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Assessment of heavy metal contamination of soils and plants in and around open cast mines of Sukinda, India

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ABSTRACT : Mining activities generate huge amount of wastes with extremely high concentrations of heavy metal that have adverse effects on ecosystems and human health. Metal contamination extended several kilometers away from the mine sites probably by wind and water. Native vegetation was directly affected by the pollution. Hence, understanding the dynamic of metals in soil and plants is essential for ecosystem management and risk assessment. The present study was designed to assess the toxic metals *viz.*, lead (Pb), cadmium (Cd), nickel (Ni) and chromium (Cr) present in the soil and plant samples of 18 plant species collected from nearby areas Sukinda chromite mining zone. Samples of soil and plants were collected from six different sites and were analyzed for pH, EC, Cr, Cd, Pb and Ni by pH meter, conductivity meter and atomic absorption spectrophotometer, respectively. Soil pH was slightly acidic in nature and varied from 5.5 to 6.4. Total heavy metal concentrations in soils were in the order of Cr> Ni> Pb> Cd. Cr and Ni exceed the critical limit value of WHO specified standard. Accumulation of metals in the plant species and in their organs varies, e.g. accumulation of heavy metal was higher in stem as compared to leaf. *Ailanthus excelea* Roxb. has highest capability for accumulating Cr in the shoot part as compared to other collected plants. The plants can ideally be used as the possible application in agricultural reconnaissance surveys, reclamation and revegetation of adversely affected mining environment.

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Environmental disturbances resulting from human activities, such as deforestation, land clearing or mining deeply modify the dynamics and functioning of ecosystems (Vitousek *et al.,* 1997). The cessation of such disturbances generally leads to the long-term natural reconstitution of the ecosystem (Holl, 2002). Mining activities generated spoils, effluents and dust with outstandingly large concentrations of heavy metal (Cr, Pb, Cd, Ni, Zn) or metalloids (As) which have adverse effects on biological receptors and ecosystems (Wiegleb and Felinks, 2001). The spatial distribution and degree of contamination is mainly governed by the ways of dissemination of metal pollutants from the source into the environment. In general, mining causes a large amount of destruction of the environment in the form of alteration of the landscape, deterioration of vast land areas, extinction of wildlife, etc. (Ezeaku and Davidson, 2008). In open cast mining large amount of excavated overburdens is dumped on the surface (mine spoils), that may contain various trace metals. Most of these trace metals are toxic in nature and affect the surface and subsurface environment when its concentration exceeds the permissible limit. Weathering of mine spoils, dumped on the surface produces leachate which on interaction with the parent rocks assimilates heavy metals during its subsurface journey. Surface runoff and wind erosion cause increase in concentration of the heavy metals in local biota and have significant effect on the ecosystem that may lead to geo-accumulation and subsequent bio-accumulation and bio-magnifications in the food chain. These heavy metals get accumulated through time in soils and plants and have a negative influence on physiological activities of plants (e.g. photosynthesis, gaseous exchange and nutrient absorption) causing the reductions in plant growth, dry matter accumulation and yield (Suciu *et al.*, 2008). The decontamination of highly metal-contaminated soils by physical or chemical methods is very difficult and costly (Cunningham and Berti, 2000).

Phytoremediation is one of the promising methods for reclamation of these soils by using hyper accumulator plants (Baker *et al.*, 2000; Ghosh and Singh, 2005; Lazaro *et al.*, 2006). For this, detailed studies of the soils and vegetation of such strongly metal contaminated sites and their peripheries are essential for an accurate assessment of the metal toxicity of soils and aerial plant parts with regard to the possible toxic impacts on herbivorous consumers and human health. Such studies are also necessary to provide valuable information for reasoning strategies of land reclamation in metalliferous sites. Only a restricted number of plants from the local flora are able to grow in metalliferous soils. The plant species which have the ability to successfully germinate, grow and reproduce under the adverse affected environments have to be useful for reclamation and revegetation. The reclamation of metal contaminated sites by plants native to toxic areas aims to stabilize the soil, immobilizing trace elements in the rhizosphere and thereby reducing the risks of the dissemination of metalliferous dust by wind, water erosion or by downward water percolation from the root zone.

Hence, an attempt was made to assess the heavy metal accumulation capacity of indigenous plant species in the Sukinda, chromite mine zone of Odisha. It is expected that the results generated from this study will be useful for the complete understanding of the restoration potential of these plants in the phytostabilization of mining areas.

EXPERIMENTAL METHODOLOGY

Site description :

Sukinda lies between latitude 21° 1' to 21° 4' N and longitude 85° 45' to 85° 48' E and is a part of Sukinda valley, Jajpur district, Odisha. Sukinda, ultramafic belt of Odisha forms an E-W trending V-shaped valley bounded by the Daitari and Mahagiri hill ranges of Precambrian quartzites and banded iron formation as shown in Fig. A. Sukinda valley contains about 98 per cent of chromium reserve and it has been exploited mostly by open-cast mining process since 1950. Most of the mines are located in the central part of the valley and are leased to various companies. The ultramafic rocks carry large reserves of chromite ores in the form of thick seams, lenses and pods are extensively altered and laterized (oxidized). As many as ten chromite seams, each several metals in thickness are known in the area and the mineral is being extensively exploited by open-cast mining. Several such

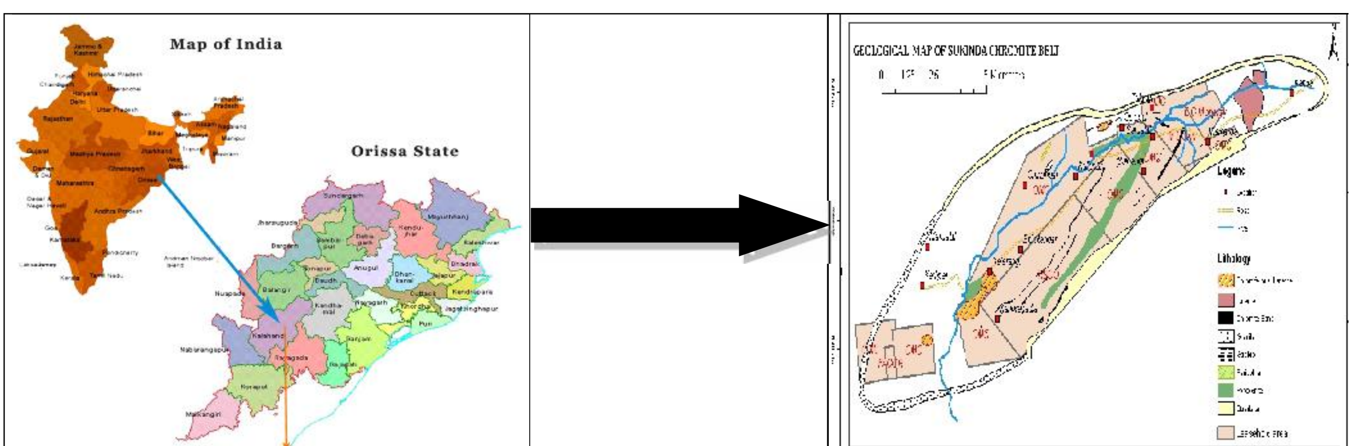

Fig. A : Location map of the study area

chromite quarries are being operated by different agencies in these regions. The giant mining companies are Orissa Mines Corporation (OMC), Indian Metals and Ferro Alloy, TISCO, etc. (Dhakate, 2008). Activities of mining, roasting and smelting of elements has caused disastrous effects on the vegetation and overall environment (Amiro and Courtin, 1981; Gratton *et al*., 2000; Nkongolo *et al*., 2008; Vandeligt *et al*., 2011 and Narendrula *et al*., 2012 and 2013). Assessment of the levels of metal bioavailability and bioaccessibility is critical in understanding the possible effect on soil biota (Ettler *et al*., 2012 and Juhasz *et al*., 2011).

Sampling :

Soil samples were collected from six different zones (unreclaimed overburden dumps and native soil) of open cast mines where local vegetation is already established. The overburden mine spoils are collected by random grid method of 10 m × 10 m grid. In case of the native soil, the samples were collected from 5–15 cm depth (‘A’ horizon) of the top soil, which is usually contaminated by the mine spoil and also affected by air pollution and anthropogenic sources of pollutants. GPS (Garmin) instrument was used to correctly find out the sampling locations in the field. The map of the study site shown in Fig. A. The samples were collected in self-locking polythene bags. To avoid the metal contamination, plastic spatula was used.

Soil analysis :

The soil samples were oven dried for two days at 60 °C at the laboratory, crushed and pulverized to pass through 2-mm sieve. For each soil sample, various physico-chemical parameters such as pH, EC, texture, CEC were analyzed. Heavy metals *viz*., Pb, Cd, Fe, Ni and Cr were also estimated. Soil sample measuring 1 g and 2 g of plant sample was digested in a mixture of concentrated HNO_3, H_2SO_4 and H_2O_2 (2:6:6) as prescribed by Saison *et al*. (2004) for 30 minutes using Microwave Accelerated Reaction System (MARS, CEM®). Towards the end of the digestion, the flasks were brought to near dryness. The solutions were made with 20 ml each in measuring cylinder with double distilled water and examined for heavy metals by AAS at CSIR-

Table A : Brief descriptions of different site of the study area

Location site	Site-1	Site-2	Site-3	Site-4	Site-5	Site-6
Latitude	21 º03’49”N	20 º59’18”N	24 º47’49”N	22 º13’49”N	23º03’49”N	25 º73’49”N
Longitude	85 º 47’32”E	82º19’89”E	83º47’21”E	86º68’29”E	85º47’32”E	81º25’56”E

Table B : List of plant species and family sampled

Species No.	Scientific name	Family
1.	*Cassia alata* (L.) Roxb.	Caesalpinioideae
2.	*Thephrosia purpurea* (L.) Pers.	Fabaceae
3.	*Alstonia schloraris* (L.)R.Br.	Apocynaceae
4.	*Ailanthus excelsa* Roxb.	Simaroubaceae
5.	*Oroxylum indicum* (L.) Vent.	Bignoniaceae
6.	*Catharanthus roseus* (L.)G.Don	Apocynaceae
7.	*Eupatorium odoratum* L.	Asteraceae
8.	*Urena lobata* L.	Malvaceae
9.	*Sida cordifolia* (Burm.f.)Borssum	Malvaceae
10.	*Cassia tora* L.	Leguminosae
11.	*Grewia tiliifolia* Vahl.	Malvaceae
12.	*Schleichera oleosa* (Lour.) Oken	Sapindaceae
13.	*Blumea lacera* (Burm.f.) D.C	Asteraceae
14.	*Phyllanthus amarus* Schum and Thonn.	Phyllanthaceae
15.	*Cleistanthus collinus* (Roxb.)Benth.ex.Hook.f.	Phyllanthaceae
16.	*Acacia auriculiformis* A.Cunn.ex.Benth	Fabaceae
17.	*Saccharum* sp.	Poaceae
18.	*Pteris* sp.	Pteridaceae

IMMT. Mean values of triplicate of each sample of the soil and plant samples were calculated and considered. Soil pH was determined using a portable pH meter (Hanna instrument model 209) in a 1:5 soil–water suspension. Soil electrical conductivity (EC) was measured using a conductivity meter (Hanna instrument model 209).

Plant analysis :

Dominant plant samples (divided into leaf and shoot) from each site were collected. Leaves and stems were collected separately at various points around the circumference of the tree and these are made into a composite sample. Care was exercised to collect matured plant materials that have gone through the main process of mineral accumulation. All plant samples were sealed with polythene bags in the field and transported into the laboratory for further analysis. A total of 18 plant species such as *Cassia alata* Linn., *Thephrosia purpuria* (Linn.) Pers., *Alstonia schloris*. L.R. Br., *Ailanthus excelsa* Roxb., *Oroxylum indicum* (L.) Benth. ex Kurz, *Catharanthus roseus* (L.) G. Don, *Eupatorium odoratum* L., *Urena labata* Linn., *Sida cordifolia* L., *Cassia tora* L., *Grewia tiliaefolia* Vahl., *Schleichera oleosa* (Lour.) Oken., *Blumea lacera* (Burm.f.) D.C., *Phyllanthus amarus* Schum. & Thonn., *Cleistanthus collinus* (Roxb.) Benth.ex Hook.f., *Acacia auricuformis* A. Cunn. ex Benth, *Saccharum* sp., *Pteris* sp., was collected in the month of December, 2013. Before analysis, each plant part (stems and leaves) were carefully removed and washed (for 2-3 minutes approximately) with tap water and with deionized water to remove any soil and surface dust. Plant samples were dried in oven at 80 °C temperature for two weeks pulverized and passed through 2 mm stainless steel sieve. The list of plants collected and their families was represented in the Table B.

EXPERIMENTAL FINDINGS AND DISCUSSION

Soil pH was in the range of 5.5 to 6.3 which slightly acidic in nature. Electrical conductivity varies from 101 to 131 μS^{-1} as shown in Table 1. Heavy metal concentration in the soil was in the range of 0.2817 to 10.267 (Cr), 0.2792 to 10.9041 (Ni), 0.0200 to 6.6755 (Pb) and 0.0068 to 0. 0087 mg/kg (Cd). In the present study, Cr and Ni content in soil was higher as compared to other heavy metals. It might it due the mining operation. The concentration of Cr and Ni was higher as compared to other heavy metals, it may be due the chromite mining operations. The result showed that the concentration of Ni and Cr was beyond the permissible limit (WHO). The heavy metal concentration in soil, shoot and root was shown in Table 2. The distribution of elemental concentrations and the metal uptake in different organs of plant varies widely due to the complex process of metabolism. Each plant species has its own requirements and tolerance to elemental uptake and retention. Generally the plants take up metals to varying degrees from the substrates in which they are rooted and developed and the level of tolerance developed can often be related to the amount of metal in the soil. Plants growing on contaminated soils respond differently on their ability to take in or exclude a variety of metals (Bech *et al*., 2002). The uptake of metals, specially chromium in relation to

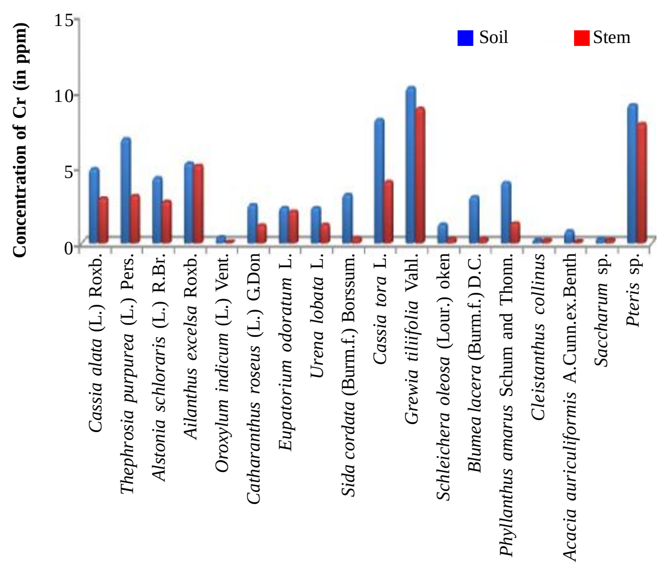

Fig. 1 : Concentration of Cr in rhizospheric soil and aerial parts of plants

Table 1 : Soil pH and EC

Site	Site 1			Site 2			Site 3			Site 4			Site 5			Site 6		
Sample No.	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
pH	6.5	6.2	5.9	6.2	6.3	5.9	6.8	6.2	5.5	5.9	5.8	6.1	5.9	6.0	5.7	6.1	5.5	6.0
EC	102	124	116	105	101	108	111	115	120	131	119	120	124	127	123	109	107	103

Table 2 : Distribution of heavy metals (in ppm) in leaf, stem and soil

Sr. No.	Plant species	Parts	Concentration of heavy metal in mg/kg			
			Cr	Pb	Ni	Cd
1.	*Cassia alata* (L) Roxb.	RS	4.9301	0.0308	9.0191	0.0068
		Stem	2.9869	0.0150	8.1708	0.0064
		Leaf	1.8969	0.0178	0.8406	0.0077
2.	*Thephrosia purpurea* (L.) Pers.	RS	6.8969	1.8293	8.1412	0.0017
		Stem	3.1610	0.0062	1.8027	0.0035
		Leaf	1.0196	0.0494	0.4545	0.0125
3.	*Alstonia schloraris* (L.) R.Br.	RS	4.3327	2.1726	6.7996	0.0057
		Stem	2.7715	0.1974	2.2129	0.0064
		Leaf	0.2817	0.1172	0.4203	0.0074
4.	*Ailanthus excelsa* Roxb.	RS	5.2999	4.8561	10.9041	0.0037
		Stem	5.1539	0.2098	1.7760	0.0098
		Leaf	4.8688	Nd*	0.2226	0.0101
5.	*Oroxylum indicum* (L.) Vent.	RS	0.3910	6.6755	2.2050	0.0068
		Stem	0.0385	0.1851	0.4162	0.0159
		Leaf	1.0234	0.0400	0.1035	0.0112
6.	*Catharanthus roseus* (L.) G.Don	RS	2.5563	0.4442	1.3903	0.0041
		Stem	1.2092	0.3393	0.7617	0.0181
		Leaf	1.7389	0.0350	0.0333	0.0141
7.	*Eupatorium odoratum* L.	RS	2.3740	0.4010	1.4108	0.0066
		Stem	2.1211	0.3208	0.5092	0.0146
		Leaf	1.1324	0.0649	0.3062	0.0122
8.	*Urena lobata* L.	RS	2.3691	1.0949	0.7084	0.0039
		Stem	1.2532	0.2221	0.4498	0.0058
		Leaf	1.1033	0.2036	Nd*	0.0120
9.	*Sida cordata* (Burm.f.)Borssum	RS	3.2380	3.5907	1.2307	0.0057
		Stem	0.3547	0.4010	0.6482	0.0181
		Leaf	1.4159	0.0699	0.0678	0.0069
10.	*Cassia tora* L.	RS	8.1469	1.0350	3.3849	0.0052
		Stem	4.0891	0.5121	1.0254	0.0066
		Leaf	2.8976	0.1851	0.3153	0.0045
11.	*Pteris* sp.	RS	9.1432	2.0050	2.1355	0.0077
		Stem	7.8965	0.9678	1.8743	0.0089
		Leaf	6.8950	0.6754	0.0979	0.0075
12.	*Grewia tiliifolia* Vahl.	RS	10.2671	3.0964	5.1796	0.0081
		Stem	8.9012	0.3987	1.6749	Nd*
		Leaf	7.9182	0.3208	0.8951	Nd*
13.	*Schleichera oleosa* (Lour.) Oken	RS	1.2668	1.0100	0.8265	0.0013
		Stem	0.2720	0.1833	0.0704	0.0086
		Leaf	0.3976	0.1563	0.0846	0.0105
14.	*Blumea lacera* (Burm.f.) D.C	RS	3.0881	0.9150	1.5937	0.0041
		Stem	0.2685	0.1294	0.1526	0.0123
		Leaf	0.3399	0.1186	0.2011	0.0081
15.	*Phyllanthus amarus* Schum and Thonn.	RS	4.0172	0.8649	1.0915	0.0042
		Stem	1.3607	0.1725	0.1939	0.0063
		Leaf	1.4114	0.1132	0.2842	0.0105
16.	*Cleistanthus collinus* (Roxb.)Benth.ex.Hook.f.	RS	0.1712	0.1200	1.3224	0.0059
		Stem	0.1665	0.1348	0.0846	0.0100
		Leaf	0.1482	0.0863	0.0902	0.0088
17.	*Acacia auriculiformis* A.Cunn.ex.Benth	RS	0.8359	0.0970	0.6364	0.0074
		Stem	0.0945	Nd*	0.5193	0.0100
		Leaf	0.1059	Nd*	Nd*	0.0107
18.	*Saccharum* sp.	RS	0.2647	0.0200	0.2792	0.0048
		Stem	0.1981	Nd*	0.0897	Nd*
		Leaf	Nd*	Nd*	Nd*	Nd*

RS.*-Rhizosphere soil; Nd*- Not detectable; Cr-Chromium; Cd-Cadmium; Ni-Nickel; Pb-Lead the soil was shown in Fig. 1. The resulted it was concluded that *Ailanthus excelsa* Roxb. has highest.

Conclusion

The present paper aims to evaluate plant and soil contamination with metals in and around largest mine waste area located in Sukinda of Jajpur district, Odisha. From the result, it can conclude that the indigenous plants can tolerate the mental stress and able to flourish. Hence, they can be ideally used for reclamation. Accumulation of metals varied greatly among plant species and uptake of an element by a plant is primarily dependent on the plant species, its inherent controls and the soil quality (Chunilall *et al*., 2005). The different plant organs show wide variations in respect of accumulation of different elements. The high concentration of an element in one particular organ does not imply that this is the best part of the plant to sample for biogeochemical prospecting. The structure of the sediment has also been considered very important that affect the extent of the metals taken up by the plants. Furthermore, studies are needed to determine the growth performance, biomass production and phytoextraction of metals of these species in metal contaminated soils for their better management, conservation and value addition. From this study, it may be concluded that the *Ailanthus exile* has a special ability to accumulate higher amounts of Cr but there is needs for further studies get extra information on its optimum ability to accumulate the Cr content.

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