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Geochemistry of the Heavy Metals in the Tansrift Mine (Atlas of Beni Mellal, Morocco) – A Pollution Assessment

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ABSTRACT

The Tansrift mine is an open-pit exploitation mine that mines copper substances. It is located on the southwestern flank of the Beni Mellal Atlas, 9 km Northeast of Ouaouizaght village. The mining activity delivered about 650 000 t of 1.5% Cu, with an estimated reserve of 1 Mt to 1.32% Cu. In this study, seven hazardous heavy metals (Cd, Cr, Cu, Pb, Zn, Fe, and Ni) have been studied in the tailing and exploitation of the Tansrift mining district. The geochemical analysis contents of the metals were measured in the samples collected from this area. In addition, the pollution indexes, including the geo-accumulation index, the enrichment factor, the contamination factor, and the pollution load index, were used to assess pollution levels caused by those heavy metals. The Igeo index revealed a high to extreme copper contamination with a value above 4. As for the contamination factor, extreme and moderate contamination is shown by the copper and chrome in the totality of the exploitation and tailing areas. Moreover, the pollution load index shows very high pollution in all samples. The climatic conditions are also affecting the pollution of the atmosphere by contaminated dust and the water table and watershed by the contamination from the tailings and mineralized structures.

Keywords: Tansrift mine, heavy metals, tailing, environmental impact, copper mineralization, pollution indexes.

INTRODUCTION

The mining sector plays a crucial role in the economy of countries. This sector is based on several stages for made metal production and industrial products. These stages combine mineral exploration, mining assessment, mining exploitation, and mine tailing restoration. Therefore, mining exploration and metallurgy are accompanied by heavy metal contamination with a negative environmental impact. This contamination is due to the tailing in nearby agricultural areas (El Hachimi, 2006; El Hachimi et al., 2013; Kowalska et al., 2018; Karaouzas et al., 2021). This mining site can contaminate useful soils and watersheds in the area. As a consequence, there is a potential risk to habitats. Sun et al., (2018), Wang et al., (2019), Abouian Jahromi et al., (2020), and Barakat et al., (2022) describe that mining activities pollute the surrounding areas without any control over contamination by the products of mine tailings without restoration. The environmental pollution by heavy metals in regions with anthropogenic pressure (Akujobi et al., 2012).

In recent years, several researchers have been interested in studying the contamination of agriculture zones and hydrographic watersheds by heavy metals from mining wastes/tailing and open-pit mining. In Morocco, several studies have been carried out on mining tailing from several mines and watersheds where agriculture e.g., (Lakrim et al., 2011, 2012; El Hachimi et al., 2013; Oumenskou et al., 2019; Assabar et al., 2023; Podgórska and Jóźwiak, 2023). One of these mines is the former Tansrift mine, situated approximately 9 km northeast of the village of Ouaouizaght on the southwest side of the Beni Mellal Atlas. The mine, known for exploiting copper mineralization, operated as an open-pit mine (Ibouh et al., 2011). Metallurgical processes for the mined ore are conducted adjacent to the mine, and the resulting tailings are disposed of in porous soil detritus, coexisting with agricultural activities. The non-restoration and water-leaching activity in tailing and exploitation areas create many problems, notably the rapid fluctuation of metal concentrations across both time and space. sediments can absorb certain amounts of heavy metals, suggesting a stabilization of the environment by these materials rather than by water (Blanquet et al., 2004). However, another quantity of metals remains in the environment, leading to pollution of the groundwater, the agricultural, and the environment. This pollution is assessed through the study of heavy metal concentrations in the areas of the Tansrift site.

Environmental pollution affecting both water and agricultural soils with heavy metals typically creates health problems, especially among children (Ibrahim et al., 2006; Bathla and Jain, 2016; Derouiche et al., 2020; Raj et al., 2021). Among these issues, oxidative stress and inflammation play a role in the pathophysiology of chronic kidney disease (Derouiche et al., 2020), which are exacerbated by water contaminated with heavy metals. Bathla and Jain (2016), Ibrahim et al. (2006), and Raj et al. (2021) describe that heavy metals present in products and water are sources of poison and toxicity for the population. The objective of this work consists of an environmental study of the Tansrift mine based on an assessment of the degree of contamination of the Tansrift mine's tailing and areas of exploitation by heavy metals (Cd, Pb, Zn, Ni, Cu, and Fe) from samples collected in these areas. To determine the impact of these metals from the calculated contamination indices such as the geo-accumulation index (Igeo), contamination factor (CF), enrichment factor (EF), and finally the pollution load index (PLI). Moreover, the work also conducted geological cross-sections to demonstrate the presence of groundwater contamination in Beni Mellal and its potential influence on the irrigation of agricultural areas in the Tadla-Al Bahira plain.

MATERIALS AND METHODS

The Tansrift mining presentation

The Tansrift mine is located in the south-west flank of the Beni Mellal Atlas, more precisely in the NE part of the Ouaouizaght syncline (Fig. 1b). It is the birthplace of one of the tributaries of the Oued Al Abid which engages water at the dam level of Bin El Ouidane (Fig. 1b). In addition, this river is one of the main tributaries of Oued Oum Rabia which is engaged in the Atlantic Ocean (Fig. 1a). It allowed partial irrigation of agricultural land in the Al Bahira-Tadla plain. In addition, it is one of the main sources of aquifers in the region.

Geologically, the Tansrift mine is located at the Ouaouizaght syncline (Figs. 1a, b). This syncline is occupied by the Jurassic-Cretaceous series. This series begins with the massive limestones and marls of Lias. These series are covered by red and greenish marls and limestone corniches attributed to the Aalenian-Bajocian age (Souhel et al., 1993, 1986). While the Dogger begins with greenish-brown marls with limestone passages. The mineralized zone of the Tansrift mine is hosted in sandy sandstones (Fig. 1C), generally attributed to Callovian-Barremian (Charrière and Haddoumi, 2016). The Cretaceous brings together Aptian sandy limestone, sand, and marl with gypsum passages attributed to the Infra-cenomanian (Albian). These series are capped by the sand, the Cenomano-Turonian limestone bar, and the yellow marls of Maastrichtian (Ettachfini and Andreu, 2004).

The Tansrift mine is an open pit mine following the mineralized structures in several locations. It is interested in the exploitation of copper substances. During the four years of operation (1974–1978), the mine delivered approximately 650,000t of ore to 1.5% Cu with an estimated reserves of 1Mt to 1.32% Cu (Ibouh et al., 2011).

Sampling and parameters

The samples studied were taken from the areas of the Tansrift mine and more specifically from mine tailing to soils and mining areas. The geochemical analysis of these samples is done to quantify the concentrations of metals: Cd, Cu, Ni, Pb, Zn, and Fe. This analysis was carried out at the Laboratory of the National Office of Hydrocarbons and Mines (ONHYM). The sediment pollution degree assessment is based on several calculated parameters. These parameters are calculated from the collected samples' geochemical analyses and the sediments' natural background. Among these parameters are the index of geo-accumulation (Igeo), enrichment factor (EF), contamination factor (CF), and pollution load index (PLI).

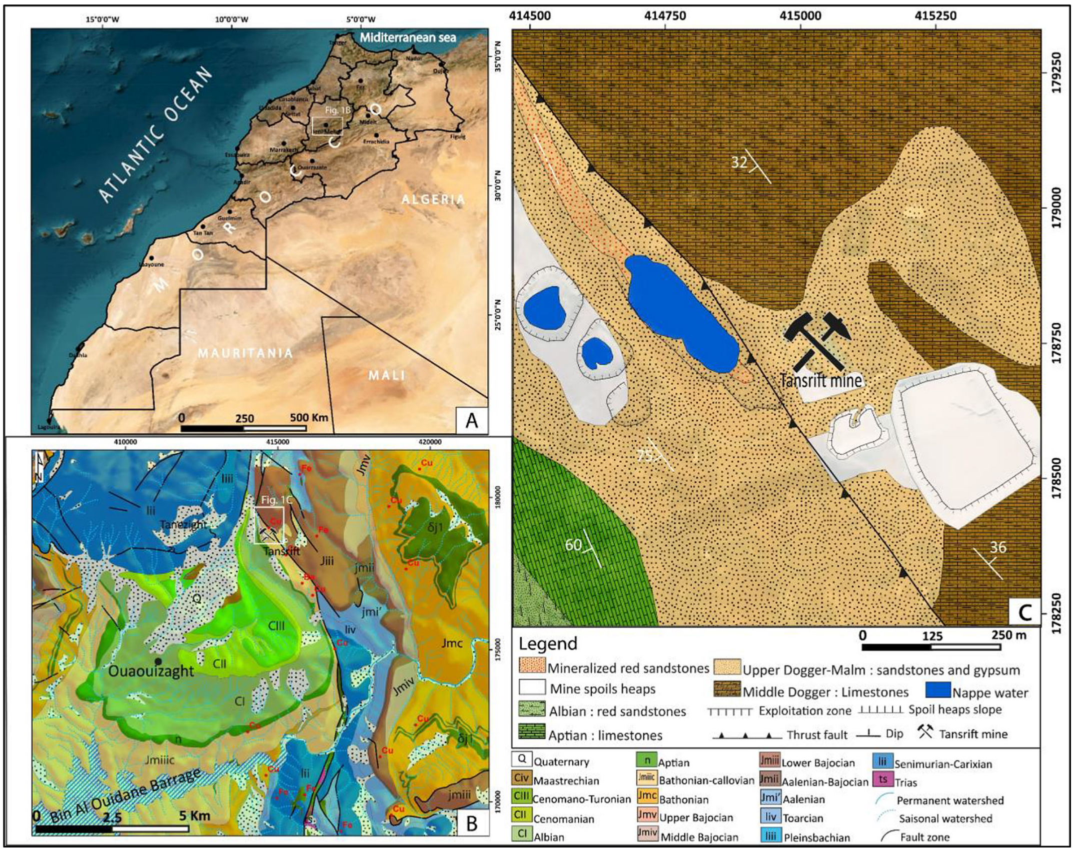

Figure 1. The study area geological maps; (a) the study area geographical location (Google maps); (b) The Ouaouizaght syncline geological maps (from Beni-Mellal geological map 1/100 000 after Monbaron, 1985); (c) the geological map of the Tansrift mine

Geo-accumulation index

The geo-accumulation index (Igeo) is defined by Müller (1969), whose purpose is to interpret the level of sediment pollution. It is calculated according to the following Equation 1:

$$\text{Igeo} = \log 2 \left(\frac{Cn}{1.5\ Bn}\right) \tag{1}$$

where: *Cn* – the heavy metal contamination in the samples; *Bn* – the heavy metal geochemical background and 1.5 is the constant related to the natural container fluctuation given by the environment. Based on the Igeo value, Müller (1969) classifies the pollution level of the soil into seven classes noted in Table 1.

Enrichment factor

The enrichment factor is used to estimate the origin of heavy metals (Zoller et al., 1974). Therefore, it is used to assess the degree of sediment pollution. This factor was defined by the Equation 2:

$$EF = \frac{(C/Fe)Sample}{(C/Fe)Background} \tag{2}$$

where: (*C/Fe*) *sample* – the heavy metal container in the analyzed sample and (*C/Fe*) *background* is the heavy metal geochemical background.

According to Selvaraj et al. (2004), and Barakat et al. (2022), the enrichment factor of the soil divided into six categories based on the value of EF (Table 1).

Contamination factor

The contamination factor is a parameter that expresses the level of heavy metal contamination presented in the samples (Hakenson, 1980). This is a ratio given by the following equation [3]:

$$CF = \frac{C\ metal}{C\ background} \tag{3}$$

where: *C metal* – the concentration of heavy metal in samples, *C background* – is the concentration in uncontaminated sediments.

Table 1. Pollution Indices Igeo categories defined by Müller (1969), the Enrichment factor by (Sutherland, 2000)

Igeo	Contamination	EF	Enrichment
Igeo ≤0	Uncontaminated	EF <1	No enrichment
0< Igeo ≤1	Slightly contaminated	1≤ EF <3	Minor enrichment
1< Igeo ≤2	Moderately contaminated	3≤ EF <5	Moderate enrichment
2< Igeo ≤3	Moderate to severely contaminated	5≤ EF <20	Significant enrichment
3< Igeo ≤4	Severely contaminated	20≤ EF <40	Very high enrichment
4< Igeo ≤5	Severe to extremely contaminated	EF ≥40	Extremely enrichment
Igeo >5	Extremely contaminated		

The contamination factor values give the level of pollution according to Hakenson (1980) remarked in Table 2.

Pollution load index

The pollution load index (PLI) is a parameter that give quantitative total estimation for the level pollution by the heavy metals presented in the sample. It calculated by the following equation 4:

$$PLI = (CF1 \times CF2 \times CF3 \times \ldots \times CFn)^{\overline{n}} \quad (4)$$

where: the *PLI* is categorized according to Zhang et al., (2018) which divided it into four classes (Table 2).

RESULTS AND DISCUSSION

The situation and description of the Tansrift mine tailing

Exploitation zone study

The primary product (Ore) of the Tansrift mine from the open pit areas of the inclined mineralized structure (Fig. 2a, b). It is composed mainly of copper and iron ores, presented by covellite (CuS), chalcocite (Cu_2S), cuprite (CuO), and malachite ($Cu_2CO_3(OH)_2$) as copper products. While the associated iron product is composed of chalcopyrite ($CuFeS_2$), pyrite (FeS), hematite (FeO) and limonite (FeO $(H_2O)_n$). While the study by Ibouh et al. (2011) shows the presence of silver ore associated with arsenic (proustite, Ag_3AsS_3). On the other hand, the mining activity of this mine was reaching the piezometric levels of the bathono-callovian water table (Figs. 1a, c). In addition, the area known for intense rainfall (rainfall exceeds 300 mm/year after Nouaim et al., 2023). This induces a strong leaching of the mineralized structure (Fig. 1b, d, e). Therefore, it reflects an enrichment of developed soils and contamination of surface and groundwater by heavy metals.

Tailing study

The tailing for the Tansrift mine (Fig. 3) is the products obtained after copper metallurgic operations using flotation concentration. These residues constitute a mineral solid mud (comprising the rest of the ore and the chemicals products) of a less whitish color (Fig. 3a, b, c, d). They deposited in the open on porous terrain having a subtabular topography. Mining tailing from this mine were dumped in three locations near the mining area where the small tributaries of Oued Al Abid watershed. They occupy more than seven hectares with an estimated tonnage exceeding 300 000 t. The first mine spoil heap occupies more than 5.6 hectares with a height of 7 m (Fig. 3d); while the other two tailing's locations occupy a set of 1.4 hectares with a height of 7 meters for the second spoil heap (Fig. 3b), and a distributed height for

Table 2. The categories of contamination factor from Hakenson (1980), and the pollution index loaded from Tomlinson et al, (1980)

CF	Contamination	PLI	Pollution
CF <1	Low contamination	PLI <1	Unpolluted
1≤ CF <3	Moderate contamination	1≤ PLI <2	Moderately polluted
3≤ CF <6	Considerable contamination	2≤ PLI <3	Highly polluted
CF ≥6	Highly contamination	PLI ≥3	Extremely polluted

Figure 2. The Tansrift mine exploitation area; (a) the mine exploitation areas (Google earth); (b) the mineralized structure hosted in sandstone; (c) the exploitation reaches the contaminated water table; (d) natural leaching product of mine tailings; (e) contaminated soil in the mine exploitation area

the third one (Fig. 3c). These tailing are characterized by a fine to very fine granulometry including clay and sandy sequences (Figs. 3e, f).

These mining tailings are subject to fairly significant seasonal precipitation due to its location in the Beni Mellal Mountain chain. This precipitation is responsible for the supergenic alteration of mining tailing minerals and consequently the leaching of polluting products to agricultural soils (Fig. 3b, d). In addition, this area is considered an area the birth of tributaries that engage at the Bin Al Ouidane Dam. Therefore, the infiltration of mine tailings affects the waters of tributaries and quaternary aquifers.

Geochemistry of the tailing samples

The contamination of the Tansrift mine tailing by heavy metals shows considerable

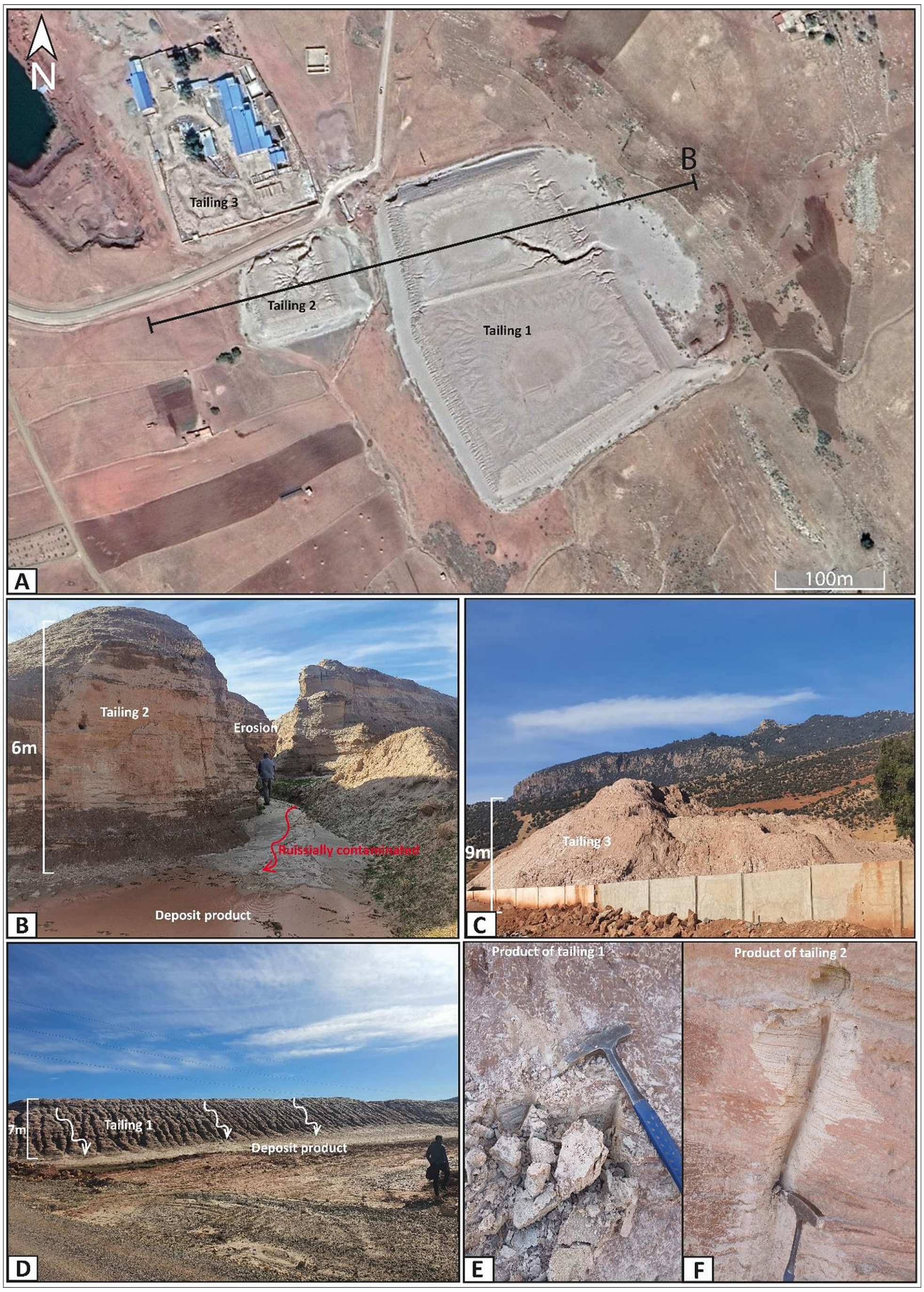

Figure 3. Mine tailings from the Tansrift mine; (a) Erosion and run-off from mine tailings 2; (c) The third mine tailings with their erosive aspect; (d) The first mine tailings with their erosive aspect and products in the surrounding soils; (e) Mine residues from mine tailing No. 1; (f) Products from mine tailings No. 2

concentrations of these various heavy metals. Geochemical analyses of the samples to demonstrate heavy metal enrichment are presented in Table 3. The mean value of element Cd in the samples is 2.33 g/t with values varying between 1 and 5ppm for mine releases and the value of 2 for the soils of the area of exploitation. While the average value of Cr is 114.g/t with a variation between 87 and 162 ppm. Cu is characterized by an average value of 2754.83 g/t with a variation between 795 ppm and 4938 ppm. Lead, zinc and nickel have average values of 39.17 g/t, 62.67 g/t and 55.33 g/t, with variations between 25 and 64 ppm for Pb, 44 and 103 ppm for zinc and 44 and 74 ppm for nickel respectively. Fe is the major element in all samples with a fluctuation between 5209 and 34934 ppm with an average of about 11224.67 ppm. The average values of heavy

Table 3. The results of geochemical analyses of samples from the Tansrift mine

Element	Cd	Cr	Cu	Pb	Zn	Fe	Ni
Sample	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Ou13	1	110	795	64	103	34934	72
Ou14	3	101	1392	25	55	7415	44
Ou15	1	162	4938	40	68	5209	48
Ou16	5	118	4063	32	44	6674	44
Ou17	2	87	1224	37	47	6429	50
Ou 18	2	110	4117	37	59	6687	74
Mean	2,33	114,66	2754,83	39,17	62,67	11224,67	55,333
Min	1	87	795	25	44	5209	44
Max	5	162	4938	64	103	34934	74

metals were generally higher with background values. For a better assessment of the degree of enrichment of tailing and waste pits and exploitation area by heavy metals. It is necessary to make a comparison of the results of geochemical analyses of these heavy metals with the regional standard of Beni Mellal which makes by Oumenskou et al. (2019). It is also noted that Barakat et al. (2022) based on the same standards.

The pollution indexes

Geo-accumulation index of the heavy metals

Table 4 shows the geo-accumulation index values of the samples in this study. Based on the categories defined by Müller (1969) in Table 1. For the Cadmium element, the samples collected from mine tailing show moderate contamination with uncontaminated levels (Igeo <0); whereas soils developed in the areas of exploitation indicate low contamination (Igeo = 0.65). The Chromium is an element with moderate to high contamination in most samples (Table 4).

Then that the Tansrift mine is a copper mine, this element is considered as major element of a strong to extreme contamination of the soils of the mine whose minimum value of Igeo is 4.08 (Table 4). The geo-accumulation indices of the lead element show negative values except sample OU13; therefore, the samples do not admire any contamination by this element with low contamination in OU13. While the other heavy metals (Zn and Ni), the Igeo values are low to negative which shows a low contamination to their absence.

The enrichment factor of heavy metals

The enrichment factor is a parameter similar to the geo-accumulation index (Rubio et al., 2000). Calculation of Tansrift mine enrichment factor by heavy metals (Cd, Cr, Cu, Pb, Zn, Ni and Fe) shows low to moderate enrichments with EF values ranging from 0.29 to 3.11 (Table 5). It is noted that the soil samples in the areas of exploitation show a minor enrichment compared to mining tailing, which are characterized by the presence of a minor to moderate enrichment.

Table 4. Geo-accumulation indices for samples analyzed from the Tansrift mine

Igeo							
Samples	Element						
	Cd	Cr	Cu	Pb	Zn	Fe	Ni
Ou13	0.13	1.54	4.08	0.39	0.65	0.94	0.61
OU14	1.22	1.42	4.88	-0.96	-0.25	-1.29	-0.098
OU15	-0.12	2. 1	6.71	-0.29	0.05	-1.805	0.027
OU16	1.89	1.64	6.43	-0.61	-0.58	-1.45	-0.098
OU17	0.84	1.20	4.70	-0.40	-0.48	-1.50	0.09
OU18	0.74	1.54	6.45	-0.40	-0.15	-1.45	0.65
MEAN	0.94	1.60	5.87	-0.32	-0.07	-0.70	0.23

Table 5. The enrichment factor (EF) for the analyzed samples from the Tansrift former mine

EF							
Samples	Element						
	Cd	Cr	Cu	Pb	Zn	Fe	Ni
Ou13	0.57	0.96	0.29	1.63	1.64	3.11	1.30
Ou14	1.22	0.88	0.50	0.64	0.88	0.66	0.79
Ou15	0.48	1.41	1.79	1.02	1.08	0.46	0.87
Ou16	1.93	1.03	1.47	0.82	0.70	0.59	0.79
Ou17	0.93	0.76	0.44	0.94	0.75	0.57	0.90
Ou18	0.87	0.96	1.49	0.94	0.94	0.59	1.34

Contamination factor and heavy metal pollution load index

Based on the results of the heavy metal contamination factors of samples presented in the table 6. Values given by copper show very high contamination in all samples with FC values ranging from 25.32 to 157.26. While, contamination related to the Chrome element is generally considerable to high noted by the contamination factor value greater than 3.45; The O16 samples show the maximum value in both elements (Cu, Cr). It is also noted that heavy metals (Ni and Zn) generally show average contamination factors values (Range 1 to 2.35) indicating moderate contamination in all samples. For Iron, the majority of samples show a low contamination except for Ou13 which indicates a moderate contamination of up to 2.88. While samples show moderate to considerable cadmium metal contamination with FC values ranging from 1.18 to 4.88 (Table 6). The calculated values of lead metal FC show an interval between 0.77 and 1.97 (Table 6), and therefore a low to moderate contamination.

The pollution load index (PLI) of the Tansrift mine samples show values between 2.33 and 3.43 with an average value of 2.88, the maximum value of which is that of the O13 sample with the value of 3.43, followed by O16 and O18 with the PLI values of 3.07 and 3.12 respectively indicating extreme contamination (Table 6). The other samples (Ou14, Ou15 and Ou17) show values ranging from the minimum value of 2.33 (PLI Ou17) to 2.90 (PLI Ou15), the results of which indicate high heavy metal pollution (Table 6).

Mine environmental pollution effect

The enrichment of mining waste and the area of exploitation of the Tansrift mine with heavy metals (Table 5) reflects contamination of the surrounding soil, waters and atmosphere. In fact, during rainy periods and since the region is mountainous, precipitation exceeds 400 mm (Nouaim et al., 2023). Consequently, the leaching and release of heavy metals dissolved in the waters of the groundwater that flows into the waterproof rocks (Fig. 4A, B), and in the surface waters along the small rivers passing through the Tansrift mine and which engages at the dam level of Bin El Ouidane. On the other hand, during dry periods, weather conditions cause strong winds and the drying of mining debris (Fig. 4A). These conditions fly the finest particles

Table 6. Contamination factors and pollution load index for the samples analyzed from the Tansrift mine

CF								PLI
Samples	Element							
	Cd	Cr	Cu	Pb	Zn	Fe	Ni	
Ou13	1.65	4.36	25.32	1.97	2.35	2.88	2.29	3.43
Ou14	3.50	4.00	44.33	0.77	1.26	0.61	1.40	2.44
Ou15	1.38	6.43	157.26	1.23	1.55	0.43	1.53	2.90
Ou16	5.55	4.68	129.39	0.98	1.00	0.55	1.405	3.07
Ou17	2.69	3.45	38.98	1.14	1.07	0.53	1.59	2.33
Ou18	2.50	4.36	131.11	1.14	1.35	0.55	2.36	3.12
Mean	2.88	4.55	87.73	1.20	1.43	0.92	1.76	2.88

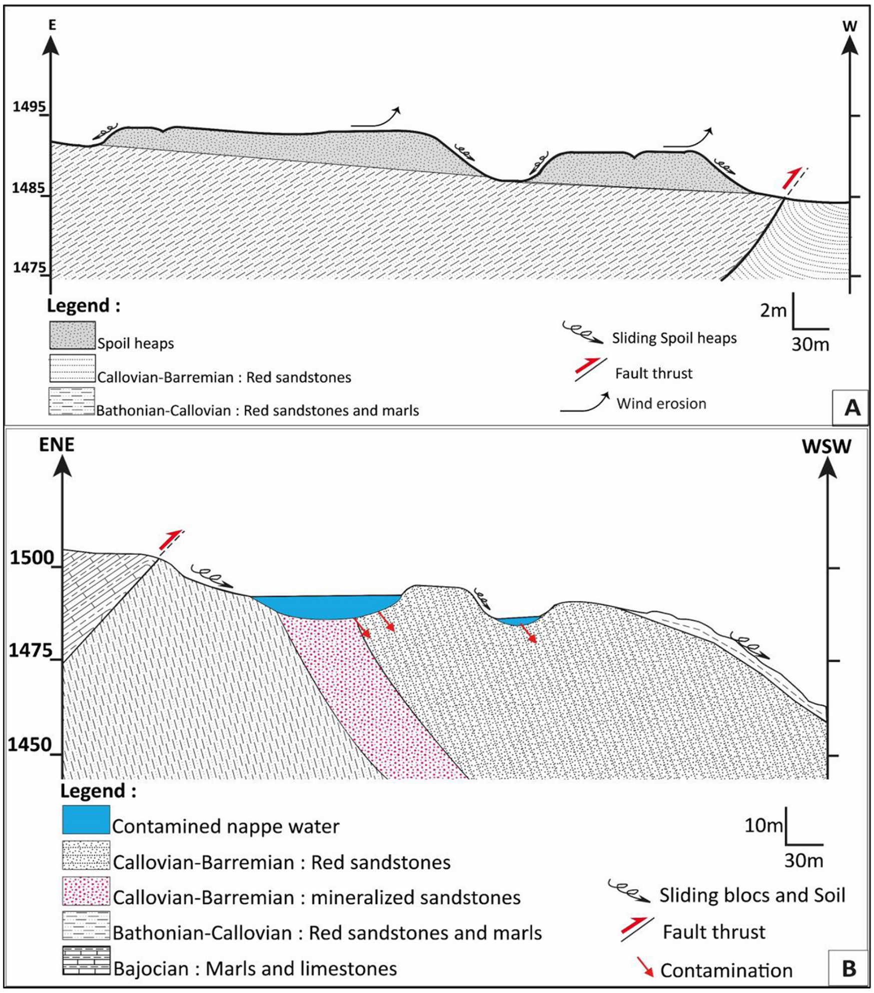

Figure 4. The cross-section of the Tansrift mine; (a) the geological cross-section of the Tansrift mine tailings; (b) the geological cross-section of the Tansrift mine exploitation zone

from these non-vegetalized tailing, toxic suspension minerals rich in heavy metals that precipitate into nearby villages and agricultural land, according to (Slowik et al., 2008; Steinnes et al., 1997). Therefore, the population in the surrounding areas of the Tansrift mine may suffer from kidney diseases, especially in children and infants. We added the extended exposure to hazardous metals such as lead (Pb), copper (Cu), zinc (Zn), iron (Fe), aluminum (Al) and cadmium (Cd), results in the penetration of the blood-brain barrier, causing dopaminergic neuronal degeneration (Raj et al., 2021).

CONCLUSIONS

This study examines the extent of contamination and pollution in the mining tailings and exploitation areas of the Tansrift mine by heavy metals (Cd, Cr, Ni, Cu, Pb, Fe, and Zn). The assessment of metal pollution is based on various indices derived from geochemical analyses of samples collected from the tailing and exploitation areas. The findings reveal a risk classification for the elements in the following order: Cu > Cr > Cd > Ni > Fe > Zn > Pb. This study revealed the presence of severe copper contamination, as indicated by a contamination factor exceeding 25.32 and a geo-accumulation index consistently higher than 4.08. In contrast, contamination factors and geo-accumulation indexes for other elements confirm low to moderate pollution. Additionally, the pollution load index (PLI) for samples collected from the tailing and exploitation zones of the Tansrift mine confirms a high to extreme pollution, with PLI values surpassing 2.33. These index values point to a high level of pollution in the Tansrift mine area, encompassing soil, watershed, and water table. The findings highlight significant anthropogenic and natural risks arising from the non-restoration of mining tailings as kidney diseases, and dopaminergic neuronal degeneration.

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