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RESEARCH ARTICLE

ASSESSING POLLUTION FROM TRACE METALS ELEMENTS AND ANALYSING ECOLOGICAL RISKS IN THE TAILINGS FACILITY AND SURROUNDING SOILS AT THE SABODALA MINE

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Abstract

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Contamination and pollution of soil by trace metal elements (TM) pose serious environmental and health problems because they are not biodegradable. Trace metals are naturally present in soils in varying concentrations. However, these concentrations increase with mining activities, forming stocks of pollutants that are potentially toxic to the environment. This study seeks to quantify the TM content in the tailings facility and surrounding soils at the Sabodala mine. A total of seven samples of mine tailings and soil were taken from the tailings pond (S1 to S7) and eight from the soil surrounding the pond (S8 to S14). Geochemical characterization was performed using inductively coupled plasma atomic emission spectroscopy (ICP-AES). The results obtained show that the average concentration values are very disparate and vary depending on the metal and the sampling site. The average concentrations of As (378.30 mg/kg), Sb (96.92 mg/kg), Ni (119.59 mg/kg) and Cd (4.31 mg/kg) in the mining tailings are significantly higher than those in the surrounding soils (10.16; 5.82, 22.99 and 0.50 mg/kg for As, Sb, Ni and Cd, respectively). Based on contamination indices (IP and I_{geo}), mining residues are moderately to heavily contaminated with arsenic, antimony, cadmium, and nickel, unlike the surrounding soils. The distribution maps for As and Sb reveal local and irregular pollution in the tailings facility. The ecological risk potential of arsenic (293.3) in mining residues is high, unlike that of antimony (34.92), cadmium (38.4), and nickel (39.75).

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In the soil surrounding the tailings facility, the ecological risks posed by trace metals are low. The average ecological risk index for trace metals in mining residues is considerable (406.37) and low for surrounding soils (21.65).Arsenic is the main contributor to this index (72.17% for mine tailings and 36.02% for soils). While these results provide valuable information on the quality of the mine tailings and surrounding soils in the tailings facility, the contamination status must be assessed periodically. Knowledge of the spatial distribution of pollution must serve as a basis for future tailings pond rehabilitation projects.

Introduction:-

The footprint of mining is deeply ingrained in human existence. However, this need for development carries with it a risk: environmental pollution[1, 2, 3]. Trace metals such as arsenic, cadmium, antimony, nickel, etc.

Are among the toxic elements released into the soil, water, and air during mining and mineral processing. Such heavy metals can contaminate soil and groundwater, which will later have an impact on human health [4, 5, 6]. Several studies have shown that these heavy metals can be transferred from the soil into the food chain via plant roots [7, 8, 9]. Several studies have examined tms pollution at mining sites and their surroundings, as well as the impact of mining activities on the environment [10, 11, 12, 13]. These studies have shown that pollution from tms can irreversibly affect the ecosystem if suitable protective measures are not taken quickly. Due to erosion in contaminated areas, tms can be dispersed into river systems or in the form of aerosols, several kilometres away from their sites of origin. This widespread contamination makes the phenomenon even more devastating and difficult to control [14, 15, 16]. This study aims to assess the level of pollution in mining waste and the soil surrounding the tailings pond caused by trace metals and their ecological risks. This approach will enable us to estimate, from a qualitative and quantitative perspective, the degree of contamination of the surrounding soil by tms and to consider appropriate prevention and risk management measures.

MATERIAL AND METHODS:-

Geographical location and description of the Sabodala tailings facility:-

Sabodala is located in southeastern Senegal, approximately 700 kilometres from Dakar, within the Mako greenstone belt, which forms the western part of the Birrimian gold province. The area studied is in the town of Sabodala, which is part of the Sabodala district, the Saraya department, and the Kedougou region. The study area comprises the first tailings storage facility of the Sabodala gold mine, covering approximately 380 hectares, and the surrounding land (Figure 1). Following the latest raising of the dike, the maximum storage capacity is 48.8 million m³, of which 35 million m³ was already occupied by waste in February 2024 [17].

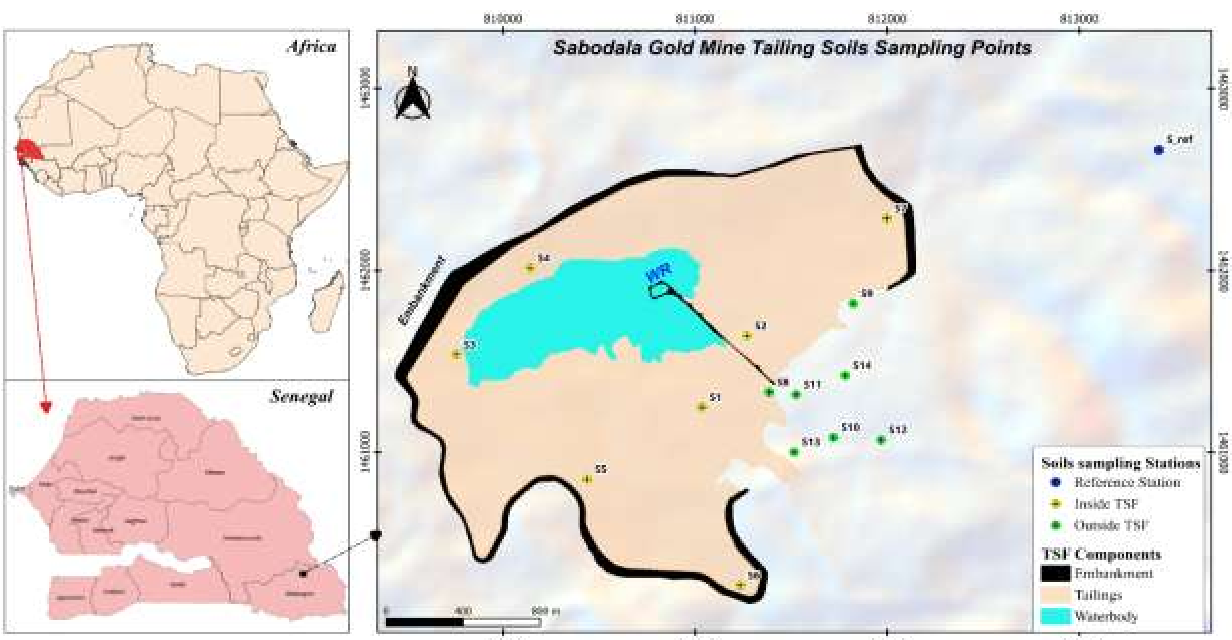


Figure 1: Geographical location and location of sampling stations.

Preparation of soil samples:-
The soil samples collected in the field were first dried in a room at room temperature. The samples were then sieved. Chemical analysis was performed on the fine fraction (particles ∅< 63 µm) of the sediments, to which trace metals preferentially bind [18].

Determining the ph:-
Ten (10) grams of the fine fraction (particles ∅< 63 µm) of each sample, taken separately, were placed in a 100 ml beaker. Next, 25 ml of distilled water was added to the beaker containing the fine fraction, and the mixture was stirred for one (1) hour. The ph was then measured by immersing the Hanna ph meter probe into the supernatant. Finally, the reading was taken after the digital display of the ph meter had stabilised.

Determining the electrical conductivity (EC) of soils and mine tailings:-
The principle consists of shaking 10 g of soil in 50 ml of distilled water for two (2) hours (1/5 aqueous extract). After filtration, electrical conductivity (EC) is measured using a Hanna-type multi-parameter meter.Assessing soil acidity and salinity is essential to understanding how these factors affect plant growth. Table 1 shows the assessment of soil acidity and salinity according to ph[18]and electrical conductivity [19].

Table 1: Assessment of soil acidity and salinity based on ph and electrical conductivity[18, 29]

Ph	Appreciation of soil ph	EC (ms/cm	Appreciation of the of soil salinity
< 3.5	Hyper acid	EC < 0.6	Unsalted
3.5 < ph < 4.2	Very acid	0.6 <EC < 1.2	Little salty
4.2 < ph < 5	Acid	1.2 <EC < 2.4	Salty
5 < ph < 6.5	Low Acid	2.4 <EC < 6	Very salty
6.5 < ph < 7.5	Neutral	EC > 6	Extremely salty
7.5 < ph < 8.7	Basic		
> 8.7	Very basic		

Extraction Of Metals From Soil Matrices:-
The extraction and determination of total tms in soils were carried out using a mixture of hydrofluoric, perchloric, and nitric acids in accordance with standards NF X 31-147 and NF ISO 14869-1. The principle consists of digesting 1.2 g of particles with a diameter of less than 63 µm in 2 ml of nitric acid (HNO_3) ≥ 65%, 10 ml of hydrofluoric acid (HF) at 40% and 2 ml of perchloric acid ($HClO_4$) at 60% in a 100 ml conical glass flask on a hot plate at 100°C for 2 hours. The hot solution was cooled and filtered through filter paper. The resulting solution was diluted with 50 ml of distilled water and stored in quechers (Quick, Easy, Cheap, Effective, Rugged, and Safe) tubes. After extraction, trace metals are analysed by inductively coupled plasma atomic emission spectrometry (ICP-OES).

Calculation of trace metal content in soils:-
The calculation of ETM levels is based on the following formula: T (ppm) = C x V/S where:
- ✓ T = Concentration of the element in mg/kg.
- ✓ C = Concentration of the element in mg/L as determined by ICP-OES.
- ✓ S = Weight of soil sample in g (1.2 g).
- ✓ V = Final extraction volume in ml (50 ml).

For water samples, the ICP-OES-determined levels are the concentrations of tms in the water.
Pollution index

The pollution index is the average of the ratios of trace metal concentrations in soil samples to threshold limits. We took four trace metals (As, Sb, Ni, and Cd) and the limits of FNOR NF U44-041[20]. This index provides an overall indication of the pollution level of each sample. If the pollution index is less than one, the environment is not polluted; otherwise, the environment is polluted. It is calculated using the following formula:
PI = $([\boldsymbol{As}]/\mathbf{20}+[\boldsymbol{Sb}]/\mathbf{2}+[\boldsymbol{Ni}]/\mathbf{20}+[\boldsymbol{Cd}]/\mathbf{2})\ /4$
Geo-accumulation index (I_{geo})
The geo-accumulation index is proposed by [21] in [22]to determine sediment contamination by metals. This index, which is empirical in nature, compares a given concentration with a value considered to be the geochemical

background. Thus, the coefficient 1.5 (correction factor) accounts for variations in background levels that may be caused by lithological effects. The Igeo is calculated using the following formula:

$I_{geo} = \log_2(Cn/_{1,5Bn})$

Cn: concentration of metal n in soils.

Bn: Geochemical background for metal n.

1.5: constant taking into account natural fluctuations in the content of a given substance in an environment as well as anthropogenic fluctuations.

The geochemical backgrounds for the metals As, Sb, Ni, and Cd are 12.9, 16.64, 92.35, and 0.54 mg/kg, respectively. This data was obtained from the reference site. The I_{geo} values enable seven contamination level classes to be defined, as shown in Table 2. The Geo Accumulation Index (I_{geo}) provides information on the level of accumulation of metallic elements in mining tailings. It is assessed using the following formula:

Table 2: Classes defined by the geo-accumulation index [21].

Igeo	Values ranges	Intensity of pollution
0	(-∞, 0)	Uncontaminated
1	(0, 1]	Uncontaminated to light Contamination
2	(1, 2]	Moderate contamination
3	(2, 3]	Moderate to high contamination
4	(3, 4]	High contamination
5	(4, 5]	High to extreme contamination
6	(5, +∞)	Extreme contamination

Contamination factor:-

The Contamination Factor (CF) is used to express the level of soil contamination by each of the different metals. It is expressed by the following relationship:

$FC = \text{Teneur du métal}/\text{Fond géochimique du métal}$

The geochemical backgrounds for the metals As, Sb, Ni, and Cd are 12.9, 16.64, 92.35, and 0.54 ppm, respectively. The FC values are interpreted below as suggested by [23, 24]:

- ✓ $FC < 1$: Low contamination
- ✓ $1 \leq FC < 3$: Moderate contamination
- ✓ $3 \leq FC < 6$: Significant contamination
- ✓ $FC \geq 6$: Very high contamination

Potential ecological risk

The individual potential ecological risk factor is calculated by:

$E_1^n = T_R^N \times cf_n$ where $cf_n = Cn/_{Bn}$

Cfn is the contamination factor for element n.

E_r^n is the ecological risk potential of element n.

Tr^n is the toxic response factor for metal or metalloid n.

The Tr^n toxic response factors for Cd, As, Sb, and Ni are 30, 10, 6, and 5, respectively [25, 26].

According to the criteria for assessing the ecological risk potential of an element, the following classes should be considered:

- ✓ $Er < 40$: potential ecological risk potential of the weak element.
- ✓ $40 \leq Er < 80$: moderate potential ecological risk potential of the element.
- ✓ $80 \leq Er < 160$: high ecological risk potential of the element.
- ✓ $160 \leq Er < 320$: very high ecological risk potential of the element.

The composite ecological risk index (ERI) indicates the potential ecological risk of trace metals in soil. Proposed by [23], it has been widely used to assess the potential ecological risk of trace metals in soils and has been calculated using the following formula 3 [27, 28]:

$ERI = \sum En$

ERI is generally classified into four groups:

- ✓ $IRE \leq 150$: low risk
- ✓ $150 < IRE \leq 300$: moderate risk

- ✓ 300 < IRE ≤ 600 : significant risk
- ✓ IRE > 600 : high risk[29,30]

Results and Discussion:-

Ph

Figure 2 shows that the mining tailings are basic (8.09 <ph< 8.16) [19](Table 1). This alkalinity is due to the presence of carbonates, silicates, and the addition of lime to neutralize acids during the treatment of mining waste[17]. The surrounding soils also have alkaline ph levels [19] ranging from 7.51 to 7.94 (S8 to S14). These values are generally lower than those of mining tailings.

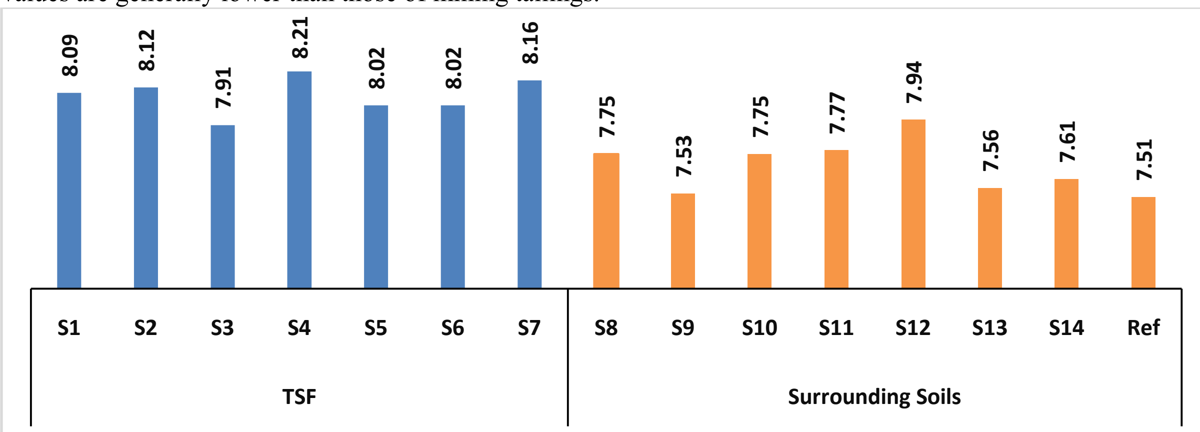


Figure 2: Variation in ph of mine tailings and surrounding soils

Electrical Conductivity (EC)

The electrical conductivity (EC) values of mining tailings show significant spatial variations. They range from 649.4 to 8,080 µs.cm⁻¹ (Figure 2). Mining tailings range from salty to very salty[20]. For the surrounding soils, electrical conductivities range from 55.03 to 65.95 µs.cm⁻¹ and are similar to those of the reference station (55.06 \µs.cm⁻¹).Despite the erodibility of the mine tailings in the tailings facility, the surrounding soils are not affected by wind. This is due to the moisture content of the mine tailings generated by the rotary discharge system with a tap lance.

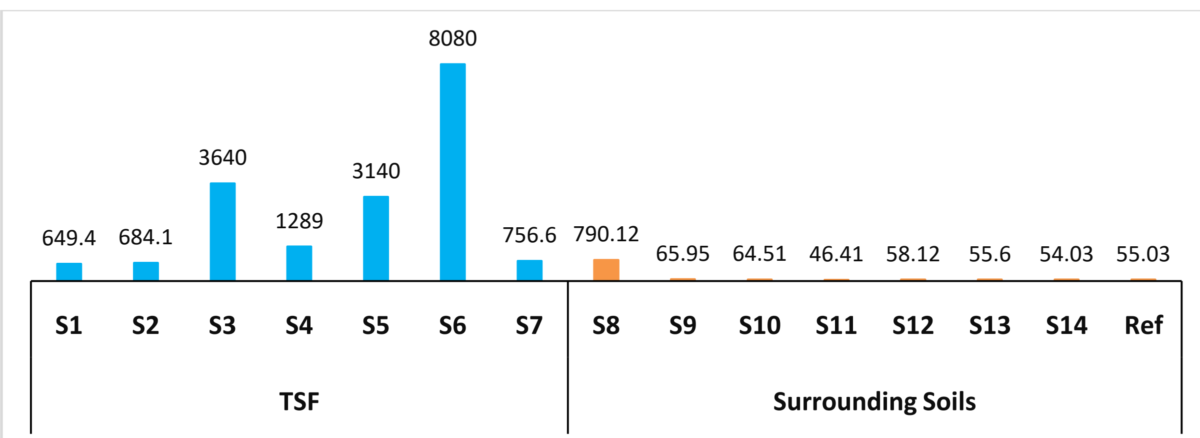


Figure 3: Surface dynamics of electrical conductivity (EC) in mine tailings and surrounding soils

Geochemistry of mine tailings and surrounding soils

Distribution of trace metals

The concentrations of As, Sb, Ni, and Cd in the samples are shown in Table 3.

Table 3: Concentrations of trace metals (As, Cd, Ni, and Sb) in mine tailings and surrounding soils (mg/kg)

Matrices	Stations	As	Sb	Ni	Cd
Mine Tailings	S1	632.32	162.24	108.99	6.24
	S2	254.59	49.92	111.49	2.95
	S3	687.54	208	59.9	7.07
	S4	432.64	93.6	92.76	5.82
	S5	420.16	128.96	111.07	4.58
	S6	56.16	8.32	232.12	1.16
	S7	164.74	27.45	110.24	2.37
Surrounding Soils	S8	9.56	6.24	25.38	0.49
	S9	12.06	9.15	27.45	0.5
	S10	11.23	4.58	21.22	0.46
	S11	12.48	10.4	49.5	0.62
	S12	8.74	3.33	13.72	0.5
	S13	9.98	3.74	13.72	0.54
	S14	7.07	3.33	9.98	0.45
Reference Station	Ref	12.9	16.64	92.35	0.54

The average concentrations of trace metals in mining tailings are 194.23, 51.37, 70.53, and 2.41 mg/kg (Table 3) for arsenic, antimony, nickel, and cadmium, respectively. These average values are much higher than those of the upper continental crust (UCC) [31, 32]and the target values (except for cadmium) authorized by the WHO [33, 34, 35].

Table 4: Concentrations of etms in surrounding soils.

Matrices	Elements	Max	Min	Moyenne	Ref	CCS*	VC**
Mine Tailings	Arsenic	687.54	56.16	378.3	12.9	1.5	20[a] ; 5[b]
	Antimony	208	8.32	96.92	16.64	0.2	2
	Nickel	232.12	59.9	119.59	92.35	20	20[a] ; 50[b]
	Cadmium	7.07	1.16	4.31	0.54	0.102	2
Surrounding Soils	Arsenic	12.48	7.07	10.16			
	Antimony	10.4	3.33	5.82			
	Nickel	49.5	9.98	22.99			
	Cadmium	0.62	0.45	0.5			

Global average upper continental crust (UCC).

Target values, referring to the maximum desirable levels of elements in unpolluted soils.

Sources of permissible limits in soils: World Health Organization [34, 36]

Figure 4 shows the variation diagrams for trace metal content in the matrices studied. There is a significant difference in TME content between mining residues and surrounding soils. This difference is due to the mineralisation of the gangue.

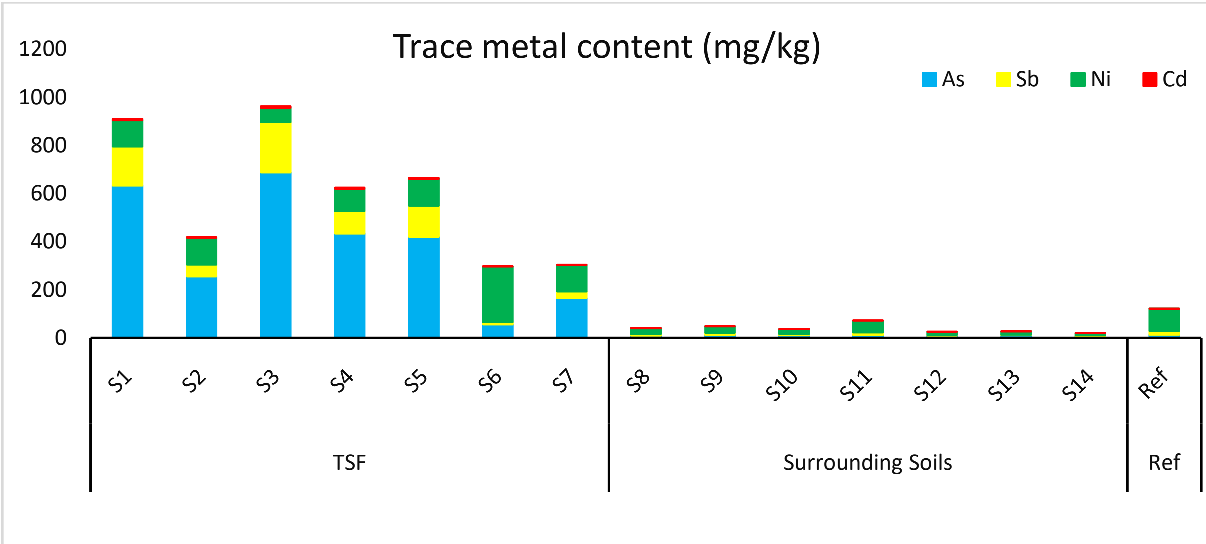


Figure 4: Variation in trace metal content (As, Cd, Ni, and Sb) in mine tailings and surrounding soils in the tailings facility.

Figures 5 and 6 show the spatial distributions of arsenic and antimony concentrations in the Sabodala mine tailings and surrounding soils. This representation shows an irregular distribution of tms (As and Sb) in the environment studied. This distribution depends on the ore being processed and the rotary discharge system of the tap-hole type.

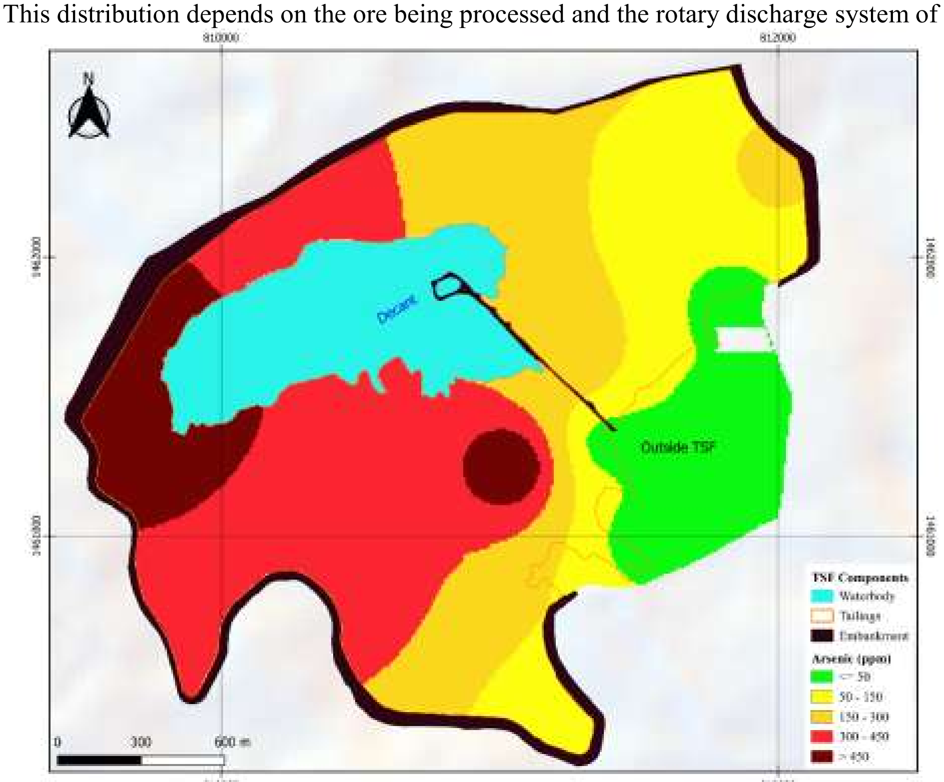


Figure 5: Spatial distribution of arsenic concentrations in the tailings facility and surrounding soils compared to the local geochemical background

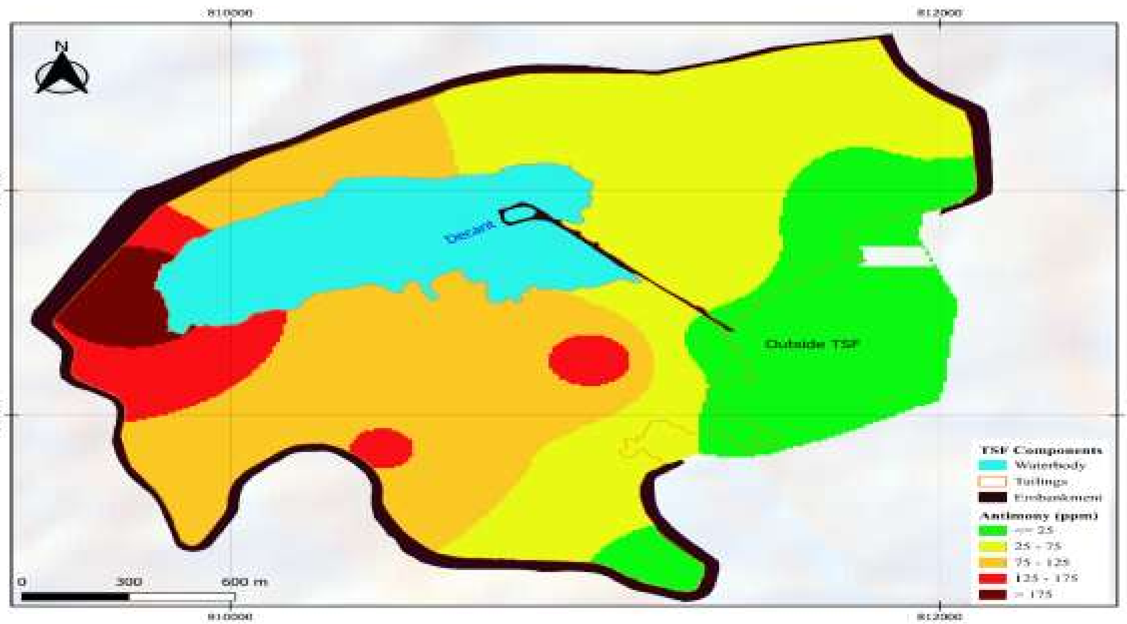


Figure 6: Spatial distribution of antimony contents in the tailings facility and surrounding soils compared to the local geochemical background

Contamination Indices

To help figure out the quality of the waste and the surrounding soil, pollution, geo-accumulation, and concentration factors were measured.

Pollution index (PI) of tailings and surrounding soil

The results obtained show highly variable PI values from one station to another, with values ranging from 2.41 to 19.04 for mining tailings (Figure 7). The pollution indices for mining tailings (S1 to S7) are greater than one, indicating polymetallic contamination. These mining tailings have high IP values similar to those found in the Moroccan mines of Mibladen (IP: 34.7) and Zeida (PI: 20,52) [37]. Similar values are frequently observed in regions with mining activities. [2, 7]report IP values greater than 1 in soils from several mining regions in Korea. The surrounding soils have pollution indices below unity, indicating that they are not contaminated. The contamination of the tailings pond can therefore be considered local.

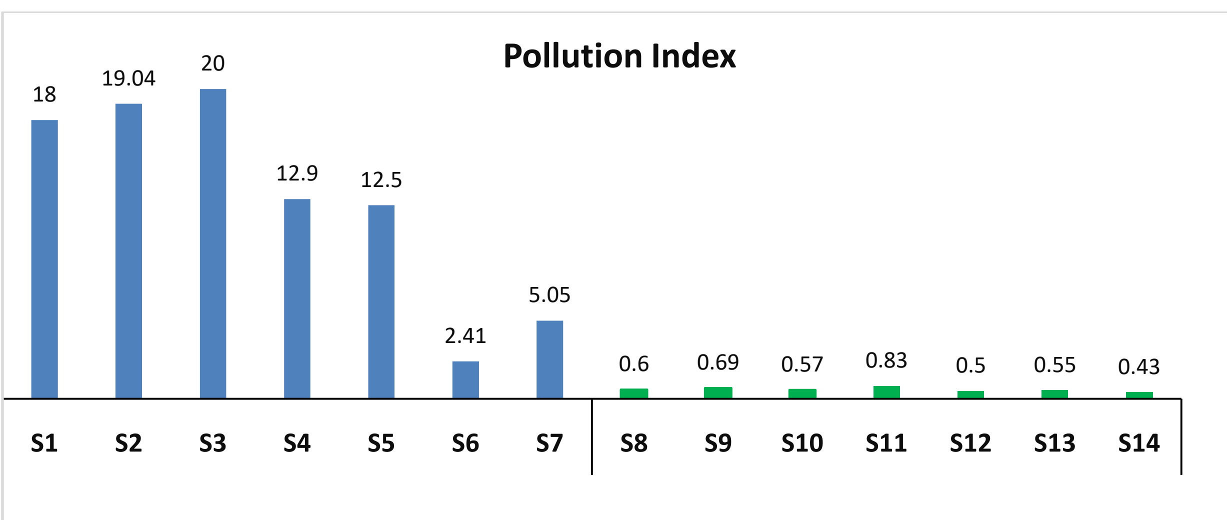


Figure 7: Variation in pollution indices for mine tailings and surrounding soils

Figure 8 shows spatial variation in the pollution index within the tailings pond. The red colour indicates high polymetallic pollution (As, Sb, Cd, and Ni). This spatial distribution is due to variations in the ore gangue and the rotating tap-type discharge system. The surrounding soil is not affected by residues from the tailing facility. Thus, it can be said that the contamination is local.

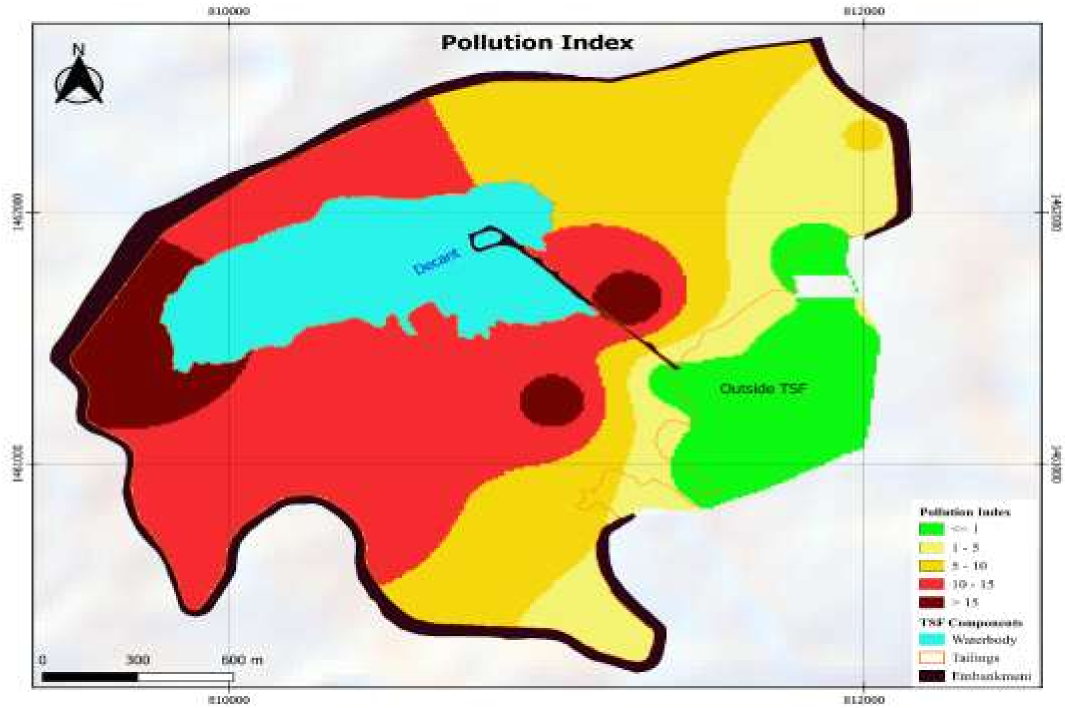


Figure 8: Spatial distribution of the pollution index of mining tailings and surrounding soils at the Sabodala mine

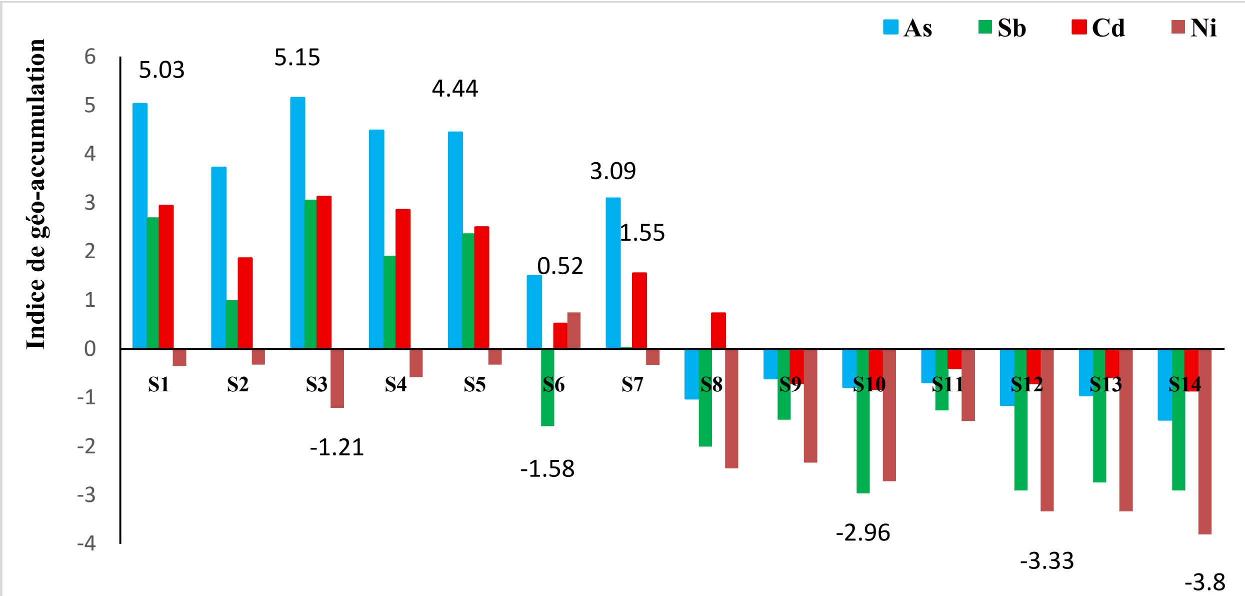
Geo-accumulation index

The I_{geo} values for the four trace metal elements are shown in Figure 9. In mining tailings, the geo-accumulation index values for arsenic, antimony, and cadmium are generally positive (Table 5), indicating moderate to extreme contamination. There is a high accumulation of arsenic in mining tailings. For nickel, the geo-accumulation index is negative, indicating an absence of nickel contamination in mining tailings. For the soils surrounding the tailings pond, the geo-accumulation indices for As, Cd, Ni, and Sb are negative ($I_{geo} < 0$), indicating that the soils are not contaminated with trace metals.

Table 5: Geo-accumulation index of trace metals (As, Cd, Ni and Sb) and contamination level

Matrice	Stations	As	Sb	Cd	Ni	Categories
Mine Tailings	S1	5.03	2.7	2.94	-0.35	- Moderate to extreme contamination in As, Sb and Cd. - Absence of contamination with Ni
	S2	3.72	1	1.86	-0.32	
	S3	5.15	3.06	3.12	-1.21	
	S4	4.48	1.91	2.85	-0.58	
	S5	4.44	2.37	2.5	-0.32	
	S6	1.5	-1.58	0.52	0.75	
	S7	3.09	0.04	1.55	-0.33	
Surrounding soils	S8	-1.02	-2	0.73	-2.45	$I_{geo} < 0$ Uncontaminated in As, Sb, Cd and Ni
	S9	-0.6	-1.45	-0.7	-2.33	
	S10	-0.78	-2.96	-0.82	-2.71	
	S11	-0.68	-1.26	-0.39	-1.48	
	S12	-1.15	-2.9	-0.7	-3.33	
	S13	-0.95	-2.74	-0.58	-3.33	
	S14	-1.45	-2.9	-0.85	-3.8	

Figure 9: Geo-accumulation indices of trace metals (As, Cd, Ni and Sb) in the tailings pond and surrounding soils



The geo-accumulation indices for trace metals (As, Cd, Ni and Sb) in the tailings pond are significantly higher than those in the surrounding soil. For the latter, negative geo-accumulation indices indicate an absence of pollution.

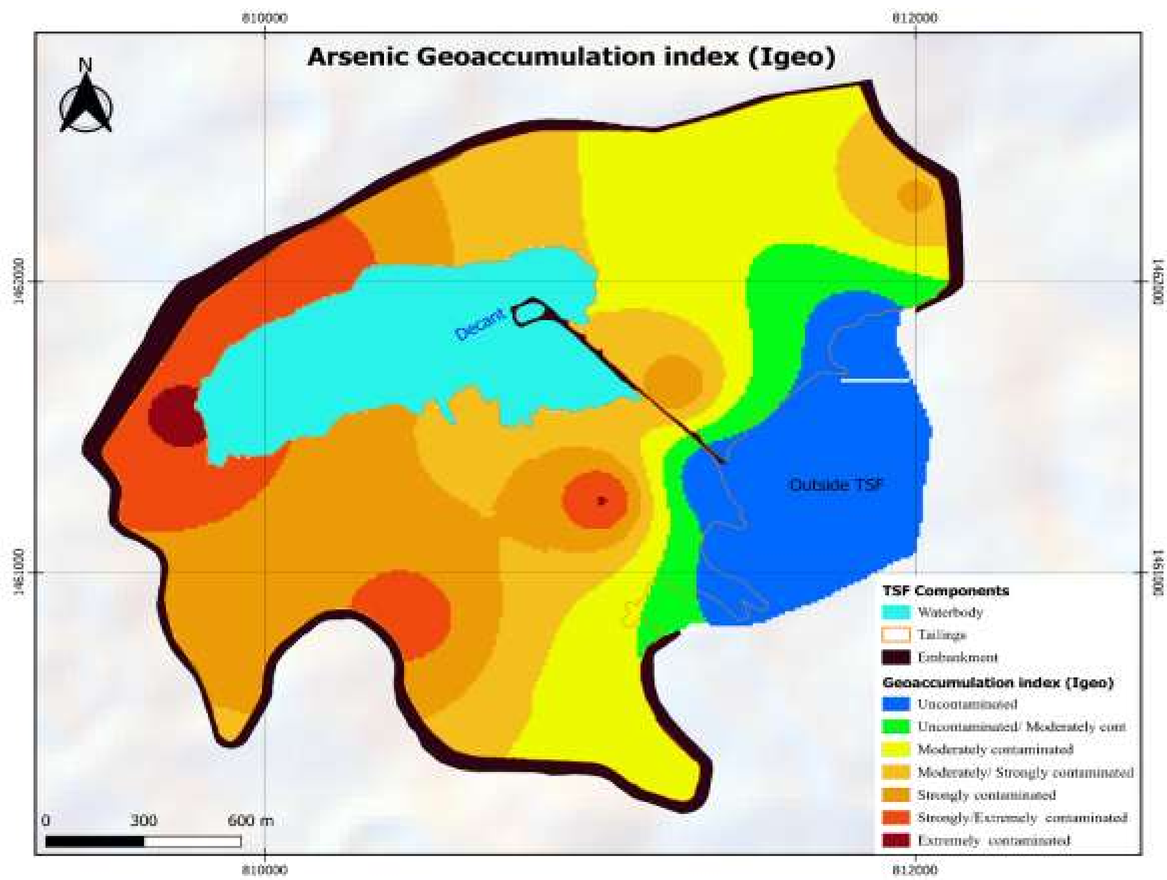


Figure 10: Spatial distribution of geo-accumulation indices for trace metals (As) in the tailings pond and surrounding soils

Contamination factors

In mine tailings, the cfs for arsenic, antimony, and cadmium greatly exceed the unit (Figure 11), indicating an increase in the levels of these elements in the tailings pond with a degree of pollution reaching “very high contamination.” For the surrounding soils, contamination factors never exceed the threshold for the first class (CF < 1), indicating low or no contamination (Table 6).

Table 6: Contamination factors and degree of contamination of different metals [23, 24].

	Stations	As	Sb	Cd	Ni	Categories
Mine Tailings	S1	49.02	9.75	11.55	1.18	Very high contamination in As, Sb and Cd and moderate in Ni
	S2	19.74	3	5.46	1.2	Very high contamination in As, considerable in Sb, Cd and moderate in Ni
	S3	53.3	12.5	13.09	0.64	Very high contamination in As, Sb and Cd and moderate in Ni
	S4	33.53	5.62	10.77	1.01	Very high contamination in As and Cd, considerable in Sb and moderate in Ni
	S5	32.57	7.75	8.29	1.2	Very high contamination in As, Sb and Cd and moderate in Ni
	S6	4.35	0.5	2.14	2.54	Very high contamination in As, moderate Cd and Ni and low in Sb
	S7	12.77	1.65	4.38	1.19	Very high contamination in As, considerable in Cd and moderate in Sb and Ni
Surrounding soils	S8	0.74	0.37	0.9	0.27	Low contamination in As, Sb, Cd and Ni
	S9	0.93	0.55	0.92	0.3	Low contamination in As, Sb, Cd and Ni
	S10	0.87	0.27	0.85	0.23	Low contamination in As, Sb and Ni and moderate in Cd
	S11	0.97	0.625	1.15	0.53	Low contamination in As, Sb, Cd and Ni
	S12	0.67	0.2	0.92	0.15	Low contamination in As, Sb, Cd and Ni
	S13	0.77	0.22	1	0.15	Low contamination in As, Sb and Ni and moderate in Cd
	S14	0.54	0.2	0.83	0.11	Low contamination in As, Sb, Cd and Ni

To determine the degree of risk of a metal being released into the environment, assessing the contamination factor can be considered an effective approach [24]. A high contamination factor value indicates a high risk to the environment. The concentration factors for each metal and the respective degrees of contamination are presented in Table 6 [23]. In the tailings facility, arsenic, antimony, and cadmium (S1 to S7) show considerable to very high levels of contamination. The most problematic metals in these mining residues are therefore arsenic, antimony, and cadmium. For soils in the vicinity of the tailings pond, metal contamination is generally low.

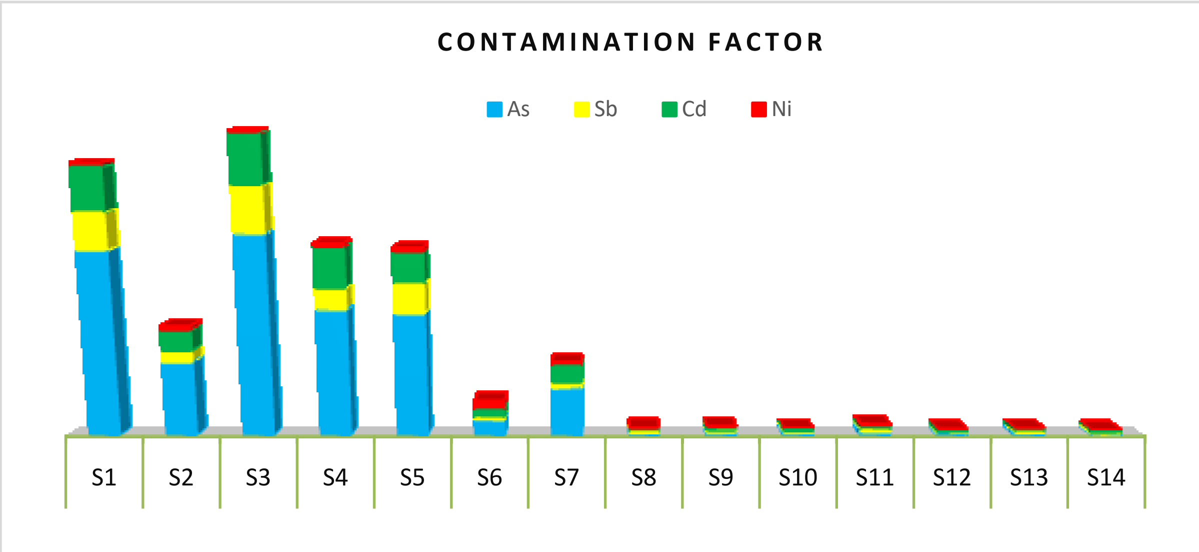


Figure 11: Estimated Contamination factors for each metal at the various sampling points

Pollution gradually decreases with distance from the tailings facility. Stations S8 to S14 are only slightly contaminated as they are located outside the tailings facility.

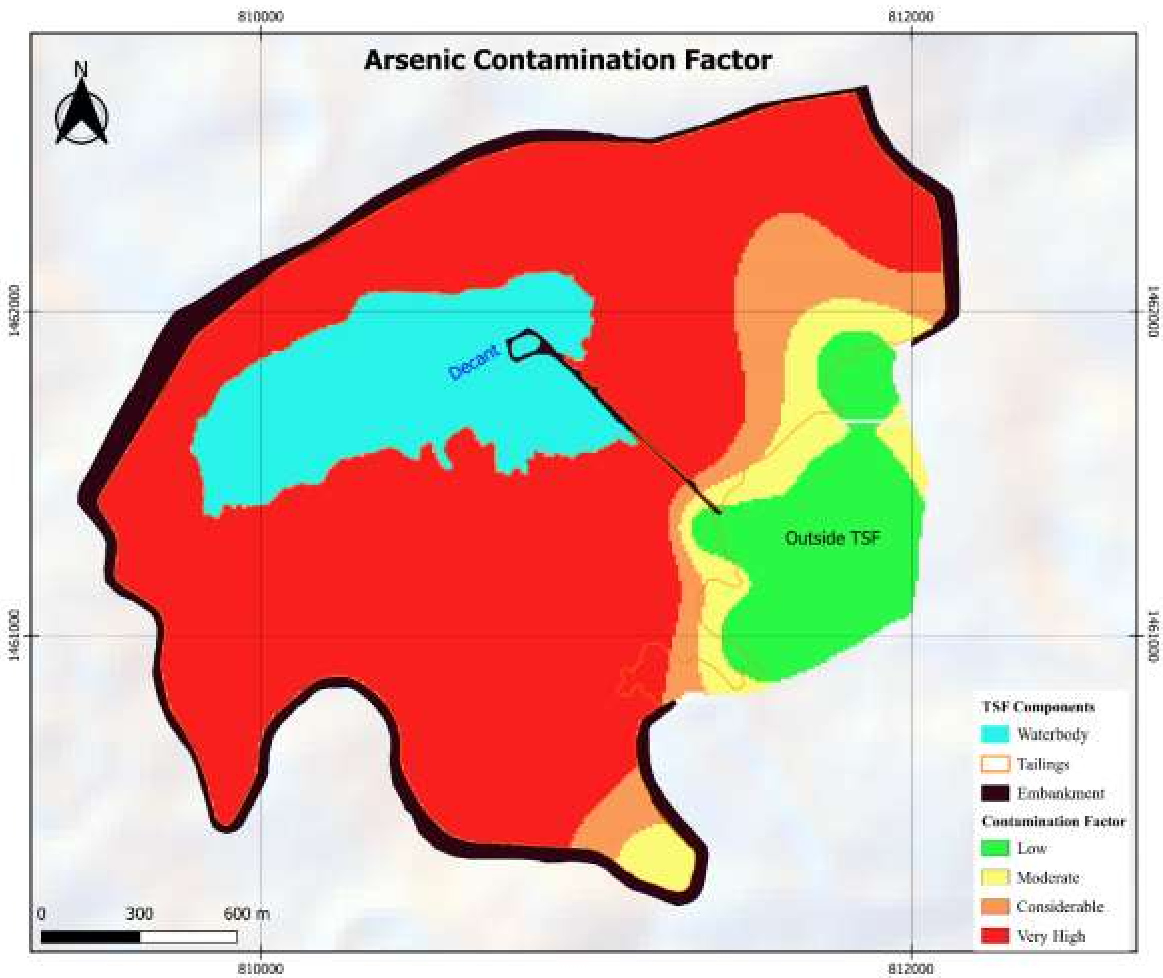


Figure 12: Distribution of the arsenic contamination factor in soils in and around the tailings facility

Ecological risk of metals and metalloids

The calculated E_r^n and ERI values used to assess the ecological risks of the four trace metals in the tailings pond and surrounding soils are presented in Table 7.

Table 7: Ecological risk potential of heavy metals in the tailings pond and surrounding soils

Matrices	Elements	Moyenne (% contribution)	Minimum (% de contribution)	Maximum (% de contribution)
Mine Tailings	Arsenic	293.30 (72.17 %)	43.5	533.3
	Antimony	34.92 (8.5 %)	3	75
	Nickel	39.75 (9.78 %)	10.7	65.45
	Cadmium	38.40 (9.44 %)	19.2	76.2
	IRE	406.37	76.4	749.95
Surrounding soils	Arsenic	7.8	5.4	9.6
	Antimony	2.04	1.2	3.72
	Nickel	4.61	4.15	5.75
	Cadmium	7.2	3.3	15.9
	IRE	21.65	14.05	34.97

The average values of ecological risk potentials for each metal or metalloid in mine tailings vary in the following order: As (293,3) > Sb (34,92) > Cd (38,4) > Ni (39,75). Among these trace metals, arsenic presents a high ecological risk potential for mining residues ($160 < Er^n \leq 320$). The average Er^n values for Sb, Ni and Cd are below 40, indicating a low ecological risk potential. The average ecological risk potential of each metal or metalloid As (7.80), Sb (2.04), Cd (7.20) and Ni (4.61) in the surrounding soil is low, indicating local contamination of the tailings facility. The average ecological risk index value for trace metals in the tailings facility is 406.37. This value indicates a considerable potential ecological risk in the mine tailings (Table 7). This ecological risk index confirms the need to confine mining tailings in the facility used to date. Among these trace metals, arsenic contributed the most (72.17%) to the total ERI value of metals or metalloids. Gold mining, particularly open-pit mining, is a significant source of particulate matter enriched with arsenic as an associated metal.

CONCLUSION:-

The study aims to assess the spatial distribution of trace metal concentrations (As, Sb, Cd, and Ni) in the tailings facility and surrounding soils at the Sabodala mine. The acid-base status of these soils shows alkaline mining tailings and slightly alkaline soils. This alkalinity plays an important role in the immobilisation and non-bioavailability of tmes in mine tailings and surrounding soils. The results obtained show very disparate concentrations of heavy metals (As, Sb, Ni and Cd) in the mine tailings, which exceed the geochemical background levels and those of the soils surrounding the tailings facility.Pollution and geo-accumulation indices and contamination factors in the matrices (tailings and surrounding soils) indicate accumulation of tmes in the tailings facility. This accumulation of TME is localised and does not spread to surrounding soils, which have PI indices below unity and negative I_{geo} values. The distribution maps for arsenic and antimony and the indices (IP and I_{geo}) reveal irregular contamination of the tailing's facility. These pollution maps produced as part of this work could serve as a basis for research into the rehabilitation of the tailings facility. Except for arsenic, the ecological risk posed by each metal or metalloid is low. The soil surrounding the mine tailings pond does not pose an ecological risk. The results indicate that arsenic should be monitored as a priority due to its high incidence and the significant risks it poses in mine tailings. These results provide valuable information to the mine for designing effective strategies to reduce arsenic exposure by adjusting mining operations to minimise metal and metalloid inputs.

Research should be considered for the future rehabilitation of tailings facility contaminated with heavy metals, particularly arsenic and antimony, using, for example, biological treatment methods such as phytoremediation of contaminated soils.

Conflicts of interest

The authors of this manuscript declare that they have no conflict of interest of any kind, either between the authors themselves or between the authors and third parties.

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