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Metal extraction competence of plants on waste dumps of magnesite mine, Salem District, South India

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Abstract

This ex-situ study aims to assess the metal extractive potential of fourteen agriculture plants (*Vigna unguiculata, Gossypium hirsutum, Jatropha curcas, etc.*). It was conducted on Magnesite mines which had above permissible levels of Cadmium and Lead. There was no significant difference in the total chlorophyll *a* and *b*, carbohydrate and protein contents in the plants grown in the mining soil and adjacent control area (farm soil). While considering the phytoextractive potential, out of the 14 plants studied, *V. ungiculata, O. sativa, S. bicolour, S. indium, R. communis, M. uniflorum, G. hirsutum* and *J. curcas* contained a considerable amount of heavy metals Cd and Pb other test plants. The experiment confirms that these plants have the potential to accumulate the toxic trace elements from soil, especially from mining waste or dump. Further studies deal with metal tolerant index, metal transfer factor, translocation factor and MREI index values auger their potential phyto-extractive properties. The present study will pave the way for in-depth related studies in future.

Keywords: *Mine tailings, Trace elements, Agriculture plants, Phytoremediation.*

1. Introduction

For the past two decades, people have been concerned with degradation and contaminations rampant in the mining dump yards which had been laid waste. This is a problem for both the industrialised nation as well as the developing countries. It has also been found out that some of the consequences of anthropogenic pollution are transmission of contaminants, accumulation of toxic or recalcitrant chemicals in soil, destabilization of ecological balance and human health hazards [1-2]. Remediation of soil contaminated with toxic metals is exigent and unlike organic compounds metals are hard to degrade. The cleanup of metals which is usually expensive requiring exhaustive physical or chemical processes [3] which may, sometimes be ineffective. Therefore, an alternative process involving phytoremediation is the only promising option left for remedial strategies, and it is also comparatively cheaper. The plants can be effectively used for phytoextraction [4-5], phytovolatilization and phytostabilization [6]. Among all the various phytoremediation processes phyto-extraction has been suggested by various authors as a viable technology for the removal of potentially toxic metals from soil. Phytoextraction involves two types of operation: Phyto-mining and Phyto-remediation. Phytomining is the phyto-extraction of metals for commercial gain, although it has never been tested industrially. It can be used in conventional mining operations with limited commercial prospects. It also has the potential to be used in mining areas which are normally ignored by commercial ventures, but extracted using conventional methods. The plants used for phyto-extraction processes promisingly and considerably decontaminates the polluted soil [7]. This technology has gained more fascination in recent years due to its low cost implementation, environmental benefits and better efficiency compared with other traditional methods [8]. Only a few plant species are known to survive and reproduce in soil contaminated with Pb, Cd, Ni, As and Cr [9]. One such application was extensive phytoremediation process carried out to remedy the heavy load of heavy metals (Cd, Hg and Pb) and radioactive isotopes such as U^{238}, Cs^{137} and Sr^{90} from industrial waste sites [10-12], mine tailings [13] and metal contaminated soil [14]. The plants growing on mining waste or mining tailings are subjected to heavy stress from the toxic metals. It lead to changes in their growth physiology, bio molecule accumulation causing stress toxicosic effects like reduction of biomass, chlorophyll content, carbohydrate and protein content [15]. This study identifies the extent of physiological constrains effected by phytoremediation processes (heavy metal removal) on the test plants selected for this purpose. Normally biomass and chlorophyll content [16] of plants is an important benchmark for their phytoremediation efficiency [17], this aspect is also studied along with the phyto-extractive properties.

2. Material and methods

2.1. Site description and samples collection

Soil samples were collected from open cast magnesite mine (latitude: 11.69’74’68, longitude: 78.10’29’31) and adjacent agricultural lands in Salem district, Tamil Nadu, South India. The corporate company dealing with extraction of magnesite has been operating in a large site in the vicinity for two decades. The company had been converting large tract of land around the mine as dump yard. Main source of pollution in the dump soil is the dust emanating from the mining and calcinations activities, which mainly contains $MgCO_3$ and MgO (Dept. of Geology and mining, Govt. of Tamil Nadu, India). In spite of the severe contamination of the soil, some grasses and few tree species were found to inhabit these mining dumps i.e, *Azadirachta indica* and *Acacia nilotica*. The region gets approximately about 650mm precipitation annually and it also considerably contributes to the spread of pollutants. The area was earmarked for mining and reported to contain residual soil to a depth of approximately 75cm and the above ground biomass mostly comprised scrub vegetation. The sampling was conducted on a heap of mine waste dump where mining was ceased 10 years ago. Three mine and three farm soil samples were collected in a dirt-free container from the heap region and farm soil respectively. The collected soils were air-dried at room temperature and sieved (12 diameter) to remove dusts and stones.

2.2. Physicochemical and metal analysis

The pH of soil sample was determined by dissolving 5g of soil in 12.5 ml of distilled water and measured using glass electrode [18]. The Electrical conductivity (EC) was determined by the method of Sudduth et al., [19] ,while the N, P, K, $CaCl_2$ and texture were analyzed using standard procedures as followed by the Department of Agriculture, Govt. of Tamil Nadu, India. The total heavy metal content in the soil samples was analyzed through acid digestion method [18, 20]. Calcium content was estimated using the soil (mine based on the modified method of Thomas [21]. The digested liquid was filtered through Whatman filter paper No. 0.5 and the heavy metal contents of filtrate were analyzed using inductively coupled plasma-optical emission spectrometry (ICP-OES, Perkin-Elmer, USA). High Analytical grade reagents were used for the above analyses.

2.3. Greenhouse experiment

The air-dried soil samples (2 kg) mixed with sterile cow dung manure (metal free) in the ratio of 1:6. The prepared soil was taken in polyethylene bags and the plants (*Vigna radiata* (L.) Wilczek, *V. mungo* (L.)Hepper, *V. unguiculata* (L.)Walp., *Eleusine coracana* (L.) Gaertn., *Cajanus cajan* (L.) Druce, *Pennisetum glaucum* (L.) R.Br., *Macrotyloma uniflorum* Lam., *Oryza sativa* L., *Sorghum bicolour* L., *Sesamum indicum* L., *Ricinus communis* L., *Brassica juncea* L., *Gossypium hirsutum* L. and *Jatropha curcas*L.), obtained from TNAU Coimbatore and Danishpet Nursery garden, Salemwere sown in triplicates. These plants were preferred due to their better adaptability and their short life span was fully analysed. In addition, it should be useful to understand the response of these crops on metal polluted environment (in both physical and biomolecule level). These plants were cultivated in a greenhouse with semi natural light condition in the range of 400–450 $\mu mol\ m^{-2}\ s^{-1}$ and temperature adjusted to 30 ±2 ^oC for eight weeks. The moisture content of each polyethylene bag was maintained at 75% (water holding capacity) [22] and monitored every two weeks. The bags were watered with 50 ml de-ionized water every 2 days. Necessary precautions were taken while watering the plants to avoid the spill/leakage of water from polyethylene bags, which may lead to pseudo-results. The germination rates (%) of the plants were recorded as followed by Etham et al. [23].

2.4 Chlorophyll analysis (*a* and *b*)
The total chlorophyll content (*a* and *b*) of the plants was estimated using young leaves of plants subjected to phyto-extraction using a spectrophotometer at two different wavelengths (647 and 664 nm) as per the modified protocol of Doong et al. [24].

2.4.1 Macro nutrient analysis
The leaf samples (0.2 g) were taken from the mid shoots of each plant (the intermediate plant leaves are perfect to analyse macronutrients, contains more amount of the molecules than young or matured leaves) to analyze and estimate the bio molecules (carbohydrate and protein), based on the modified method of Jones et al. [25].

2.4.2. Heavy metal analysis of plants
The shoot and roots of each plant were harvested and washed thoroughly with deionised water, rinsed well with distilled-deionized water, washed again with 0.1N HCl for a few seconds and further rinsed with distilled-deionized water to remove the foreign substances in rhizosphere region. Later fresh and dry weight of plants were measured (dried at 60°C). The metal content of the plants were estimated by mashing and acid digestion methods described by McGrath and Cunliffe [4] and the ensuing digest was analyzed using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES, Perkin-Elmer, USA).

2.5. Data analysis
2.5.1. Transfer factor
Metal concentration of extracts from soils and plants was calculated on the basis of dry weight. The plant concentration factor (PCF) was calculated as follows [26].

$$PCF = \frac{C\ plant}{C\ soil} \qquad (1)$$

Here, C_{plant} and C_{soil} represent the heavy metal concentration in extracts of plants and soils on dry weight basis, respectively.

2.5.2. Translocation factor
Translocation of metals from roots to shoots of each plant was calculated by using a modified method of Mishra et al. [27].

$$TF = \frac{Concentration\ of\ element\ in\ Shoot}{Concentration\ of\ element\ in\ Root} \qquad (2)$$

2.5.3. Tolerance Index
The heavy metal tolerance index of plants was calculated by using the following equation [28].

$$\text{Tolerance index} = \frac{\text{The mean height of the plant growing on metal contaminated soil}}{\text{The mean height of the plant growing in garden soil}} \times 100 \qquad (3)$$

2.5.4. MATNAT remediation efficiency index (MREI)
The researchers newly framed this index (including software: © 2011 Copyright reserved) to estimate better remediation efficiency value of the plant by using the following formula.

$$MREI = \frac{(m-n)/o}{p \times q} \qquad (4)$$

Here, **m** is the amount of pollutants before remediation, n denotes the amount of pollutants after remediation, **o** represents the amount of sample (polluted soil) taken for remediation, **p** is the duration (in months) of the remediation process and **q** stands for the number of plants taken in the remediation process.

2.5.5. Statistical analysis
The correlation coefficient values of metals uptake by each plant was analyzed by using Pearson correlation coefficient method and it was computed using SPSS software statistical package12 [54].

3. Results
3.1. Soil analysis
The results of physicochemical characteristics of waste dumps of mine and adjacent soils are given in Table 1. The mine waste is reported to have an alkaline pH (8.12) and impermissible limits of Cd (2070mg/kg^{-1}), Pb (443 mg/kg^{-1}) and possessed an even higher Mg^{2+} (5330mg/kg^{-1}) and Ca^{2+} (4907 mg/kg^{-1}) concentrations. The farm soil had a neutral pH (7.10) and an unacceptable amount of Cd (37.98 mg/kg^{-1}) and Pb (416 mg/kg^{-1}). The mine tailings (waste dump) showed the lowest quantity of K (49.42/kg hectare^{-1}), Mn (3173 mg/kg^{-1}) and in addition they also contained Cr (69.69mg/kg^{-1}), Zn (1141 mg/kg^{-1}) and Cu

(65.96mg/kg^{-1}). The total N content of mine and adjacent soils (86.48 and 185.32 kg hectare^{-1}) were lower than the permissible limits (Table 1) the P content of mine soil was beyond the permissible limit (32.12 kg hectare^{-1}). The farm soil had the sufficient concentration of K (126.02 kg hectare^{-1}), P (19.76 kg hectare^{-1}) and higher concentration of Mn (4614mg/kg^{-1}), Cr (102.4 mg/kg^{-1}), Zn (659mg/kg^{-1}) and Cu (95.42 mg/kg^{-1}) respectively. There was no significant variation in the values of Electric conductivity (EC 0.1 dsm^{-1}) and $CaCl_2$ was not detected in both the test soils.

Table 1.The physicochemical and metals (mg/kg^{-1}) characteristics of magnesite waste dump and farm soil

S.No	Physico-chemicals/Metals	Magnesite soil	Farm soil	Permissible limit (BIS)
1	pH	8.12±.5	7.10±.5	6-8.5
2	Temperature	30^{o}C ±2	30^{o}C±2	-
3	ECs (dsm^{-1})	0.1±0.0	1±0.0	0.1-1
4	$CaCl_2$	Nil	Nil	-
5	Texture	SCL	RLL	-
6	N (kg/hectare^{-1})	*86.48±.78	*185.32±1.1	114-180
7	P (kg/hectare^{-1})	**32.12±.90	19.76±.4	4.6-9
8	K (kg/hectare^{-1})	*49.42±.52	126.02±.98	49-113
9	Ca mg/kg^{-1}	4907±2.57	2089.23±1.98	52000
10	Mg	5330±3.26	4274.12±2.18	9000
11	Cd	2070 ±2 .43	37.98±1.42	2-6
12	Cu	65.96±.12	95.42±2.41	100
13	Fe	2222±1.07	1802.3±1.07	129000
14	Zn	1141±1.79	659.31±1.2	300
15	Cr	69.96±.27	102.48±.96	1000
16	Mn	3173±2.81	4614.69±3.4	1000
17	Pb	443±.96	416.79±3.6	200

Table 1. SCL: Sand-Clay-Loamy soil, **RLL**: Red, Loamy and Lateritic. *****lower than the permissible limit.******higher than the permissible limits. The values are average of mean of triplicates. The permissible limit for serial number 1-8 adopted from Tamil Nadu soil testing laboratory and 9-17 (in ppm) data's were adopted from Ramamurthy and Kannan [53].

3.2. Growth parameters of plants

The germination rate (%) of most of the plants from mine soil was lower (*V. mungo* (80%), *E. coracana* (70%), *P. glaucum* (93%), *M. uniflorum* (90%), *S. bicolour* (65%), *S. indium* (95%), *R.communis* (75%) and *G. hirsutum* (70%), compared to plants grown in soils (Table 2). The germination rate of rest of plants (*V. radiata*, *V. ungiculata*and *J. curcas*) on the mine soil was stable (Table 2). The total biomass of most of the plants from mine soil was lower than that of farm soil with the exception of *J. curcas* and *V. ungiculata*.

3.3. Chlorophyll (*a* and *b*) and Macronutrients

The results of chlorophyll (*a* and*b*) content in plants on mine and adjacent soils are presented in Figure 1. A similar amount of chlorophylls was observed in most of the plants from both test soils (2.8 to 10 mg g^{-1}), except for *V. radiata* (2.8 mg g^{-1}) and *S. indicum* (2.0 mg g^{-1}). Whereas, *M. uniflorum*had higher amount of chlorophyll *a* and *b* (10 mg g^{-1}) from mine soils compared to its counterpart in adjacent soil (4 mg g^{-1}). The mine grown plants i.e., *V. radiata, V. mungo* and *V. ungiculata,* (100 to 30, 50 to 40, 60 to 35 mg g^{-1} contained a low amount of carbohydrates than that of farm soils, while as *M. uniflorum* and *J. curcas* contained more amount of carbohydrates (150 to 180 mg g^{-1} & 175 & 98 mg g^{-1}) compared to adjacent soil. *E. coracana C. cajan, O. sativa, S. bicolour, S. indium, R. communis, B. juncea* and *P. glaucum* (all grown in mine soil) had more or less similar amounts of carbohydrates compared to normally grown farm plants (Figure 2). *G. hirsutum* and *J. curcas* from the magnesite mine soil had higher amount of protein (362 and 396 mg g^{-1}) than other plants (Figure 3).

3.4. Phytoextraction efficiency of plants

The results of phyto-extractive efficiencies of these plants showed a higher concentration of Cd observed in the roots of *J. curcas* (92 mg kg^{-1}), *R. communis, M. uniflorum* (55 and 85 mg kg^{-1}),*E. coracana* (36 mg kg^{-1}), *C. cajan* (32 mg kg^{-1}),*P. glaucum* and*G. hirsutum* (each 28 mg kg^{-1})than other plants. Shoots of *O. sativa, S. bicolour, S. hirsutum* and *V. ungiculata* contained more concentration of Cd (98 to 73mg kg^{-1}). *V. mungo* exhibited better uptake and transfer of Cr (153 mg kg^{-1}) from roots to shoot (111 mg kg^{-1}) and there was a significant absence of Cd uptake (Table 3). The Cd concentration in root and shoot of plants

from farm soil was less (2 to 23 mg kg^{-1} in roots and 9 to 25 mg kg^{-1} in shoots).
The shoots and roots of all plants from the normal adjacent soil showed an average accumulation of Cr in the range of 446 to 75 mg kg^{-1} in roots and 177 to 35 mg kg^{-1} in shoots. The higher quantities of Pb and Mn contents were observed in roots (in the range of 1041 to 113 mg kg^{-1} of Pb and 2771 to 251 mg kg^{-1} of Mn) and shoots (826 to 75 mg kg^{-1} of Pb and 1238 to 297 mg kg^{-1} of Mn) of almost all plants from mine soil. This can be due to physicochemical properties (alkaline pH, perfect electric conductivity EC (dsm^{-1}), nature of mine (0.1dsm^{-1}) and high metal stress of mine soil. The amount of Pb and Mn in root and shoot of plants from the farm soil were in the range of 376 ± 27 mg kg^{-1} of Pb in roots & 135 ±11 mg kg^{-1} in shoots and 1899 ± 97 mg kg^{-1} of Mn in roots & 575 ± 65 mg kg^{-1} in shoots respectively. The correlation coefficient of the metal removal efficiency of individual plant was significant at the $P < 0.05$ level (2-tailed) and the correlation between each plant for each metal extraction was significant at $P < 0.01$ level (2-tailed) (Table 4).

3.5. Soil - plant interaction

3.5.1. Metal tolerance index, metal transfer and translocation factor

The values of metal tolerant indexes as well as metal concentration of plants differed considerably. All the plants are reported to contain certain metal tolerant index (viz. 104.0, 110.34, 152.38, 104, 108.51, 85.71, 51.16, 90.32, 90.90, 127.7, 116.0, 110.5 and 113.4) except in *O. sativa.* The values of translocation factor indicate that metals are accumulated by the plants and are equally retained in roots and shoots in most plants except in *V. radiata, V. mungo* and *V. unguiculata* (which had values in the range of 0.305 to 9.250 for Cd and 0.462 to 5.398 for Pb and 0.279 to 3.458 for Mn) (Figure 4). The results of metal transfer factor of plants showed that *J. curcas, R. communis* and *O. sativa* have higher values followed by *M. uniflorum, V. unguiculata* and *G.* hirsutum (Figure 5).The MATNAT remediation efficiency index values are useful in indentifying the high metal removing efficiency of plants and the results are given in Table 5.

Table 2. Biomass of the plants from magnesite (waste dump) mine and farm soil

Name of the plant	Magnesite dump			Farm soil		
		Dry mass (in g)			Dry mass (in g)	
	G.R %	Root	Shoot	G.R %	Root	Shoot
V. radiata	75	0.17 ±.003	0.77 ±.004	75	0.29 ±.004	1.59 ±.004
V. mungo	80	0.22 ±.007	1.65 ±.004	85	0.20 ±.004	1.27 ±.004
V. ungiculata	100	0.40 ±.014	2.69 ±.004	100	0.33 ±.004	2.38 ±.004
E. coracana	70	0.04 ±.001	0.05 ±.004	98	0.07 ±.004	0.26 ±.004
C. cajan	90	0.34 ±.021	2.11 ±.004	80	0.41 ±.004	3.01 ±.004
P. glaucum	93	0.11 ±.004	0.33 ±.004	100	0.15 ±.004	0.49 ±.004
M. uniflorum	90	0.05 ±.001	0.87 ±.004	95	0.11 ±.004	1.15 ±.004
O. sativa	90	0.05 ±.001	0.15 ±.004	80	0.18 ±.004	0.96 ±.004
S. bicolor	65	0.11 ±.002	0.40 ±.004	80	0.18 ±.004	0.72 ±.004
S. indium	95	0.02 ±.001	0.21 ±.004	98	0.07 ±.004	0.52 ±.004
R. communis	75	0.06 ±.001	0.24 ±.004	80	0.15 ±.004	0.53 ±.004
B. juncea	96	0.060 ±.003	0.12 ±.004	95	0.17 ±.004	0.56 ±.004
G. hirsutum	70	0.51 ±.009	1.35 ±.004	90	0.45 ±.004	1.52 ±.004
J. curcas	100	0.32 ±.024	2.15 ±.004	100	0.29 ±.004	2.00 ±.004

The values are given in the table is average mean of triplicates and standard deviation of ± ofreplicates. **G.R;** Germination Rate

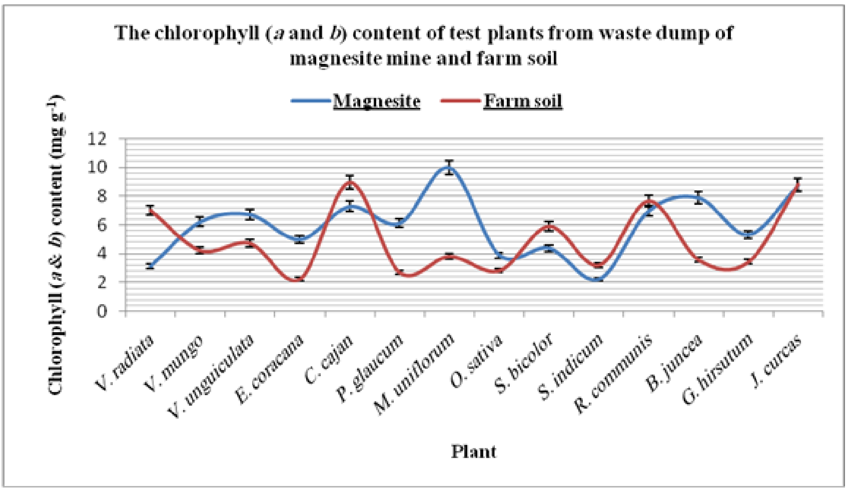

Figure 1. Chlorophyll (a and b) content of test plants grown in mine waste and adjacent soils

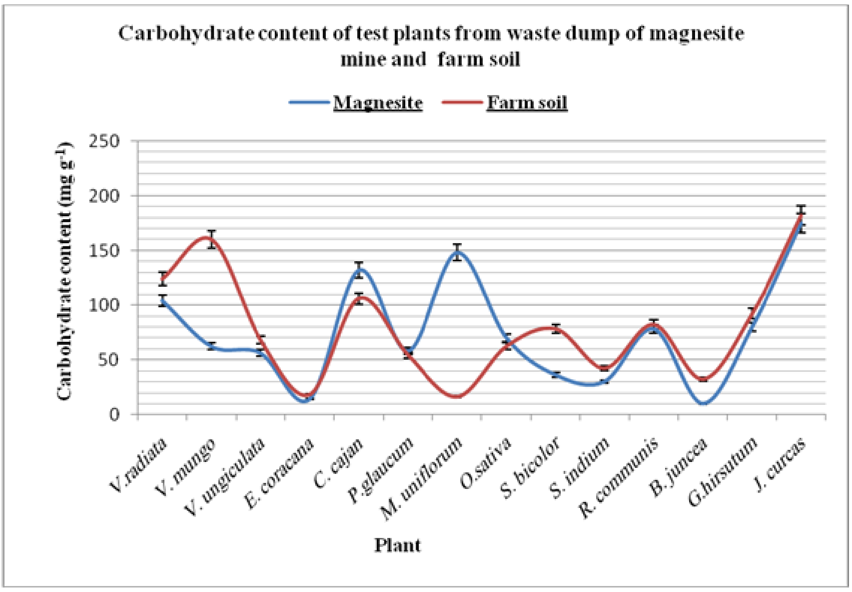

Figure 2. Carbohydrate content of test plants grown in mine waste and adjacent soils

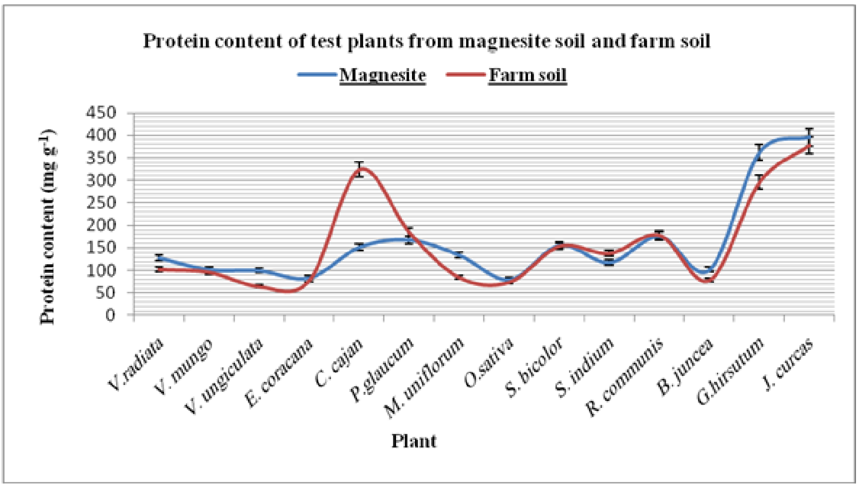

Figure 3. Protein content of test plants grown in mine waste and adjacent soils

Table 3. Metal extractions by plants from waste dump of magnetite mine and farm soil (mg kg-1).

Name of the plants	Magnesite mine								Farm soil							
	Cd		Cr		Pb		Mn		Cd		Cr		Pb		Mn	
	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot
V. radiata	5 ±.02	0	179 ±1.7	141 ±.99	241 ±1.3	261 ±.96	705 ±1.4	383 ±1.0	2 ±.00	0	56 ±.31	43 ±.65	27 ±.13	75 ±.56	275 ±1.4	112 ±.92
V. mungo	0	0	153 ±1.1	111 ±1.2	285 ±1.1	349 ±1.7	957 ±1.8	481 ±1.1	0	0	46 ±.21	31 ±.34	41 ±.56	51 ±.67	361 ±.98	121 ±.81
V. ungiculata	0	78 ±1.3	128 ±1.6	141 ±1.4	286 ±1.4	585 ±2.1	658 ±1.7	321 ±1.1	0	9 ±.02	35 ±.38	29 ±.45	95 ±.21	75 ±.93	241 ±1.2	95 ±.32
E. coracana	36 ±.78	11 ±.34	268 ±1.4	51 ±.45	211 ±.99	161 ±.94	726 ±1.3	812 ±1.8	17 ±.12	13 ±.01	97 ±.89	12 ±.02	31 ±.65	45 ±.67	347 ±1.1	206 ±.96
C. cajan	32 ±.65	21 ±.12	92 ±.98	61 ±.13	352 ±1.2	206 ±.89	851 ±1.2	342 ±1.4	11 ±.03	17 ±.60	26 ±.48	17 ±.31	96 ±.23	68 ±.53	625 ±1.2	116 ±.97
P. glaucum	28 ±.40	13 ±.20	167 ±.68	134 ±.75	389 ±2.1	235 ±2.1	563 ±1.3	563 ±1.1	0.01 ±.00	12 ±.03	54 ±.96	56 ±.42	72 ±.65	69 ±.74	198 ±.98	98 ±.69
M. uniflorum	85 ±1.1	29 ±.71	261 ±.94	73 ±.22	313 ±1.8	412 ±1.6	711 ±1.4	725 ±1.1	21 ±.10	12 ±.02	63 ±.31	92 ±.32	95 ±.46	117 ±.76	156 ±1.1	175 ±1.0
O. sativa	.01 ±.00	98 ±.82	414 ±1.3	177 ±1.1	153 ±1.0	826 ±2.4	801 ±1.6	642 ±1.4	9 ±.02	18 ±.17	93 ±.25	89 ±.59	74 ±.36	135 ±.97	236 ±.89	204 ±.99
S. bicolor	23 ±.54	73 ±.12	382 ±2.5	35 ±.27	113 ±.97	241 ±1.5	714 ±1.9	252 ±.89	11 ±.01	21 ±.09	102 ±.75	16 ±.36	34 ±.13	75 ±.58	193 ±.99	65 ±.86
S. indium	8 ±.30	74 ±.32	215 ±1.3	151 ±.86	132 ±1.0	805 ±2.2	358 ±1.3	1238 ±2.8	3 ±.01	16 ±.05	81 ±.65	64 ±.56	65 ±.38	105 ±.79	154 ±.98	458 ±1.0
R. communis	55 ±.94	71 ±.56	75 ±.95	166 ±1.4	602 ±2.3	751 ±1.7	421 ±2.0	1223 ±3.1	13 ±.12	25 ±.21	13 ±.31	25 ±.45	107 ±.89	111 ±.79	149 ±.64	575 ±1.3
B. juncea	16 ±.65	3 ±.0	181 ±1.4	91 ±.62	162 ±1.1	75 ±.56	251 ±1.4	652 ±1.7	11 ±.03	0	51 ±.26	47 ±.29	86 ±86	11 ±.03	97 ±.78	132 ±.38
G. hirsutum	28 ±.46	36 ±.02	342 ±2.1	82 ±.93	207 ±1.5	325 ±1.1	426 ±1.8	297 ±.86	8 ±.05	21 ±.21	103 ±.84	33 ±.31	68 ±.46	112 ±1.1	135 ±.95	83 ±.56
J. curcas	92 ±1.2	41 ±.62	446 ±1.8	129 ±.39	1041 ±2.8	405 ±1.4	2771 ±3.6	774 ±2.4	23 ±.20	11 ±.07	96 ±.98	46 ±.33	376 ±.97	96 ±.37	1899 ±2.8	208 ±1.5

The mentioned values are mean value of triplicate

Table 4. Pearson's correlation coefficients (r) between the waste dumps of magnesite mine and plants

Name of the plants	Name of the metals			
	Cd	Cr	Pb	Mn
V. radiata	-.44	-.78	.06	.18
V. mungo	-.85	.(a)	-.96(*)	.(a)
V. unguiculata	.41	.88	-.15	-.33
E. coracana	.49	.77	-.18	.92
C. cajan	-.89	.00	.80	.98(*)
P. glaucum	.09	.50	-.45	.95(*)
M. uniflorum	.17	.31	.07	.04
O. sativa	.08	-.37	-.03	-.05
S. bicolor	-.81	.94	-.27	.98(*)
S. indicum	.49	-.84	-.31	.78
R. communis	-.88	-.07	.41	.71
B. juncea	-.15	.48	.32	-.47
G. hirsutum	.42	.67	-.12	.71
J. curcas	-.15	.03	.61	-.89

(*) - Correlation is significant at the 0.05 levels (2-tailed) and the correlation between the each plant for each metal is 0.01 levels significantly (2-tailed)

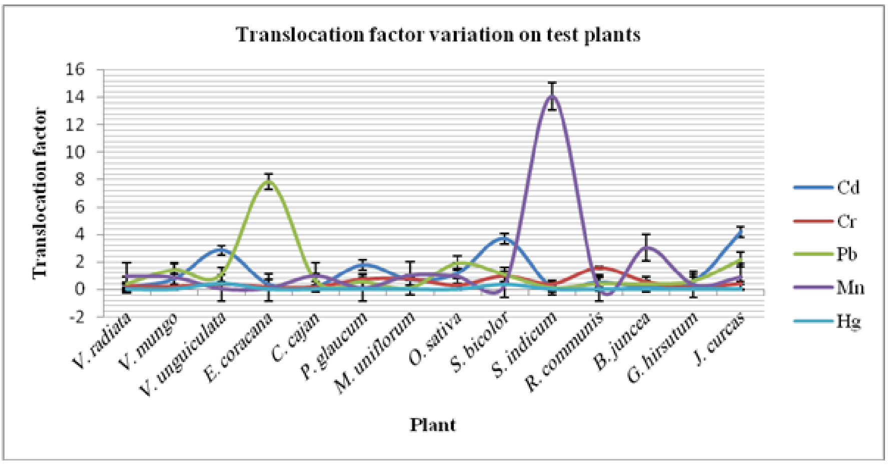

Figure 4. Translocation factor variation of test plants grown in mine waste and adjacent soils

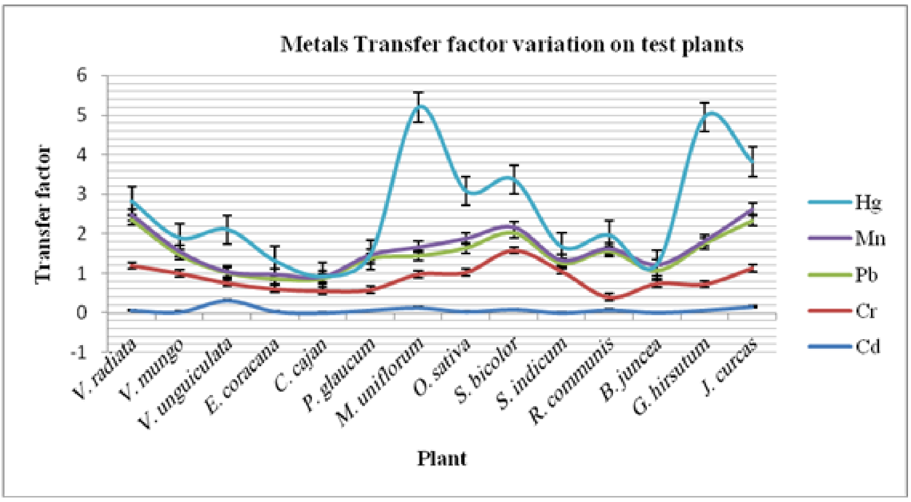

Figure 5. Metals Transfer factor variation of test plants grown in mine waste and adjacent soils

Table 5. MATNAT remediation efficiency index (MREI)

Name of the plants	Name of the metals			
	Cd	Cr	Pb	Mn
V. radiata	4.203	0.017	0.014	0.024
V. mungo	1.483	0.022	0.016	0.013
V. unguiculata	0.011	0.032	0.012	0.012
E. coracana	2.540	0.010	0.011	0.024
C. cajan	7.027	0.011	0.013	0.013
P. glaucum	4.324	0.022	0.012	0.024
M. uniflorum	7.891	0.042	0.023	0.033
O. sativa	2.324	0.021	0.022	0.028
S. bicolor	5.567	0.012	0.011	0.015
S. indicum	7.027	9.783	7.791	0.012
R. communis	4.540	0.032	0.023	0.024
B. juncea	1.081	0.011	0.022	0.025
G. hirsutum	4.324	0.011	0.024	0.033
J. curcas	9.243	0.023	0.044	0.040

The effective index values are considered as 0.010 onwards

4. Discussion

Phytoremediation is an eco-friendly cost effective technology, as compared to classical physical, chemical and even to the microorganisms-based bioremediation techniques. The results of heavy metal analysis of present investigation showed that the highest levels of Cd, Pb and Cr were found in the waste dump of bauxite mine, indicating that these wastes are the key elements for soil pollution. The presence or absence of soil microbe and macronutrients determine the viability of plants on soil type. The high Mg^{2+} concentration in mine soil is due to hydrolysis of $MgCO_3$, whereas the high MgO in the dusts are responsible for increasing soil pH [29] and they play an important role in nutrient cycling in plants [30]. The result of Yang et al. [31] partially correlates with the present findings and highlights the chemical composition of magnesite mine tailings. It showed the effects of mining on soil exposed to Mg dusts, i.e., increase in Mg^{2+} concentration, change in pH, the Mg^{2+}/Ca^{2+} ratio and decrease in availability of N, P, and Ca. All these parameters would significantly affect the colonization and growth pattern of plant because of mine overburden and deposition of waste dump in adjacent sites [32]. The pH and heavy metals (Cd and Pb) of farm soil may also increase in future due to improper mining activity if not prevented at the latest. Yang et al. [31] reported that high pH can result in significant loss of N by volatilization since NH tends to convert to NH_3 gas, which later diffuses from alkaline soil to the atmosphere [30]. Robinson [7] stated that the physical characteristics of contaminated soil are also important for the selection of remediating plants.

The total biomass values of most of the plants from mine soil was lower than that of soil with the exception of *J. curcas* and *V. ungiculata.* The condition may be due to low P concentration in plants grown in mining soil, because P levels determine the production of higher biomass and metal sorption processes in plants [14]. Similar reports [17] also state that biomass is an important factor in considering the phytoremediation efficiency of plants. Robinson [7] explained that high biomass yielding plants are required for the effective phyto-extraction process.

The chlorophyll (*a* and *b*) content in plants are very important for high biomass production via photosynthesis [16]. *V. radiata*, *V. mungo* and *V. ungiculata* (100 to 30, 50 to 40, 60 to 35 mg g^{-1}) are reported to contain a low amount of carbohydrates compared to farm plants. Likewise, Azmat et al. [33] and Jones [25] reported that higher concentration of heavy metals in the soil (Cd) decreases the nutritive values of plants (bean). The plants *E. coracana, C. cajan, O. sativa, S. bicolour, S. indium, R. communis, B. juncea* and *P. glaucum* had a similar amount of carbohydrates in mine soil compared to farm plants. Similarly, *G. hirsutum* and *J. curcas* from the magnesite mine soil reported to contain high amount of proteins. The results are closely correlated with the reports of Rolli et al. [34], who estimated the biochemical parameters (total chlorophyll, protein and carbohydrate) of *Spirodela polyrhiza* on metal (Cd) treatment and also showed a significant increase of plant bio molecules at lower concentration of cadmium.

The high amount of Pb and Mn noticed in root and shoot of plants from the farm soil indicates the spreading of metal contamination to the adjacent soil. This finding is supported by the results in maize (in farm site) which can accumulate high levels of Cd [35-36]. Further, Carrillo et al. [37] extensively studied and highlighted metal accumulation in wild plants from regions surrounding mine wastes. The results of our study were moderate, compared with the results of Shanab et al.[22], on multi metal contaminated soil using plants. Lombi et al. [38] observed that the concentrations of Cd, Cu, Ni, Pb, and Zn were higher in the roots than shoots of *S. bicolour*, andthese plants were recommended for phyto-stablization processes. On the other hand, Mangkoedihardjo and Surahmaida [39] had recommended *J. curcas* for lead and cadmium contaminated soils. Yun-Guo et al.[40] performed an experiment in phyto-remediation efficiency on magnesite mine tailings by using *Gnaphalium afine*, *Pteris vittata*, *Rhus chinensis* etc., and they conclude that these plants are also suitable for the remediation of mine tailings sites.

Obviously, the metal accumulations in plant tissues have been raised with increasing concentration of metal as well as the period for plant growth [41]. *Brassica juncea* has also been declared to be a promising plant for metal phytoremediation because of its moderate to high Zn and Cd accumulation and high shoot biomass [42].

Under chelate-induced conditions, Indian mustard [43] has been successfully used to remove Pb from solution culture and contaminated soil. Baker[44] studied *in situ* heavy metal remediation using plants. The result of present study was clearly indicates that maize and Indian mustard was uptake the Pb chelates in certain concentrations of mine soil except cow dung manure. Similar kinds of plants have already been used in phytoremediation processes i.e. *Alpine pennycress, Ipomea alpine, Haumania strumrobertii, Astragalus racemosus* and *Sebertia.* They have been reported to have a high uptake (bioaccumulation) potential for Cd, Zn, Cu, Co, Se and Ni [45]. Crops like Willow (*Salix viminalis*), maize (*Zea mays*), Indian mustard (*Brassica juncea*) and sunflower (*Helianthus annuus*) too have shown high uptake potential and tolerance to heavy metals [46-47]. On the other hand, Solange Romeiro et al. [48] have reported that *R. communis* is a hyper-accumulator species for Pb and also have great tolerance to lead at lower concentrations. The present study is strongly supported by Kumar et al. [28] who report in metal tolerant index of *J. curcas* from the metal contaminated soils.

The translocation factor is very important for the selection of plants for removing heavy metals and determining the bioaccumulation of heavy metal [49]. The results of metal transfer factor of selected plants correlated with the results reported by Mishra et al. [27], who reported higher translocation and transfer factors in the case of *L. minor* for Cu (0.74) and lower for Zn in *S. polyrrhiza* (0.30) from aquatic environments. Another study was done by Turan and Esring [50] who reported a higher heavy metal uptake by roots of *Brassica napus* L. than shoots. Maize also has better translocation factor for Pb [51] on metal contaminated soil. Nevertheless, Khan et al. [52] studied the importance of metal transfer factor in edible plants from metal contaminated soil and the result suggesting that translocation for LMW (Long term waste water irrigation)-PAHs (polycyclic aromatic hydrocarbons) is faster than HMW(Heavy metal waste)-PAHs in lettuce plants.

5. Conclusions

The results of present investigation highlights the fact that heavy metal concentrations in the mine waste dump as well as farm soil exceeds the permissible limits of Cd and Pb. Out of fourteen plants studied, *V. ungiculata, O. sativa, S. bicolour, S. indium, R. communis, M. uniflorum, G. hirsutum* and *J. curcas* have better phyto-extraction efficiency (Cd and Pb) based on tolerant index, transfer and translocation factors and MREI value in magnesite mine soil. These plants are heavy-metal tolerant and have average metal extraction ability with moderate bioaccumulation factor. Based on these attributes, it can be concluded that these plants are capable of continuous phyto-extraction / phyto-stablization / rhizo-remediation of metals from contaminated soils. The intensive cultivation of these plants in the polluted soils is valuable in reducing pollution, rehabilitate wastelands and create healthy environments.

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