th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9208476/v1

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Additional Declarations: No competing interests reported.

Pollution Characteristics and Risk Assessments of Mercury in the Soil of Chami (Dakhlet Nouadhibou, Mauritania): Preliminary study

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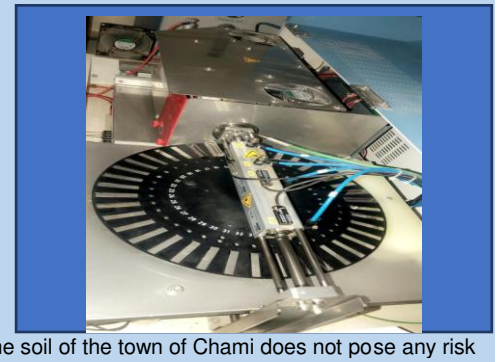
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Abstract: Due to the rapid expansion of mining, the economy of town of Chami in Mauritania has experienced swift growth. However, this rapid expansion brings the risk of soil pollution by mercury (Hg) as a result of increased mineral processing activities. In order to study the characteristics of soil Hg pollution in Chami and assess the health risk, a total of 14 samples were collected from seven sites from the town of Chami. The results revealed that the soil Hg concentration varies widely from 0.0061 to 0.658 mg/kg with an average of 0.233 mg/Kg in first campaign. In second campaign, the soil Hg concentration varies widely from 0.063 to 0.819 mg/kg with an average of 0.258 mg/Kg. The results of the laboratory analysis were further elucidated using pollution indices such as the Single Pollution Index, Contamination Factor, Ecological Risk Factor and the Geo-accumulation Index. These environmental indices revealed that the soil is seriously polluted with Hg. However, the values of the total non-carcinogenic risk assessment index (HI) were found to be far less than 1. These results reveal that the soil of the town of Chami does not pose any risk to human health.



Keywords: mercury, contamination, pollution, Chami, Mauritania.

Introduction

The mining has become a major economic activity and a source of income for a significant number of the population of several African countries **(1)**. Like others anthropogenic activities, the exploitation of mining potential probably remains a source of contamination of soils and aquatic media by several harmful chemical substances **(2-6)**. However, the soil is considered as one of the final destinations of chemical wastes.

Among these harmful and hazardous chemical substances, the mercury (Hg), according to the literature, is a highly toxic pollutant **(7- 9)**. Several incidents of Hg pollution have been reported around the world prompting more attention to be paid to Hg pollution.

Soil is the very important reservoir of Hg in the ecosystem. It is important to note that the human activities and dry deposition of gaseous element Hg may also make significant contributions **(10, 11)**. As soil Hg pollution is characterized by some characteristics such as the latency, the persistence, the high toxicity, and the irreversibility highlighting the importance of a comprehensive assessment of Hg pollution status and the health risk of soil **(12- 17).**

In Mauritania, artisanal gold mining has become a booming activity in 2016. However, Hg is the most commonly used in

this process in Mauritania. During this process, Hg is rejected to the environment through mining liquid and solid waste, or emitted to the atmosphere (18). In the course of artisanal and small-scale gold mining activities, an amalgam is formed by mixing Hg and gold. Then, the amalgam is heated to extract the trapped gold, releasing Hg vapors into the air and hence, exposing miners and in habitants of neighboring areas (19). Once Hg reaches aquatic systems, a small fraction is converted by bacteria to methylmercury (MeHg) at the water-sediment interface (20). Then, MeHg is able to enter into the food chain (21), biomagnifying and bioaccumulating (22), thus, consumption of contaminated fish or seafood also compromises human health (23).

Therefore, it is important to conduct this preliminary study to assess Hg contamination, pollution, and environmental risks on soil pollution in the town of Chami with Hg using several indices of contamination and pollution. In addition, the associated health risks were then assessed by determining the levels of Hg exposure and then calculating the hazard index (HI) and the hazard quotient (HQ). The results obtained by this preliminary work will contribute to a more comprehensive understanding of the risks arising from human exposure to Hg in the study area town of Chami.

Materials and Methods

Study area

Located approximately 250 km from the Nouakchott city, the town of Chami is a department of the Dakhlet Nouadhibou region, in the northern part of the Senegal Mauritania basin in southwestern Mauritania between latitudes -16°0' and -16°15'W and longitudes 20° and 20°15'N. This area is rich in industrial activities and particularly mining. It is important to note that the Chami processing center, gold recovery activities are intense and continue day and night. In addition, Hg is extensively used in the various stages of gold extraction.

Soils sampling and analysis

To determine the variation of Hg concentration in the soils at the Chami processing sites, 14 samples were collected. The soil samples were collected 20 cm bellow the ground surface. The resulting soil samples were then securely bagged. The geographic coordinates of the sampled points were determined using a GPS (Figure 1). The soils samples were transported directly to the Laboratory. The Hg content in the collected soil samples was analyzed by Direct Hg Analyzer (DMA80, Millstone) equipment. The determination of Hg is carried out following the procedure indicated by [24].

The Table 1 give some information related to the geographical position of the sites of the study area.

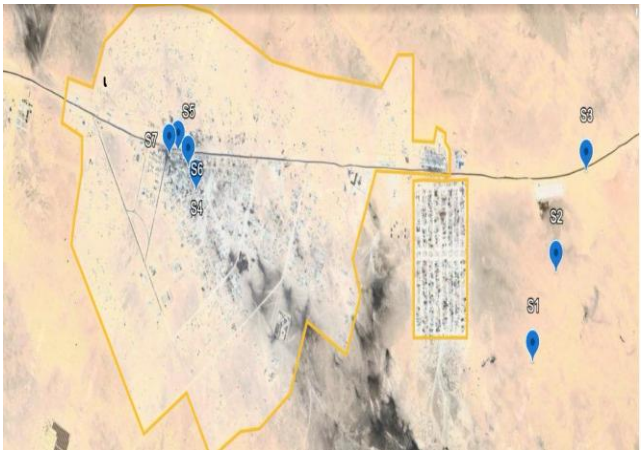


Figure 1. Location of the study area

Table 1. Coordinates of the studied sites along the Chami

Sites	Location	Coordinates
S1	Treatment Center	20.13495 15.96841
S2	Treatment Center	20.13497 15.96341
S3	Treatment Center	20.13467 15.95758
S4	Market	20.16421 15.9734
S5	Market	20.16531 15.97261
S6	Market	20.16639 15.9723
S7	Market	20.13495 15.96841

Soil pollution indices

Several indices of contamination and pollution sych as Single Pollution Index, Contamination factor, Ecological risk factor, and Index of geoaccumulation were illustrated as follows.

Single Pollution Index (PI)

In this study, the Single Pollution Index (PI) is used to determine which heavy metal represents the highest threat for a soil environment. The PI was calculated by equation (1):

$$PI = \frac{C_n}{GB} \qquad (1)$$

Where Cn is the content of Hg in soil and GB is value of the geochemical background. IP > 1 corresponds to a soil polluted by Hg.

Contamination factor (Cf)

According to the definition given by Loska et al, (25), the contamination factor (Cf) was calculated by equation (2):

$$C_f^i = \frac{C_n(sample)}{B_n(Bacground)} \qquad (2)$$

Four contamination categories are defined for C_f: C_f<1 (low contamination factor indicating low contamination); 1 ≤C_f<3 (moderate contamination factor); 3≤C*f* <6 (considerable contamination factor); and C_f > 6 (very high contamination factor).

Ecological risk factor (Er^i)

According to Håkanson (1980), reported by Qingjie et al, (26), the ecological risk factor (Er^i) express quantitatively the potential ecological risk of a given contaminant and calculated by the following equation (3):

$$E_r^i = T_r^i \times C_f^i \quad (3)$$

Where T_r^i is the toxic- response factor for a given substance, and Ci_f is the contamination factor. The T_r^i values of Hg by Håkanson (1980) reported by Qingjie et al, (26) is 40.

Index of geoaccumulation (Igeo)

According to Loska, et al., (25), the index of geoaccumulation (Igeo) was done by the following equation (4):

$$I_{geo} = \log_2 \frac{C_n}{1.5Bn} \quad (4)$$

Where C_i is the measured concentration of the Hg i in the soil, and Bn is known as the geochemical background concentration or reference value of the Hg i. Factor 1.5 is used because of possible variations in background values for Hg in the environment. According to Buccolieri, et al, (27), the Igeo was distinguished into seven classes by Müller.

Soil Hg health risk assessment

The soil Hg enters the human body via dermal contact and subsequent ingestion, direct oral ingestion, and inhalation of airborne particulate matter reported by Wang et al, (28). We present the risk models for four exposure pathways and provide the corresponding calculation formula, according to the Chinese Environmental Site Assessment Guideline and the American environmental health risk assessment methodologies (29). The route of direct human skin contact is done by the following equation (5):

$$EDI_{skin} = \frac{C \times SA \times AF \times ABS \times EF \times ED}{BW \times AT} 10^{-6} \quad (5)$$

In the above, EDI is the chronic daily exposure, mg·(kg·d)$^{-1}$; C is the measured concentration, mg·kg^{-1} ; SA is the skin area that may be in contact with soil, cm^2 ·d^{-1} , the reference value is 5000 cm^2 d1; AF is the adsorption coefficient of skin to soil, mg·cm^{-2} , the reference value is 1 mg·cm^{-2}; ABS is the skin respiration rate, the reference value is 0.001; EF is the exposure frequency, d·a^{-1} , the reference value is 350 d·a^{-1}; ED is the exposure period, a, the reference value is 25 a; BW is body weight, kg, the reference value is 55.9 kg; AT is the exposure period, d, and the reference value is 365×ED (d) (30). The route of direct oral ingestion is expressed by the following equation (6):

$$EDI_{oral} = \frac{C \times IFP \times EF \times ED}{BW \times AT} 10^{-6} \quad (6)$$

Where EDI, C, EF, ED, BW and AT all refer to formula (5). IFP is soil intake, mg·d^{-1}, the reference value is 114 mg·d^{-1}. The route of ingestion via breathing (7):

$$EDI_{breath} = \frac{C \times IR \times EF \times ED}{BW \times AT \times PEF} \quad (7)$$

Where EDI, C, EF, ED, BW and AT all refer to formula (5). IR is air intake, m^3·d^{-1} , and the reference value is 20 m^3·d^{-1} (31). PEF is the soil dust generation factor, the reference value is 1.32×10^9 (28). The route of Hg vapor inhalation is given by the following equation (8):

$$EDI_{steam} = \frac{C \times IR \times EF \times ED}{BW \times AT \times VF} \quad (8)$$

In the above, EDI, C, EF, ED, BW and AT all refer to formula (5). IR refers to equation (5). VF is the evaporation coefficient, m^3 ·kg^{-1}, and the reference value is 32 657. 6 m^3 ·kg^{-1} ' (28).

For mercury, non-carcinogenic risk assessment is generally conducted and evaluated using the hazard quotient HQ:

$$HQ = \frac{EDI_i}{RfD_i}$$

In the above, EDIi is the chronic daily exposure, mg·(kg·d)$^{-1}$; RfDi is the reference dose for risk assessment of various pathways, mg·(kg·d)$^{-1}$; RfDskin = 2.4×10^{-5} mg·(kg·d)$^{-1}$, RfDoral= 3.0×10^{-4} mg·(kg·d)$^{-1}$; RfDbreath = 1. 07×10^{-4} mg·(kg·d)$^{-1}$ (29); RfDvapor = 1×10^{-3} mg·(kg·d)$^{-1}$ (28). The total non-carcinogenic risk value of Hg in different pathways is expressed as HI, expressed by the following equation:

$$HI = \sum_i^n HQ_i$$

When HI or HQ > 1, it is considered that there is a potential non-carcinogenic risk; when HI or HQ < 1, the risk is considered to be small or negligible.

Results and Discussion

Mercury Levels in the Soils Studied

Results for total mercury levels in various soils in the town of Chami are shown in Table 2. It indicates that in the town of Chami, the soil Hg concentration varies widely from 0.0061 to 0.658 mg kg^{-1} with an average of 0.233 mg/Kg and a standard deviation of 106.31 in first campaign (C1). In second campaign (C2), the soil Hg concentration varies widely from 0.063 to 0.819 mg kg^{-1} with an average of 0.258 mg/Kg and a standard deviation of 100.45. The Hg levels found in this study were higher than values reported for Pra basin southwest Ghana (0.04-0.45 mg/kg) (32). The Hg values obtained in the present study were higher than the permissible limit issued by the WHO Standard of 0.05 mg/kg (33).

Table 2. Spatio-temporal variation of Hg (mg/kg) concentrations

	Campaing 1	Campaing 2
S1	0.0287	0.1102
S2	0.0492	0.1011
S3	0.0061	0.0626
S4	0.2347	0.2583
S5	0.658	0.1968
S6	0.1807	0.819
S7	0.4702	0.258
Max	0.658	0.258
Min	0.0061	0.063
Mean	0.233	0,258
Std	106.31	100.45

Moreover, according to the results in Table 2 we observe that only the sites S4, S5, S6 and S7 facing the wind have very higher Hg contents. These results indicate that the polluted soils of Chami become a possible source of propagation of Hg in the environment, either through the wind. Similar results are reported by Sun & Yang **(29).**

Soil pollution indices

The results for the PI factors for mercury in the soils in the town of Chami are highlighted in Table 3.

Table 3. Mercury pollution indices for the soils studied during both campaigns

		S1	S2	S3	S4	S5	S6	S7
PI	C1	5	8.5	1.05	40.5	113.5	31.2	81.1
	C2	19	17.4	10.8	44.5	33.9	31.2	44.5
CF	C1	4.95	8.5	1.1	40.5	113.5	31.2	81.1
	C2	19	17.4	10.8	44.5	33.9	31.2	44.5
Er^i	C1	197.9	309.3	42.1	1618.6	4537.9	1246.2	3242.8
	C2	760	697.2	431.7	1721.4	1357.2	5648.3	1
Igeo	C1	1.2	1.73	-0.4	3.29	4.32	3.0	3.99
	C2	2.5	2.5	1.9	3.39	3.12	3.0	3.39

The PI of Hg were 1.05 and 113.50 in first campaign, and 10.79 and 44.53 in second campaign (Table 3). However, the PI was more important in the sites S4, S5, S6 and S7. Therefore, since the PI was greater than 1 in all sites, it can be concluded that the soil from the town of Chami is contaminated by Hg.

The CF of Hg were 1.05 and 113.50 in first campaign, and 10.79 and 44.53 in second campaign (Table 3). However, the CF was variable according to the sites but it was more important in the sites S4, S5, S6 and S7. According to the CF, all examined sites from the town of Chami have considerable to very high contamination with Hg.

The Er^i of Hg vary from 42.1 to 4537.9 during the first campaign and vary from 431.7 to 5648.3 **(**Table 3**)**. However, the Er^i was variable according to the sites but it was more important in the sites S4, S5, S6 and S7. According to the Er^i all examined sites from the town of Chami have moderate to very high ecological risk with Hg. Similar results are reported by Bonah & Ebenezer **(34)**.

The Igeo of Hg varies from -0.4 to 4.3 during the first campaugn and varies from 1.94 to 3.39 **(**Table 3**)**. However, the Igeo was variable according to the sites but it was more important in the sites S4, S5, S6 and S7. According to the Index of Igeo, all examined sites from the town of Chami have to moderately to strongly polluted with Hg. Similar results are reported by Bonah & Ebenezer **(34)**.

Assessment of the Potential Health Risks of Soil Hg Contamination

As can be seen in Figure 2, the Health Risk Index (HI) values ranging from 0.00013 to 0.01365 in first campaign and 0.00022 to 0.0029 in second campaign. The HI values of all the approaches were far less than 1, which indicated that the soil mercury contamination in the study area was not harmful to the health.

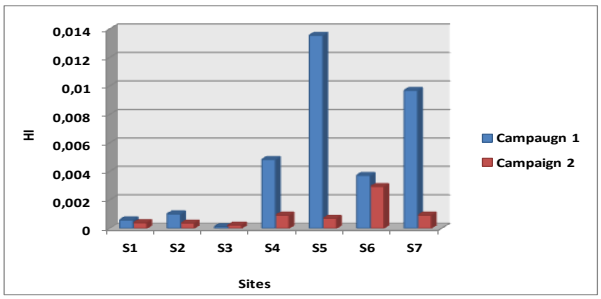


Figure 2. Spatio-temporal variation of HI

Moreover, the results for the chronic daily exposure for Hg in the soils collected from the town of Chami are highlighted in Table 4.

Table 4. Spatio-temporal variation of the chronic daily exposure (EDIi)

	Sites	ADI $_{skin}$	ADI $_{oral}$	ADI $_{breath}$	ADI $_{steam}$
C1	**S1**	2,4616E-09	5,6124E-08	7,4594E-12	3,015E-07
	S2	4,2199E-09	9,6213E-08	1,2787E-11	5,1686E-07
	S3	5,2319E-10	1,1929E-08	1,5854E-12	6,4082E-08
	S4	2,013E-08	4,5897E-07	6,1E-11	2,4656E-06
	S5	5,6436E-08	1,2867E-06	1,7102E-10	6,9125E-06
	S6	1,5499E-08	3,5337E-07	4,6965E-11	1,8983E-06
	S7	4,0329E-08	9,195E-07	1,2221E-10	4,9396E-06
C 2	**S1**	9,4518E-09	2,155E-07	2,8642E-11	1,1577E-06
	S2	8,6713E-09	1,9771E-07	2,6277E-11	1,0621E-06
	S3	5,3692E-09	1,2242E-07	1,627E-11	6,5763E-07
	S4	2,2154E-08	5,0512E-07	6,7134E-11	2,7135E-06
	S5	1,6879E-08	3,8485E-07	5,115E-11	2,0674E-06
	S6	7,0245E-08	1,6016E-07	2,1287E-10	8,6039E-06
	S7	2,2154E-08	5,0512E-07	6,7134E-11	2,7135E-06

As can be seen in **Table 4**, the order of the daily exposure coefficient under the different exposure pathways was as follows: Steam > Oral > Skin >Breath. This order showed that the steam intake is a principal exposure pathways. Hg is a volatile metal that can evaporate into the atmosphere from soil, water, and other surfaces, constituting a continual source of atmospheric emissions. Othewise, the principal risk could be the contamination of the atmosphere by the vaporization flow of Hg from the soil. Similar results are reported by Santos-Francés et al., **(35).**

Conclusion

The present and preliminary study investigated the Hg contamination, pollution, and environmental risks on soil pollution in the town of Chami with Hg using several indices of contamination and pollution. The soil Hg concentration varies widely from 0.0061 to 0.658 mg/kg with an average of 0.233 mg/Kg in first campaign. In second campaign, the soil Hg concentration varies widely from 0.063 to 0.819 mg/kg with an average of 0.258 mg/Kg. The resulted obtained by PI, CF, Er^i and the Igeo methods indicated that the soil is seriously polluted with Hg. The values of the HI in Chami City were found to be far less than 1, indicating that the soil does not pose a risk

to human health. In addition, the order of the daily exposure coefficient under the different exposure pathways was as follows: Steam > Oral > Skin >Breath. These results reveal that the steam intake is a principal exposure pathways. Othewise, the principal risk could be the contamination of the atmosphere by the vaporization flow of Hg from the soil.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The raw data required to reproduce these findings are available in the body and illustrations of this manuscript.

Author's contribution

The authors confirm their contribution to the paper as follows: study conception and design: F.S.Y, A.D.N, M.L.Z,; data analysis and validation A.D.N, H.G, B.H & M.K; draft manuscript preparation: A.D.N, H.G, Editing and writing: ….. All authors reviewed the results and approved the final version of the manuscript. All authors reviewed the results and approved the final version of the manuscript.

Funding

This research received no external funding.

Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this article

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