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Speciation of Heavy Metals in the Soil and the Tailings, in the Zinc-Lead Sidi Bou Othmane Abandoned Mine

(Marrakech, Morocco)

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Abstract

Mining activity is one of the most important sources of Heavy metals in the environment. In Marrakech region, functioning or abandoned mines represent a great hazard due to huge amounts of waste deposited in waste dumps and tailings often with high concentration of heavy metals pollution. These mining sites located near Marrakesh contain tailings abandoned for ten to twenty years. The present study was realized for the abandoned mine of Sidi Bou Othmane in order: i) -To determine the total content of heavy metal in soil and Tailings, ii)-To carry out the chemical speciation, of heavy metals in the Tailing and in the samples of soil collected in the vicinity of the mine. The pH, the electrical conductivity, Organic matter content and total carbonate content in all the samples (soil and Tailings) were measured using the standards methods, heavy metals concentration was determined by ICP-MS. Therefore, a sequential extraction scheme according to the BCR's (Community Bureau of Reference) guidelines and total acid digestion were applied to soil and Tailings samples. The results obtained showed that the abandoned mine of Sidi Bou Othmane still containing very important quantities of solid waste, these site can become potential source of pollution by releasing heavy metals. In this concern, 4 polluting heavy metals (Cd, Cu, Pb and Zn) were detected with concentrations exceeding those admitted for agricultural soil. For all heavy metals, the most contaminated sites were found in the vicinity of the mine, probably linked to weathering effect, the wind and the topography.

Keywords: Soil, tailings, heavy metals, sequential extraction, speciation.

1. Introduction

Mining and milling operations, together with grinding, concentrating ores and disposal of tailings, provide obvious sources of contamination in the surface environment, along with mine and mill waste water (Adriano 1986). As a result, elevated levels of heavy metals can be found in and around disused metalliferous mines due to discharge and dispersion of mine wastes into nearby agricultural soils, food crops and stream systems. Eventually, they may pose a potential health risk to residents in the vicinity of mining areas. Southern Morocco has a large number of metalliferous sites and has been considered as a traditional mining region since antiquity. Nowadays, it is estimated that there are still large reserves of iron (Fe), copper (Cu), zinc (Zn), silver (Ag) and lead (Pb) in the area. Both active and abandoned mines present a risk of contamination of soils, plants, groundwater and surface water by dissemination of the particles carrying metals by wind action and/or by runoff from the tailings. High mining activity can be found in Marrakech region where functioning or abandoned mines represent a great hazard due to huge of high amounts of heavy metals. In this concern, few studies have been done in this area to determine the concentration of heavy metals in the mining residues and their impact on surrounding soil and water resources (El Gharmali et al. 2004; El Adnani et al. 2007; Esshaimi et al. 2012).

The total metal concentration obtained after a strong acid digestion does not provide sufficient information of its potential hazardous effects on environment because the mobility and eco-toxicity of heavy metals depend strongly on their specific chemical forms or binding. Consequently, these are the parameters that have to be determined, rather than the total element contents, in order to assess toxic effects (Fuentes et al. 2004; Wang et al.2006). If heavy metals exist as loosely bound fractions such as soluble, exchangeable and adsorbed forms, they tend to be easily moved and dispersed. However, metals associated with organic ligands or in crystal lattices are not easily separated or mobilized. To determine the speciation of heavy metals, various methods have been developed over the last two decades involving both single and sequential extraction schemes .Although some methods have been widely used, none has been unreservedly accepted by the scientific community. For this reason the Community Bureau of Reference (BCR) in 1987 began a programme to harmonize the methodology in the sequential extraction schemes used for determining metals in a variety of matrices, including lake, lagoon and marine sediments, sewage sludge, soil and industrially contaminated made-up ground (Sahuquillo et al. 1999; Fuentes et al. 2004). The aim of this study was to determine total heavy metals contents and their chemical fractions in the mining residues and in the samples of soil collected in the vicinity of The Pb-Zn abandoned mine of Sidi Bou Othmane.

2. Materials and methods

2.1 Description of the site investigated

The abandoned Sidi Bou Othmane mine is localized at 30 km in the north of Marrakech, in the region of the Haouz district (Jbilets- Centrales) in southern Morocco (figure 1). Sidi Bou Othmane mine is located close to a rural district and surrounded by agricultural lands Their exploitation started on 1953, treating 115 tons per day of mineral (0.5% Pb,7.4% Zn and 6% pyrite) by flotation processes until its closure on 1980.

2.2 Sampling description

In order to assess the impact of the abandoned mine residues on the surrounding soils, a total of 9 samples of soils were collected in the vicinity of the mine (One sample was obtained by mixing 10 elementary samples collected on the sector) and 3 representative background samples at 1 km from the mining site in order to avoid mining contamination. Samples were taken from the upper 20 cm after removing the first layer of surface soil (2 cm). The sampling of the tailings was carried out in 4 tailings reservoirs by using a specially designed cylindrical stainless steel corer, the average sample of each tailings reservoir is considered after mixture of the various sub-samples. After collection, the soil and tailing samples were carefully transferred to clean and dry self-sealing polyethylene bags and transported to laboratory. After being air-dried in paper lined propylene trays at room temperature and disaggregated with a wooden roller, all samples were sieved through (<2mm or <100 µm) sieve. The tailings samples from each zone were thoroughly mixed and homogenized by coning and quartering. Finally the soil and tailings samples were stored at 4°C in tightly sealed polyethylene bags until its analysis. Due to the strong association and affinity of heavy metals with fine grained soil components, we used the <100 µm soil fraction for the sequential extraction and total acid digestion methods (Pickering 1986; Murray et al. 1999; Cuong and Obbard 2006).The <2 mm soil fraction was used to determine the pH, electrical conductivity (EC), Organic matter content (OM) and carbonate.

2.3 Sample analysis

The physical-chemical characterization consisted in the determination of the soil and the tailings pH, electrical conductivity (EC), organic matter content (OM) and the carbonate content of the samples according to standard methods (Aubert 1978). Total heavy metal concentration was determined by ICP-MS (Inductively Coupled Plasma Mass Spectrometer -Thermo Scientific XSERIES 2 ICP-MS, Franklyn, MA, USA) after digestion of the samples. The methodology followed for the digestion consisted in weighting 0.5 g dry sample in a PTFE digestion vessel and adding 3 mL HNO_3 (70%), 6 mL HCl (37%) and 3 mL HF (48%). The digestion vessel was placed in the chamber of the microwave system (CEM MARS 5, Matthews, USA). After digestion, the sample solution was allowed to air-cool and then diluted with deionized water. The optimized BCR sequential extraction procedure was applied to assess heavy metal fractionation in the samples (<100 µm fraction). This method was described in detail elsewhere (Plassard et al. 2000).The sequential extraction was performed using the three-step procedure recommended by BCR. Additionally, a fourth step was added, which consisted of dissolving the final residue using the same digestion procedure for the total metal determination. The method details are presented in Table 1.

Step one: Acid soluble/exchangeable fraction (F1). A 40 mL volume of 0.11 M acetic acid was added to 1 g of dried soil or tailing sample. The mixture was shaken for 16 h at room temperature (approx. 21°C) on a mechanic shaker. The extract was separated from the solid residue by centrifugation at 1200 rpm. The liquid was stored at 4°C before analysis. The residue was washed with 20 mL distilled water by shaking for 15 min, centrifuged and the washings discarded (Hanay et al. 2008).

Step two: Reducible fraction (F2). A 40 mL aliquot of 0.5 M hydroxylamine hydrochloride (adjusted to pH 1.5 with HNO_3) was added to residue from step 1. The extraction procedure was repeated as described in step 1 (Hanay et al. 2008).

Step three: Oxidizable fraction (F3). A 10 mL aliquot of 8.8 M hydrogen peroxide was added in small amounts to avoid violent reaction to the residue from Step 2. The mixture was digested at room temperature for 1 h with occasional shaking. Digestion was continued at 85°C in a water bath for 1 h. The mixture was reduced to a small volume (1–2 mL) by further heating. A second 10 mL aliquot of H_2O_2 was added and the digestion continued at 85°C for 1 h. The volume reduction was repeated. Then, 50 mL of ammonium acetate (adjusted to pH 2 with nitric acid) was added and the extraction was performed as above (Hanay et al. 2008).

Step four: Residual fraction (F4). The solid remaining at the end of the BCR procedure was digested with 3mL of HNO_3 (70%), 6mL of HCl (37%) and 3mL of HF (48%).

The resultant solution from each step was used to determine the heavy metal content in the different fractions by means of an Inductively Coupled Plasma Mass Spectrometer (Thermo Scientific XSERIES 2 ICP-MS, Franklyn, MA, USA). The isotopes ^{65}Cu, ^{66}Zn, ^{111}Cd, and the sum of ^{206}Pb+ ^{207}Pb+ ^{208}Pb were selected for the determination of the elements of interest (Cu, Zn, Cd and Pb). As internal standards 100 µg L^{-1} of ^{72}Ge, ^{115}In, and ^{209}Bi were added to both the calibration and unknown sample solutions to monitor and compensate the possible instrumental drift and matrix effects. Each experiment was conducted in triplicate and the results reported herein correspond to the average values.

3. Results and discussion

3.1 Physical-Chemical properties of soil and tailings

Some chemical characteristics of the tailings and soil in the vicinity of the zinc-lead abandoned mine of Sidi Bou Othmane are presented in Table 2. The results obtained for the soil pH measurements, revealed that, in general, all samples of tailings and soil presented a neutral to alkaline pH ranging from 7,30 to 8,12, similar to background samples. pH variations seemed to be related to heterogeneous deposits of residues in the surroundings of the mine which can cause a decrease on the pH, neutral and alkaline pH in soil and mining residues could be attributed to the presence of carbonates with a high concentration ranging from 122,35 to 131,09 mg g^{-1} for tailings ; and from 23,72 to 462,00 mg g^{-1} for soil , high values of carbonates in mining residues may be due primarily to the mixture of these mining residues with soil very rich in carbonates. The EC measurements, revealed that, all samples of tailings presented a high values ranging from 2140, 00 to 2270, 00 µS cm^{-1}, for soil, EC showed more variability than the pH, with EC values ranging from 134,6 to 600, 00 µS cm^{-1}. In general, these results are correlated with previous studies carried on Morocco soils (El Hachimi et al. 2007). A decreasing salinity gradient was also observed and the values obtained for the soil samples are significantly higher than for the background samples. The highest values are observed for samples SB4, SB8, SB11, SB29 and SB30, located nearly of the mining residues deposits. All the soil samples presented a very high Organic matter content ranging from 6,24 to 7,81%, similar to background samples , these values are due to the nature of soil (Arable land-and cultivated soils). The presence of a vegetation cover in some parts of the mining area, and the mixture of the mining residues with a soil, could explain the high values of OM content in samples corresponding to the tailings (4, 28 to 4,71%). Together with basic pH values, the presence of carbonates in the soil lead to an increase in the retention of heavy metals, mainly as carbonate salts as a consequence of the ionic exchange, the principal retention mechanism of heavy metals (Plassard et al. 2000).

3.2 Total Heavy Metal Levels in soil and tailings

Total metal concentrations were classified based on the background levels for sandy soils (Kabata-Pendias and Pendias 2000), and the upper values established by European Directive 86/278/EEC (Council of the European Communities 1986) (table 3). Values of total Pb, Zn, Cd and Cu concentrations in the samples of soil and tailings (determined after acid digestion), are shown in Table 4. As expected, in most of the mines, the tailings had higher metal concentrations than soil, the tailings from this abandoned mine contained very high levels of Zn (18,06 - 42,51 g kg^{-1}), Pb (9,24-20,63 g kg^{-1}) , Cu (117,60-127,60 mg kg^{-1}) and Cd (45,14-105,30 mg kg^{-1}). The adjacent soils were also highly contaminated with metals (Zn > Pb > Cu > Cd), according the classification of the upper values established by European Directive 86/278/EEC (Council of the European Communities 1986), more than two-thirds of the samples of soil were highly polluted with Zn, while nearly half of the samples showed levels of Zn and Cd considered to be not tolerable. Cu concentrations were mainly low, the majority of the samples showing values considered as background or tolerable levels. The soils taken near the area covered by tailings showed the highest values for all the metals (SB8, SB11, SB29 and SB30). Indeed, almost all theses samples were classified into very polluted levels (Council of the European Communities 1986) for Zn, Pb, and Cd (values particularly high for zinc and lead). SB4, SB10 and SB19were also classified into very polluted levels particularly for zinc, the rest of the samples (SB18 and SB23) were considered as background or tolerable levels (Kabata-Pendias and Pendias 2000).

All the heavy metals values determined were above the maximum values allowed in the directives (Council of the European Communities 1986) (table~~s~~ 3), it is very important to consider that these elements (particularly zinc and lead) has high toxicity, this fact suggests the common origin of all the metals analyzed and, therefore, the mining activity can be pointed out as the source for the metal pollution of the studied area: Two reasons may be suggested to explain the scattering of the metals from the mine area. Firstly, the mining residues had higher metal concentrations (Table 4), particularly Zn and lead, this fact is probably due to the post processing of the mine tailings, which were crushed, grinded and treated by flotation. This process would have recovered the small amounts of ores minerals (e.g. galena (PbS), sphalerite (ZnS)) remaining in the tailings from the original works, (the laundry was designed for a capacity of 115 tons per day (7,4% Zn 0,5% Pb, and 6% pyrite) using flotation processes). Secondly, wind transport of dust may be another important factor influencing the spreading of pollution.

3.3 Speciation of Heavy Metal in soil and tailings

Measurement of total concentration of metals in soil is useful to detect any net change due to different possible phenomena such as erosion and leaching to groundwater, but does not give any indication about the chemical form of metals in soil. Because of the dependence of metal mobility on the interaction of metal with soil, several sequential leaching procedures have been developed to selectively remove metals from the different geochemical forms. Due to the high Pb and Zn levels in the samples analyzed and the nature of the Sidi Bou Othmane mine, Pb and Zn were selected for studying their geochemical distribution in the soil samples and in tailings samples. The concentration of exchangeable, reducible, oxidizable and residual metals obtained after the application of the sequential extraction recommended by the BCR and the recovery rate were represented in Tables 5 - 6.The sum of extractable fraction of metals is reasonably similar to total contents obtained after total acid digestion. The recovery rate was 85,59 –105,66% for Pb and 91,85-106,19% for Zn.

The first fraction from the BCR extraction procedure Exchangeable (F1) includes weakly absorbed metals retained on the soil surface (such as clay minerals, organic matter and hydrous oxides) by relatively weak electrostatic interaction, metals that can be released by ionexchange processes and metals that can be precipitated or coprecipitated with the carbonates present in many soils (Marin et al. 1997; Filgueiras, Lavilla, and Bendicho 2004). This fraction is considered to be the most bioavailable of the different metal forms and it is also the most labile (Chlopecka 1996). The highest values of exchangeable fraction (step 1) were observed for Pb and Zn, especially for mining residues, the values were ranged from 35,29 to 37,48% of the total metal of Pb and from 52,94 to 59,37% of the total metal of Zn. Taking into consideration the high mobility and potential bioavailability of heavy metals in this fraction and their total concentration (Table 4), it can be concluded that these wastes could have potentially hazardous effects on the environment.

The F1 concentrations for soil samples (S8, S4, S7, S2 and S6) taken near the area were ranged from 51,35 to 87,57 % of the total metal of Zn and from 30,75to 64,35% of the total metal of Pb, the other samples (S1, S3, S5, and S9) located at distances further away from the tailings samples present the following results : The F1 concentrations were ranged from 10,75 to 47,90% for Zn and from 6,18 to 26,19% for Pb. For this fraction (F1), it can be seen that Zn concentrations were significantly higher than Pb concentrations in the majority of the soil samples. Several authors have reported the relatively high mobility of Zn in the soil environment, which makes it considerably more mobile than lead (Wilson and Pyatt 2007). Zinc is readily absorbed by clay minerals, carbonates, or hydrous oxides and is in the exchangeable form (McLean and Bledsoe 1992).

In the majority of samples collected, large amounts of Pb were mainly associated with the reducible form (F2), The concentrations (F2) represent high percentages of the total metal content between 57,51– 61,05%, and 23,23– 83,05% for tailings and soil respectively. Zn content in F2 ranged from (34,63 – 42,39%), for tailings and (0,00 – 45,70%), for soil . Although the percentages of Pb associated with F2 were higher than those of Zn, high concentrations of Zn were found in mining residues. The incoming pollutants from external polluting sources initially exist in unstable chemical forms and continued pollutant accumulation leads to the formation of precipitates, especially as reducible forms (Lee, 2006).

The Pb concentrations associated with the oxidizable fraction (F3) ranged from 1,77– 3,86% in tailing samples and from 0.00–17,86% in soil samples. F3 was the fraction with the lowest Pb content in the majority of the collected soil samples. The Zn content in F3 were ranged from 3,62– 4,83% in tailings samples and from 0.00–11,95% in soil samples. The oxidizable fraction (F3) is associated with the organic and sulfide fraction. In this study, taking into account the values obtained for the organic matter content, it seems reasonable to assume that most of the oxidizable zinc and lead were mainly associated with organic matter. Nevertheless, this fraction was too low for both Pb and Zn. This fact may be related to the findings reported when the BCR procedure was developed (Sahuquillo et al. 1999; Kaasalainen and Yli-Halla 2003), indicating that organically bound metals are extracted to some extent in the second step of the sequential extraction method. Besides, several authors have reported that oxidation of organic matter by acidified hydrogen peroxide is incomplete (Tessier et al. 1979; Gleyzes et al. 2002) and the primary sulfide minerals, including PbS (galena), sphalerite (ZnS), pyrite (FeS_2) and marcasite (FeS_2), cannot be totally dissolved by this step (Li and Thornton 2001; Cappuyns et al. 2007). The Pb concentration associated with the residual fraction (F4) ranged from 0,58 –1,95%) in tailings and from 0.00 – 21,43% for soil samples. As regards to zinc, the concentrations obtained ranged from 1,06 –1,36%) in tailings and from 1,71–50,82 % for soil samples. The residual solid should mainly contain primary and secondary minerals, which may hold trace metals within their crystal structure. Therefore, it does not seem reasonable to assume that these metals may be released under the conditions normally encountered in nature (Dang et al. 2002).

4. Conclusions

Environmental pollution by heavy metals originated from abandoned mines can become a very important source of contamination both in soil and water. Therefore, the characterization of tailings chemical and physical properties is important to assess the risk of potential environmental mobility of toxic trace metals that are contained in this kind of waste. The chemical characteristics of tailings and soil in the vicinity of the zinc-lead abandoned mine of Sidi Bou Othmane showed that in general, all samples presented a neutral to alkaline pH similar to background samples, the alkaline pH could be attributed to the presence of carbonates with a high concentration, the characterization revealed that, the electrical conductivity presents more variability than the pH. All the soil samples presented a very high organic matter content similar to background samples, these values are due to the nature of this soil (Arable land and cultivated soils), the presence of a vegetation cover in some parts of the mining area, and the mixture of the tailings with a soil, could explain the high values of organic matter content in samples corresponding to the mining residues, likewise, the influence of organic matter content, pH, carbonate levels, and interactions among these factors appeared to be central in the distribution of the heavy metals among the different geochemical phases of the soils. The total heavy metal concentrations showed that the highest concentrations were Zn, and Pb, except for S5 and S9, all the total concentrations were up the maximum allowable concentrations of heavy metals for agricultural soil from European Directive 86/278/EEC. The results obtained after the application of the sequential extraction recommended by the BCR indicated that Pb was mainly associated with the reducible fraction (F2) in all the collected samples. Zn was mainly associated with the F1 fraction (exchangeable, water- and acid-soluble) in soil and associated with the F1 fraction and oxidizable fraction (F3) in tailings, thus being more mobile and potentially more dangerous for the environment of the studied area. It would be necessary to remove or stabilize the mine waste~~.~~

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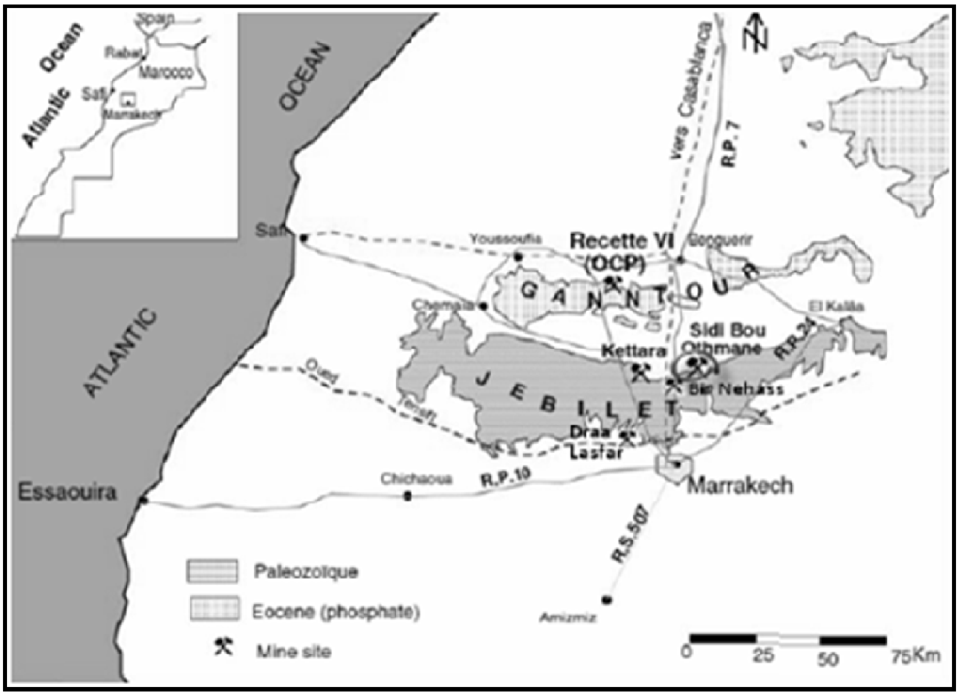

Figure 1. Location of Sidi Bou Othmane mine. (Hakkou et al., 2008)

Table 1. Modified BCR three-step sequential extraction procedure (Hanay et al., 2008).

Step	Fraction	Target phases	Modified BCR
1	Exchangeable, water and acid soluble	Soluble species, carbonates, cation Exchange sites	0.11 mol L^{-1} acetic acid
2	Reducible	Iron and manganese oxyhydroxide	0.5mol L^{-1} hydroxyl ammonium chloride at pH1.5
3	Oxidisable	Organic matter and sulphides	Hydrogen peroxide followed by 1 mol L^{-1} ammonium Acetate at pH 2
4	Residual		3 mL HNO$_3$ (70%), 6 mL HCl (37%) and 3 mL HF (48%)

Table 3. Criteria for soil classification according to total metal content (mg kg^{-1}) (Rodriguez et al., 2009).

Metal	Group 1 background levels[a]	Group 2 background levels to maximum tolerable[b]	Group 3 > maximum tolerable
Pb	2,3–70	70–300	>300
Zn	3,5–220	220–300	>300
Cu	1–70	70–140	>140

[a] Background levels in sandy soils (Kabata-Pendias and Pendias 2000)

[b] Maximum allowable concentrations of heavy metals for agricultural soils established in the European Directive 86/278/EEC (Council of the European Communities 1986).

Table 2. pH, electrical conductivity (CE), organic matter content (OM) and $CaCO_3$ content in soil and tailings in the vicinity of the abandoned Sidi Bou Othmane mine area.

		pH	CE	$CaCO_3$	OM
	Sample		(μS cm^{-1})	(mg g^{-1})	%
Tailings samples	SBR1	7,47	2270,00	124,85	4,62
	SBR2	7,30	2570,00	122,35	4,54
	SBR3	7,42	2140,00	122,47	4,28
	SBR4	7,40	2310,00	131,09	4,71
Soil Samples	SB4	7,64	454,29	30,00	6,33
	SB8	7,65	251,25	62,43	6,82
	SB10	8,04	113,46	300,5	6,96
	SB11	7,81	429,47	70,10	7,56
	SB18	7,90	227,62	94,9	6,24
	SB19	7,89	134,60	23,72	6,35
	SB29	7,54	330,19	37,45	6,50
	SB30	7,50	600,00	284,54	7,81
	SB23	8,12	136,84	462,00	7,79
Soil Background Samples	BS	8,00	100,4	99,88	6,90

Table 4. Total heavy metal contents of soil and tailings in the vicinity of the abandoned Sidi Bou Othmane mine.

	Sample	Zn (mg kg^{-1})	Pb (mg kg^{-1})	Cu (mg kg^{-1})	Cd (mg kg^{-1})
Tailing samples	SBR1	42514,28	9240,00	124,57	67,67
	SBR2	37405,71	16811,43	123,43	105,30
	SBR3	18045,71	9250,00	127,60	45,14
	SBR4	21531,43	20628,57	117,60	69,40
Soil Samples	SB4	921,00	282,00	46,50	2,89
	SB8	2604,00	816,00	72,00	6,23
	SB10	545,00	154,00	12,00	0,00
	SB11	19555,00	5723,00	61,50	13,00
	SB18	233,00	74,00	57,00	< 1
	SB19	333,00	97,00	66,00	< 1
	SB29	21550,00	6293,00	70,50	4,10
	SB30	22641,00	6706,00	55,50	12,70
	SB23	276,00	125,00	58,50	< 1
Soil Background Samples	BS	152,00	31,00	13,00	< 1

Table 5. Fractionation of Zn by BCR sequential extraction (concentration in mg kg^{-1}) for soil and tailings in the vicinity of the abandoned Sidi Bou Othmane mine.

	Exchangeable (F1)	Reducible (F2)	Oxidizable (F3)	Residual (F4)	Sum	Total concentration	Recovered %
SBR1	21248,00	16068,00	1895,00	541,60	39752,60	42514,28	93,50
SBR2	19524,80	15632,07	1335,12	389,12	36881,11	37405,71	98,60
SBR3	10032,21	7758,23	913,65	201,32	18905,41	18045,71	104,76
SBR4	12214,61	7123,76	956,45	278,32	20573,14	21531,43	95,55
SB4	436,40	416,40	26,85	31,50	911,15	921,00	98,93
SB8	1313,60	676,00	275,50	293,20	2558,30	2604,00	98,25
SB10	218,88	< 1	68,65	291,20	578,73	545,00	106,19
SB11	17916,20	2192,10	< 1	350,84	20459,14	19555,00	104,62
SB18	90,00	42,80	< 1	81,20	214,00	233,00	91,85
SB19	199,21	59,20	< 1	59,11	317,52	333,00	95,35
SB29	16912,43	1205,40	850,22	1714,25	20682,30	21550,00	95,97
SB30	13550,14	6743,26	< 1	1770,64	22064,04	22641,00	97,45
SB23	30,72	128,00	34,15	93,00	285,87	276,00	103,58
BS	85,92	0,53	0,32	56,12	142,89	152,00	94,01

Table 6. Fractionation of Pb by BCR sequential extraction (concentration in mg kg^{-1}), for soil and tailings in the vicinity of the abandoned Sidi Bou Othmane mine.

	Exchangeable (F1)	Reducible (F2)	Oxidizable (F3)	Residual (F4)	Sum	Total concentration	Recovered %
SBR1	2862,56	4809,36	185,05	51,34	7908,31	9240,00	85,59
SBR2	5771,79	8857,02	526,00	245,12	15399,93	16811,43	91,60
SBR3	2806,65	4702,83	152,23	41,77	7703,48	9250,00	83,28
SBR4	6268,26	10404,80	725,00	365,25	17763,31	20628,57	86,11
SB4	18,15	213,62	5,39	56,40	293,56	282,00	104,10
SB8	70,20	573,04	58,84	125,30	827,38	816,00	101,39
SB10	42,62	67,80	29,06	23,25	162,72	154,00	105,66
SB11	3817,86	1377,79	0,00	737,29	5932,94	5723,00	103,67
SB18	12,81	37,51	4,25	14,89	69,46	74,00	93,87
SB19	29,48	59,56	1,77	5,08	95,89	97,00	98,86
SB29	850,12	5479,86	0,00	267,89	6597,87	6293,00	104,84
SB30	2091,10	3600,46	723,56	217,07	6632,20	6706,00	98,90
SB23	15,00	63,00	20,00	20,00	118,00	125,00	94,40
BS	17,52	0,11	0,06	11,45	29,14	31,00	94,00

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