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Assessment of Soil Contamination and Plant Stress Tolerance in an Antimony Mining Area : Case Study for *Scabiosa atropurpurea* L. and *Santolina chamaecyparissus*

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Abstract The current study was conducted in antimony old mine located in the Djebel Hamimat area, in the Algerian Northeast. The purpose of the current study is to assess the trace metal contamination levels through measuring the Metalloid Trace Elements (MTE) tolerance and pollution index (MPI) in the soil-plant system. The aim was also to assess *Scabiosa atropurpurea* L. and *Santolina chamaecyparissus* MTE tolerance abilities. The results revealed that the levels of contamination in the soil are higher than the maximal contamination thresholds. The contamination index/pollution (MIP) revealed a concerning situation withan excessive to severe contamination levels for Sb, As and Pb. For pollution index (IP), multi-element contamination was also found with very high IP. In both species, it was shown that the metallic elements contents in both roots and aerial part are higher than the critical tolerance values for Sb, As, Pb and Cr. In addition, the accumulation ratio of As, Ps, Zn and Cr are higher for both plants, which qualifies them as accumulators. On the other hand, they tend for an exclusion of Pb to better resist and tolerate these metallic elements with very high concentrations in the soil. The translocation ratio shows that the two species are more adapted to the toxicity by limiting the transfer of the MTE to the aerial part. Finally, both species have specific resistance and tolerances mechanisms and accumulate MTE differently in their organs. Thus, they can be used for phytoextraction or remediation of polluted soils to reduce toxicity and contamination.

Keywords Metalloid trace elements (MTE), Pollution, Old mine of antimony, Accumulator plants, Tolerance.

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Introduction

Mining is one of the largest sources of heavy metals in our environment (Lee et al. 2001). High levels of metal concentrations can be accumulated in the vicinity of metal mines due to the superficial dispersion of the toxic material in surrounding soils, crops and streams. They can affect dramatically the human health and also make a real threat to other links in the trophic chain (Jung 2001).

Mining in Algeria goes back the 15th century (Wadjiny 1998). This activity has long been one of the most important pillars of the country's economy. In our study, we were interested in an old antimony mine in the Djebel Hamimat region. According to Sondag (1980), Rached-Mosbah and Gardou (1989), the mine generated significant quantities of spoils, which consequently resulted in the contamination of the entire region. This situation brought us to think about the presence of tolerant and accumulator plant species.

A very limited number of plants are able to grow on highly heavy metals contaminated soils. These species, which naturally develop on metals rich soils, were used as indicators during mining prospecting. Some of these plants, known as hyper-accumulators, are able to store very large quantities of metals in their aerial parts (Bani et al. 2007, Pelletier et al. 2008, Kraemer 2010, Lloyd 1995).

By heavy metals immobilization and/or absorption proccesses, these plants could constitute an interesting tool for assessment of heavy metals transfer within the ecosystem.

They also can be considered as good candidates for rehabilitation of grounds and mine spoils (Martin et al. 1996, Sbartai et al. 2012). These plants have specific defence mechanisms to reduce the toxicity of the metals by making them less available (phytostabilization) or unavailable in the natural environment.

Two strategies can be observed: The exclusion, which consists in avoiding any absorption of the metals present at very high concentrations in the soil preventing their transport inside the cell. The accumulation or even the hyper-accumulation by embedding a very high concentration of these toxic metals within the plant cells. In addition, some plants tolerate metals and protect their photosynthesis by reducing the translocation rate to the aerial parts (Aoun 2009). Several studies have been carried out in different countries, including Algeria, on the contamination or pollution of soils, plants and water by metallic trace elements (MTE) resulting from mining activity. Determining the total content of MTE, to assess soils. Metallic contamination degree, is the key for studying the contamination level and its extent in the soil-plant system (Van Oort et al. 2002, Li and Thornton 2001).

The Djebel Hamimat mining region was a subject of many studies among them, the work of Benhamdi et al. (2014) that aimed to assess the extent of MTE pollution at the Wadi Dahimine situated at the bottom of Djebel Hamimat region. The main objective of this study is to assess the metallic contamination rate (Sb, As, Pb, Cd, Cr and Zn) of soils from mine cuttings and cuttings surrounding the mine in the Djebel Hamimat region. Furthermore, we were interested in tolerance mechanism toward MTE of *Scabiosa atropurpurea* L.and *Santolina chamaecyparissus*. These two plants were not been the subject of any chemical analysis. So, it is interesting to know what is the tolerance strategy adopted by these two species and if they exhibit specificity for one or more metallic elements.

Materials and Methods

Study area

The study area is a former antimony open pit mine that has been exploited until 1952. Located near the Jebel Hamimat, at 3km north of the village of Ain Babouche, in Oum El Bouagrhi (North-Eastern of Algeria). This region is characterized by a semi-arid Mediterranean climate, with an average annual temperature of about 14.7^{0}C and an average annual precipitation of about 44 mm. Soils encountered in this region are xerochrepts (USDA 1975).

Soil and plant sampling

Stratified Random method was used for soil and plant sampling. The zone was divides into strata. Then inside each stratum the samples were taken randomly according to ecological parameters. This stratification is based on the antimony content (Rached-Mosbah

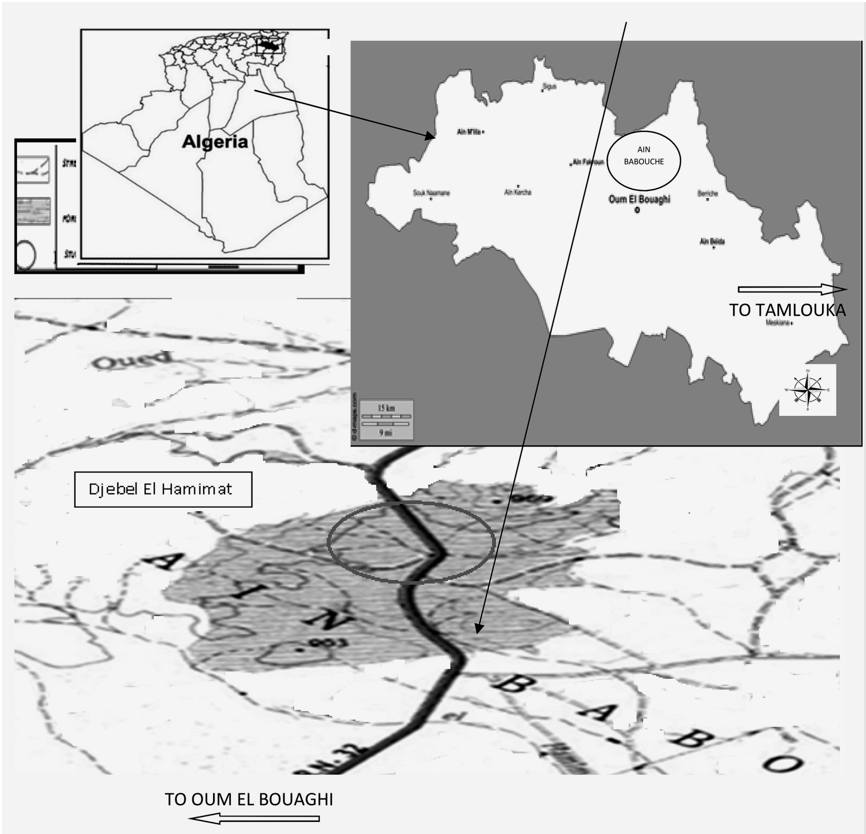

Fig. 1. Location of the study area.

1983) 24 sampling points belonging to different strata were selected (Fig. 1).

Soil sampling and analysis

In each point, four soil samples were taken to form are presentative sample. The soil sampling was carried out on the first 20 centimetres using an auger. The samples were air-dried and sieved to 2 mm. The physico-chemical analyses were carried out on the sieved soil. The pH was measured in a 1/2.5 (W/V) soil water suspension with a pH meter. The electrical conductivity (EC) was measured in a 1/5 soil/water suspension using a conductivity meter. Organic matter (OM) was quantified according Walkley and Black (1974). Total limestone was determined using Bernard's calcimeter. The available phosphorus (P_2O_5) was performed according to the method of Olsen and Dean (1965). The granulometric analysis was conductedusing the Robinson's pipette method.To assess the MTE levels in soil, an extraction was carried out by Aqua regia digestion in a microwave oven (Speedwave MWS-2 model, BERGHOF B). The mineralization was done on about 0.5 g of the soil with 6 ml of hydrochloric acid and 2 ml of nitric acid at 95^0C for 75 minutes. The mineralized fraction was analyzed by inductively coupled plasma mass spectrometry (ICP-MS) on a X7 ICP-MS (Thermo Electron).

Vegetation sampling and analysis

Sampling took place during the growing season and 24 surveys points were selected, so that both species (*Scabiosa atropurpurea* L. and *Santolina chamaecyparissus)* were presented at the same time. For each species, only one individual was plucked, washed and dried. Subsequently, the aerial part and the root portion were separated and then crushed and kept in plastic packets. For the determination of MTE level in the vegetation, we used the same experimental steps in the soil analysis process (aqua regia method).

Statistical analysis

Mean, median and standard deviation were calculated for soil and plant physico-chemical parameters and trace metal in samples contents. Spatial variations of soil and plant trace metal concentrations were tested by Anova. All statistical analyses were processed using Statistica software, version 6.0 (StatSoft Inc. 2002); to assess trace metal pollution, several indexes were calculated such as : Contamination/pollution index (MPI) and the index of pollution.

The contamination/pollution index introduced by Lacatusu (2000), allows to assess the degree of soil contamination or pollution by heavy metals. It corresponds to the ratio of the metal content measured in the soil, to the reference value of contamination.

$$MPI = \frac{Chms}{Rs}$$

MPI = contamination/pollution index, Chms = concentration of heavy metal in soil, Rs = concentration of heavy metal in reference soil (control).

Lacatusu (2000) has defined a scale of ten classes of the contamination/pollution index (MPI). The pollution index (PI) of heavy metal concentrations in the soil was calculatedusing the values of tolerable levels in soil given by Kloke (1979). The equation is as follows :

$$PI = \frac{\left(\frac{[Cd]}{3} + \frac{[Cr]}{150} + \frac{[Pb]}{100} + \frac{[Zn]}{300} + \frac{[Sb]}{10} + \frac{[As]}{30}\right)}{6}$$

When, PI values are >1.0, the soils are considered as contaminated.

To assess the degree of trace metals accumulation by plants and their mode of tolerance, two ratios were calculated, namely: The accumulation factor AF (Cottenie et al. 1979) :

$$AF = \frac{Cp}{Cso}$$

Where, Cp and Cso are metal concentrations in aerial parts of the plant and in soil respectively. A high ratio reflect the excessive accumulation of heavy metals.

The translocation factor (TF) for the two species studied was calculated according to Conesa et al. (2011) :

$$TF = \frac{Cap}{Cr}$$

Where, Cap and Cr are metal concentrations in aerial and root part respectively. If the translocation of the element is important, this factor takes a high value.

Results and Discussion

Soil physico-chemical characteristics

Statistical results of physico-chemical characteristics

Table 1. Statistical data of physico-chemical properties of soils.

	pH	MO (%)	CE (ms/cm)	Total limestone %	Active limestone %	P_2O_5 ( )	Clay (%)	Silt (%)	Sand (%)
Mean	7.63	13.36	1.03	26.52	86.06	0.16	34.29	40.29	25.34
Min	7.28	12.74	0.08	0.54	8.41	0.03	18.77	19.10	0.49
Max	8.15	14.26	3.92	57.69	98.10	0.76	45.40	65.68	55.84
Median	7.59	13.28	0.20	28.08	96.75	0.15	32.35	38.89	27.00
Standard deviation	0.20	0.35	1.30	15.24	24.11	0.14	5.91	16.68	19.53
N	24								

Table 2. Statistical data of metallic trace elements contents in soils (mg/kg), contamination/pollution index (MPI) and pollution index (pi).

	Cr (mg/kg)	As (mg/kg)	Cd (mg/kg)	Sb (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
Mean ± Standard deviation	111.54 ± 26.37	1363.29 ± 1541.86	0.88 ± 1.36	15888.97	346.21 ± 409.11	199.12 ± 98.94
Min-Max	74.49 - 170.45	40.38-6168.91	0.11-6	229.82 - 82300.32	37.87 - 1503.43	78.6 - 455.36
Median	104.43	642.68	0.32	2345.05	134.67	180.60
N	24					
Contamination reference value (Alloway 2013)						
Contamination reference value (Kabata Pendias and Pendias 2001)						
Maximal contents tolerated of soil (Matf 1998)	150	30	3	10	100	300

Table 2. Continued.

	MPI Cr	MPI As	MPI Cd	MPI Sb	MPI Pb	MPI Zn	Pollution index (PI*)
Mean ± Standard deviation	2.65 ± 0.63	290.06 ± 328.05	1.48 ±2.26	25627.36 ± 39066.43	24.72 ± 29.22	3.21 ± 1.60	
Min-Max	1.77 - 4.05	8.59 - 1312.53	0.18 - 10	370.67 - 132742.45	2.70 - 107.38	1.26 - 7.34	
Median	2.49	136.74	0.53	3782.34	9.62	2.91	
N							
Contamination reference value (Alloway 2013)	42		0.6		14	62	
Contamination reference value (Kabata Pendias and Pendias 2001)		4.7		0.62			
Maximal contents tolerated of soil (Matf 1998)							273

and trace metal contents are summerized in Tables 1 and 2. The grain size analysis using the texture triangle proposed by the United States Department of Agriculture (USDA 1975) showed that soils are loamy-sand (80% of cases) to clay-sand (20% of cases). The pH was moderately alkaline, according to the Afes pedagogical reference (2008) this can be attributed to the geological carbonate nature of the study area. Electrical conductivity showed low salinity. Average to slightly high levels were recorded for organic matter (Duthil 1971). According to Afes (1995), the studied soils can be considered as calcareous. High level of limestone is due to the geological material nature that has a predominance of limestone and marl-limestone formation in the studied area. For assimilable phosphorus, the rates were very low.

The results of heavy metals analyses (Sb, As, Pb, Zn, Cr, Cd) in the different studied soils are shown in Table 2. The results reveal the presence of all elements in the following order of abundance: Sb>As>Pb>Zn>Cr>Cd. We recorded the mean following concentrations: 15888.97 mg/kg, 1363.30 mg/kg 346.22 mg/kg and 0.89 mg/kg for Sb, As, Pb and Cd respectively. The trace mean values were very far from the medians. The values distribution is asymmetrical and can be influenced by the extreme values.This variability between the stations is highlighted by the analysis of the variance which revealed a significant effect ($p< 0.001$) for Sb, As, Pb, and Cd. With a mean concentrations of about 111.55 mg/g and 199.13 mg/g for Cr and Zn respectively. Thus, levels of these elements are very close to the medians and reflect little dispersion and spatial variation. By referring to the standards reported by Kabata-Pendias and Pendias (2001) and Alloway (2013), we note that 100% of the obtained values for Sb, As, Pb, Zn, Cr were above the contamination threshold and with 29% for the Cd (Table 2). While, 12.5%, 12.5% and 16.6% of the total Cr, Cd and Zn contents, respectively, exceeded the limit values of tolerance proposed by Matf (1998) and 100% for Sb, As and Pb exceeded the maximum tolerance thresholds proposed by the same author. Our results are similar to the works of Matthews (1982), Matthews and Thornton (1982). The study of El Hachimi et al. (2014) in a mining region in Morocco, reported high concentrations of Pb, Zn and Cd, of the same order of trace metal abundance. Moreover, Lindsay (!979) found that Pb has a high chemical affinity to carbonates and as previously indicated, the soils of the study area are dominated by carbonates, which explains the high levels of this metal in these soils. For the As, our maximum levels are very higher than the concentrations obtained by Göd and Heiss (1996) ranging from 110 to 115 µg g-1 in polluted soils in Europe. In addition, Jonhson et al. (2005) reported values ranging from 500 to 1500 µg/g for Sb : While Flyn et al. (2003) recorded a concentration of about 700 µg/g in mine sites with high levels of contamination. However, our soils exhibited very high levels then these recorded by the authors mentioned above for As and Sb.Table 3 presents the contamination/pollution indexes (MPI) for the six heavy metals recorded for the studied sites.

A result of MPI shows that the soils in the study area have excessive pollution for Sb and As in 100% and 95.8% of cases respectively. For Cr and Zn, soils were moderately polluted in 75% and 62% of cases respectively. Cd contamination/pollution index, varies from the lowest levels of contamination to the most severe level. Lead contents, showed an excessive pollution in 37% of cases, severe pollution in 29% of cases Overall, we can conclude that most studied soils have a high level of pollution, which requires immediate remediation, to immobilise metal pollution; and also to limit the dispersion of various contaminants transported by wind and water. Especially the valley of Wadi Dahimine is located at Djebel Hamimat Mining Area, which may widen the area of contamination and promote the spread of pollution.

Table 3. Rates of the different classes of the contamination/pollution index.

	16.66%	Slight pollution
Cr	75%	Moderate pollution
	4.16%	Severe pollution
As	4.16%	Very severe pollution
	95.83%	Excessive pollution
	4.16%	Slight contamination
	45.83%	Moderate contamination
	16.66%	Severe contamination
Cd	4.16%	Very severe contamination
	8.83%	Slight pollution
	8.83%	Moderate pollution
	8.83%	Severe pollution
	4.16%	Very severe pollution
Sb	100%	Excessive pollution
	8.33%	Moderate pollution
Pb	25%	Severe pollution
	29.16%	Very severe pollution
	37.50%	Excessive pollution
	16.66%	Slight pollution
Zn	62.50%	Moderate pollution
	20.83%	Severe pollution

In mine sites, heavy metal contamination in soils is associated with a pollutant mix rather than a single metal (Lee et al. 2001). For this reason, many authors have introduced the concept of the soil pollution index (PI) for abetter assessment of the multi-element contamination (Chon et al. 1998, Jung 2001, Lee et al. 2001, Smouni et al. 2010). The Pl results are shown in Table 2. PI values ranged from 8 and 1389 with a average of 273. Thus, all stations have PI>1. Our results are similar to those of Jung (2001) who found PI> 1 in an old mine soils in Korea and those of El Hachimi et al. (2014), who recorded a PI>1 with a maximum content of 35 in the soils of an abandoned mine in Morocco. In the study area, very high levels of PIs were recorded, confirming polymetallic contamination of Sb and As. These high values reflect an extremely harmful and dangerous situation, of these abandoned substrates without restoration.

Plant heavy metals contents

Metallic contamination of soils in the study area is

Table 4. Statistical data of the average levels of the metallic trace elements (mg/kg), accumulation factors and translocation factors of the different part of *Santolina chamaecyparissus* and *Scabiosa atropurpurea* L. AP : Aerial part, R : Root, WP : Whole plant.

	AP+R=WP	Mean	Min	Max	Median	Standard Deviation	Root	Accumolation factor	Translocation factor
AP, S. *chamae cyparissus* Cr	54.43	22.93	6.89	38.31	21.65	7.91			
R, S. *chamae cyparissus* Cr		31.5	12.38	57.48	27.41	13.28	57.9	0.49	0.73
AP, S. *atropurpurpurea* Cr	58.76	24.95	14.89	44.76	19.65	10			
R, S. *atropurpurea* Cr		33.81	14.49	86.19	28.94	16.86	57.5	0.53	0.74
AP, S. *chamae cyparissus* As	154.61	64.64	1.13	138.7	49.76	45.11			
R, S. *schamae cyparissus* As		89.97	1.23	191.27	71.98	60.1	58.2	0.11	0.72
AP, S. *atropurpurea* As	118.77	51.03	1.56	183.97	31.61	45.5			
R, S. *atropurpurea* As		67.74	24.55	146.82	68.43	26.11	57	0.09	0.75
AP, S. *chamae cyparissus* Cd	2.62	1.39	0.53	10.4	0.8	2.21			
R, S. *chamae cyparissus* Cd		1.23	0.71	5.65	0.98	0.98	47	2.94	1.13
AP, S. *atropurpurea* Cd	2.68	1.27	0.35	13.26	0.75	2.62	52.7	3.01	0.9
AP, S. *atropurpurea* Cd		1.41	0.68	11.1	0.95	2.12			
AP, S. *chamae cyparissus* Sb	208.4	87.91	13.4	167.37	77	48.85			
AP, S. *chamae cyparissus* Sb		120.49	29.96	219.94	110.22	65.47	57.8	0.01	0.73
AP, S. *atropurpurea* Sb	167.45	68.82	19.44	201.72	52.07	44.56			
AP, S. *atropurpurea* SB		98.63	54.55	205.65	92.99	32.07	58.9	0.01	0.7
AP, S. *chamae cyparissus* Pb	84.85	32.91	9.81	57.32	34.7	11.03			
R, S. *chamae cyparissus* Pb		51.94	21.34	78.7	50.1	13.21	61.2	0.25	0.63
AP, S. *atropurpurea* Pb	78.75	30.61	14.1	56.84	28.87	28.87			
R, S. *atropurpurea* Pb		48.14	30.2	70.58	50.1	11	61.1	0.23	0.64
AP, S. *chamae cyparissus* Zn	92.18	40.53	15.26	79.73	36.83	18.75			
PR, S. *chamae cyparissus* Zn		51.65	19.25	100.65	51.29	21.35	56	0.46	0.78
AP, S. *atropurpurea* Zn	80.27	34.72	11.11	75.32	33.87	14.73			
R, S. *atropurpurea* Zn		45.56	18.5	85.73	43.86	19.42	56.8	0.4	0.76

critical and may affect the amounts of heavy metals extracted by vegetation and thus cause toxicities. According to Lee et al. (2001), high concentrations of heavy metals in soils influence their uptake by plants and therefore can be toxic for the entire food chain. Heavy metals contents in the studied species are summarized in Table 4. The results reveal the presence of the MTE whatever the species and the organ. We recorded the following sequences : Sb > As >Zn > Pb > Cr >Cd. In aerial parts of *S.chamaecyparissus* and *S.atropurpurea* L.we recorded respectively 87.91 and 68.82 mg/kg of Sb, 64.64 and 51.03 mg/kg of As, 40.53 mg/kg and 34.72 mg/kg of Zn, 32.91 and 30.61 mg/kg of Pb, 22.93 and 24.95 mg/kg of Cr and 1.39 and 1.27 mg/kg of Cd. For roots, heavy metals concentrations for *S. chamaecyparissus* and *S. atropurpurea* were respectively 120.49 mg/kg and 98.63 mg/kg for Sb, 89.97 and 67.74 mg/kg for As, 51.65 and 45.56 mg/kg for Zn, 51.94 and 48.14 mg/kg for Pb, 31.50 and 33.81 mg/kg for Cr, 1.23 and 1.41 mg/kg for Cd. The levels in both species parts 0.0001 to 0.2 mg /kg for Sb, 0.01 to 1.5 mg/kg for As, and 50 mg/kg for Zn that exceed the contamination thresholds proposed by Market (1992). According to the contamination thresholds proposed by Reeves and Baker (2000) levels of: 1 to 5.5 mg/kg for Pb and 1.03 mg/kg for Cd. Such results are similar to the work done in Morocco in several mining sites near to the city of Midelt where *Vetiveria zizanioides*, a heavy-metal tolerant species showed 157.94 mg/kg and 55.75 mg/kg of Zn and Pb respectively that exceeded the contamination thresholds proposed by Reeves and Baker (2000).

Furthermore, Sb and As average contents in aerial and underground parts are higher toxic concentrations 5-10 mg/kg for Sb, 0.02-7 mg/kg for As proposed by Kabata-Pendias (1985), Levresse et al. (2012), Alloway (1995). Similar results were also obtained by Benhamdi et al. (2014) working on the same study site on *Hedysarum pallidum* and *Lygeum spartum* L. The recorded levels of 32.52 µg/g for As and 160.97 µg/g for Sb in *Hedysarum pallidum* and 47.56 µg/g for As and 47.57 µg/g for Sb in *Lygeum* *spartum* L. that are above the toxicity thresholds.

For Pb and Cr, heavy metals contents were mostly within the critical range: 30-300 mg/kg for Pb and 20-100 mg/kg for Cr whatever the organ and the species (Kabata-Pendias and Pendias 1992). On the other hand, Zn and Cd presented higher contents at the two parts than the critical values of tolerance fixed by Kabata-Pendias and Pendias (1992) (100-400 mg/kg for Zn and de 5-30 mg/kg for Cd). For antimony contents, our results exceeded those of Rached-Mosbah et al. (1992) who recorded 17.5 and 53 µg/g for the same study site 25 years ago.

Moreover, *S. chamaecyparissus* and *S. atropurpurea* L. more Sb, As, Zn and Pb in their roots than in their aerial parts. In contrast, Cd is more accumulated in the aerial part than in roots, with a percentage of accumulation of about 46.95% for *S. chamaecyparissus* and of about 52.68% for *S. atropurpurea* L. The percentages of accumulation in roots for *S. chamaecyparissus* and *S. atropurpurea* L. respectively were 57% and 58% for Sb and As, 56% for Zn, 61% for Pb. The distribution of the four elements inside the two plants shows that the majority of these elements are trapped in the roots. Our results are in agreement with those of Sbartai et al. (2012) who found that root-level accumulation percentage exceeded 70% for Zn, and with the findings of Zoghlami et al. (2006), Young et al. (2009). They found high concentrations of Cd accumulated in tomato roots.

These findings support the hypothesis for which the roots of some plants can be considered as trapping organs and interposing the transfer of different metals to the aerial parts, where the various physiological processes occur (Zoghlami et al. 2006, Djebali et al. 2002, Jarvis et al. 1976, Dong et al. 2006). The high concentration of Cd in the upper part is due to the competition between the Zn and Cd transport in plasmalemme as these two metals use the same carriers (Hart et al. 2002). Benhamdi et al. (2014): Recorded a higher root accumulation for *L. spartum* and *H. pallidum* respectively 43.47 and 89.33 µg/g for Sb, and 43.45 and 21.77 µg/g for As.

Sb and As accumulation results and their transfer to the aerial parts indicate that both species are tolerant. The same carriers, such as phosphate, transfer arsenic through cell membranes from the soil to plants (Asher and Reay 1979). A strong competition established between phosphate and As. It may be the cause of its low accumulation compared to antimony.

According to Kabata-Pendias and Pendias (2001), the plant presents different behavior with respect to the soil contents : It takes proportionally the heavy metals present in the soil, or it controls their non-absorption at the root level, or even it activates absorption mechanisms. Thereafter, plants case develop cellular defence strategies against the phytotoxicity of heavy metals, which enable the tolerance to large amounts of MTE in their tissues.

Another method to assess the accumulation rate of heavy metals is the accumulation factor. Results of heavy metals AF for *S. chamaecyparissus* and *S. atropurpurea* L. are summarized in Table 4. The AF of the six MTE are slightly elevated for *S. atropurpurea* L. Than *S. chamaecyparissus*. A minimum of 0.01 was recorded for Sb in both plants, other studies showed that this ratio is of 0.02 for Sb (Rached-Mosbah et al. 1992, Baroni et al. 2000, Hammel et al. 2000). The low accumulation ratio of Sb can be explained by the fact that the two studied plants accumulate weakly Sb. As a consequence, it is possible that the two plants have acquired a mode of resistance to high levels of Sb.

On the other hand, the AF of Cd varies from 2.90 to 3.01 for *S. chamaycyparissus* and *S. atropurpurea* L. respectively. Therefore both plants have higher levels than those recorded in soil and we can consider both plants as Cd accumulator. Kabata-Pendias and Pendias (2001), explained this hyper-accumulation by the fact that some plants can take the MTE, even when they are in low proportion in the soil. Reeves and Baker (2000) determined a threshold of 100 mg/kg for hyper-accumulative plants, so both plants are averagely hyper-accumulative for Cd. Moreover, the ratio of accumulation for Cr, As, Pb and Zn are very high for both plants. By referring to the standard for Cr, Pb and Zn contents in hyper accumulating plants proposed by Reeves and Baker (2000), with thresholds of 500, 1000, 1000 mg/kg respectively, it appears that the two studied plants are not hyper accumulative but can be considered as accumulators.

Regarding the translocation ratio (TF), Conesa et al. (2011) reported that species with TF greater than 1 are considered as hypera-ccumulators. The TF results for the different MTE for both plants are shown in Table 4. TF results for the studied metals are almost identical for *S. chamaecyparissus* and *S. atropurpurea* L. We recorded 0.73 and 0.74 for the Cr, 0.72 and 0.75 for the As, 1.13 and 0.98 for Cd, 0.73 and 0.70 for Sb, 0.63 and 0.64 for Pb, 0.78 and 0.76 for Zn. Except for cadmium (TF > 1). The two species seem to be adapted to toxicity by limiting the translocation of Cr, As, Sb, Pb and Zn to the aerial parts. According to Conesa et al. (2011), plants with TF<1 are considered as exclusion plants. This is the case for Sb, As, Zn, Pb and Cr whatever the species. Another hypothesis is that the translocation of some MTE such as Sb and As from the roots to the aerial parts may be limited by their precipitation at the root membrane barriers controlling their transport in the aerial parts of some plants (Perz-Sirvent et al. 2012, Shtangeeva et al. 2011). This can explain our results for Sb, As, Zn and Pb and Cr.

As previously mentioned, Cd has FT greater than 1 for both species. Ghosh and Singh (2005 a, b) consider this ability to be beneficial for phytoextraction, as it reduces metal toxicity at the root level. Thus, *S. chamaecyparissus* and *S. atropurpurea* L. can be qualified as Cd accumulators and can be described as having a form of resistance to high concentrations of this metal in the soil.

Conclusion

The objective of the present study was to assess the metallic contamination of the soils of an old antimony mine, which has been generating significant amounts of spoil resulting in contamination of the entire surrounding area. The results show that MTE were presented in the soil in an order of abundance: Sb > As > Pb > Zn > Cr >Cd and their quantity (concentration) exceed the contamination thresholds. In this case, these high levels may affect the natural properties of the soil and will require restoration and rehabilitation to remedy these soils. The calculation of the contamination/pollution index (MPI), revealed a worrying situation with excessive pollution to very severe pollution for Sb, As and Pb.

The pollution index (PI) states a multi-element contamination of the soil, with extremely high PI for all the MTE. These values reflect a worrying situation, which presents a source of continuous dispersion of the different MTE surrounding soils. So it required an urgent action to restore or rehabilitate these abandoned substrates in a context of assisted soil phytostabilization. Overall, metal levels in *S. chamaecyparissus* and *S. atropurpurea* L. and in both aerial and root parts were found to exceed the critical tolerance values proposed by several authors for Sb, As, Pb and Cr. However, for Zn and Cd higher contamination values than the normal and below the critical tolerance values were recorded. The majority of MTE sare trapped in the roots in both species, and only the Cd was more concentrated in the upper part. Moreover, the AF of As, Pb, Zn and Cr were high for both plants, which qualifies these two species as accumulators. Contrary to these elements, both plants choose to exclude Sb to better resistance and tolerance regarding its very high levels in the soil. Cd accumulation factor was very high. This strong accumulation, despite these low levels in the soil, is due to the plant physiology, which takes some MTE actively and selectively compared to other elements. The results of the translocation factor show that *S. chamaecyparissus* and *S. atropurpurea* L. are more adapted to toxicity by limiting the transfer of MTE to the aerial parts. This indicates a tendency to exclude the Sb, As Pb and Zn. Ecotoxicologically, the passage of heavy metals to the aerial parts is an unfavorable property, since accumulating MTE can alter the entire trophic chain. The transfer of Cd to the aerial parts may be considered favorable for phytoextraction because it reduces the toxicity of the metal at the root level.

In conclusion, the two species exhibit a specific mode of tolerance and they accumulate differently the MTE in their organs and therefore they can be used for the phytoextraction or the remediation of polluted soils, in order to reduce their toxicity as well as the contamination of the surrounding soils.

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