Studies on the uptake of heavy metals by selected plant species growing on coal mine spoils in sub-tropical regions of India

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Abstract: The accumulation of heavy metals in naturally occurring plants of herbs, shrubs and trees grown on South Bolanda coal mine overburdens in subtropical region of India were illustrated.. The inter-elemental relationships of different parts of five plant species including herbs, shrubs and trees with the coal mine wastes were studied. From the tree species maximum positive correlation was observed for Cu in stem and leaf of *Trema orientalis*. The stem and leaf of *Haldina cordifolia*, *Diospyrous melanoxylon* and *Ixora arborea* showed positive correlation for Cr, Fe and Cu respectively. Among the shrubs in *Phyllanthus reticulatus,* Cr in stem showed a positive correlation with Cr in leaf. Here among five species of annual herbs, the correlation coefficient for inter elemental variable of whole plant and coal mine spoil for chromium was marked in *Catharanthus roseus*. From the above investigation it was concluded that stabilization of coal mine spoils could be achieved successfully by the plantation of suitable plant species available in native area. [Journal of American Science. 2011;7(1):26-34]. (ISSN: 1545-1003).

Key words: Coalmine spoils, Heavy metal, Inter-elemental relationship, Overburden Positive correlation.

1. Introduction

The ecology of a plant community is greatly influenced by physical and chemical properties of soil, particularly presence of excess and deficiency of mineral nutrients (Miles, 1979). Mining activity has caused serious environmental disaster besides depletion of natural vegetation and land degradation.

Establishment of a vegetation cover is essential to stabilize the bare area and to minimize the pollution problem (Das, *et al*; 1992). To remediate the adverse physical and chemical properties of the sites, the choice of appropriate vegetation will be important (Wong, 2003).

The most critical processes in the ecosystem development include colonization by appropriate selected species, accumulation of nutrients both in plants and soils, changes in soil structure and reduction in toxicity. These critical processes lead to distinct and characteristic flora (Bradshaw, 1983 and Chadwick *et al*., 1987). Harthill and Mc Kell (1979) suggested that geology- soils- plant stability circuit was disturbed by mining. Destruction of soil properties like soil productivity, soil pH, soil texture, low water holding capacity, acidity, lack of nutrients and excess of toxic metals are the major factors for the vegetative stabilization of coal mine waste (Doubleday, 1974). Metalliferous mine wastes usually contain more than one metal and these may occur at toxic concentrations (Samantaray, 1991). Coal mine wastes usually contain more than one metal and some of these might occur at toxic concentrations (Deo, 1992). The effect of single metal on plants or comparison of the toxicity of two metals have been reported in different plant species (Wong and Bradshaw, 1982). In most cases, the plants need low concentrations of minerals like Zn, Cu, Al, Cr for plant growth and metabolism and presence of these in high concentrations may indicate toxicities to plant communities. In mine waste, most of the plants grow well but some species show abnormal growth because of nutrient deficiency and presence of heavy metals (Bradshaw and Chadwick, 1980, Deo, 2005). The uptake of heavy metals by various plant species growing on chromite mine spoils were studied (Samantaray *et al* 1999). High concentrations of heavy metals depressed plant growth but certain mineral elements were required in trace for good and healthy growth (Wong and Bradshaw, 1982) . The aim of the present study is to determine the inter-elemental relationships among selected plant species growing on the overburden spoils of South Bolanda coal mine, Orissa.

2. Material and Methods

Study site

The study site South Bolanda Colliery spreads over 2582.90 acres is located within Latitude 20°54'58" and 20°55'55" and Longitude 85°07'44" and 85°11'39" in South West of NCDC'S (National Coal Development Corporation), Talcher Colliery in

20°57’-85°10’ in Angul district of Orissa. The project became operational in the year 1959 and was brought under revenue account on 1.2.1961. The volume of overburden in the quarriable area has been estimated as 81.35 M.Cu.m. The area is predominantly undulating. The surface elevation varies from 103 meters in the South-East to 154 meters in the North-West above the mean sea level sloping towards south. Rock exposures are limited to few sandstone and pebble beds often stand out as small flat-topped -ridges and knolls. The climate of the area under study is subtropical with seasonal rainfall during the South-West monsoon season from June to October. Occasional rainfall breaks towards in the month of November to January. The annual rainfall ranged from 1000mm to 1500mm. The study was conducted during the three seasons of a year.

Soil sampling

Soil samples were collected from the selected coal mine overburden in different seasons of the year. The soils were collected at a depth of 0.1m by point method from the naturally occurred plants area. Specially prepared pointed bamboo pegs were used to avoid contamination and the collected samples were labelled properly. The samples were powdered by mortar and pestle in the laboratory and sieved by using a 2mm nylon sieve. The powdered samples were kept in plastic containers for elemental analysis.

Plant samples

Plant samples were collected from the coal mining overburden area where dominant number of trees, shrubs and herbs were occurred. The plants were uprooted carefully and were collected by polythene bags. Then they were brought to the laboratory washed with tap water thoroughly and then dipped in 0.1N HCl solution followed by repeated washings in distilled water. The samples were properly dried and cut into small pieces, homogenised by mortar and pestle to avoid contamination and were stored in plastic jars for elemental analysis.

Soil analysis

From the coal mine overburdens 15 samples (20g each) were collected randomly and dried at 70°C for 72 hours in the oven. One gram of dried soil from each sample was taken in a test tube. Concentrated HCl (8ml) and 2ml concentrated nitric acid in ratio of 4:1 were added and kept for over night. Diacid digestion was done on a hot plate at 105°C for 1 hour and then at 140°C until the samples were dried. After cooling, 12ml of 20% HCl by volume were added to it and the mixture was rewarmed at 80°C for 20 minutes. Then after cooling, the solution was mixed with double distilled water and homogenised by a magnetic stirrer and filtered through Whatman 42 filter paper into a 50ml volumetric flask with deionised water (McGrath and Cunliffe,1958). After filteration and dilution the digested solution was analysed for determination of Cu, Fe, Al, Cr by ICP 8410 Plasmascan (Australia) using respective wave lengths for Cu-324.754nm, Fe-238.204nm, Al-396.152nm and Cr-205.552nm.

Plant analysis

Plant samples were washed with distilled water, oven dried at 70°C in the laboratory. Powdered shoot, root and leaf samples (One gram each) of each species of tree shrub and herb (whole plant) were pre-digested in 10ml concentrated nitric acid for 12 hours followed by digestion with 5ml diacid mixture, nitric acid (HNO_3): perchloric acid ($HCLO_4$) in the ratio of 3 : 2. After that the distilled water was added to the digested samples and then filtered by Whatman-42 filter paper (Institute agronomico de St. Paulo,1978) . After suitable dilution, the samples were ready for elemental analysis by ICP 8410 Plasmascan (Australia) by using respective wave lengths mentioned before.

Statistical analysis

The data which were used on various parameters in different experiments depicted earlier were analysed statistically following statistical methods with the help of a IBM-PC computer for interpretation of the results. The significance of the correlation coefficient (r). ANOVA was used in order to establish the significance of variation between treatments at 0.05 levels. Completely Randomised Design was performed.

3. Results:

The natural vegetation of South Bolanda Coal Mine fell under the category of dry- deciduous forest type (Fig.2). The vegetation was comprised of 185 specific taxa belonging to 48 families. .Analysis of coal mine spoils samples revealed pH, 5.5; water holding capacity 11% ; organic carbon (C), 1.53% ; total nitrogen to average 0.06%; available P, 1.24 ppm; K, 125 ppm; Ca, 128 ppm and Mg , 207 ppm. The particle size of the mine spoil was sand 90%, silt 6% and clay 4%. The coal mine waste was acidic and mostly sandy loam in nature with low water holding capacity. The natural occurring plant species exhibited some morphological abnormalities in *Croton bonplandianum* with variegated leaves and clustered terminal, small sized leaves in *Catharanthus roseus*. Dwarfism and modification of floral part with induced sterility and clustering of the leaves at the top were also noted.

The inter elemental relationships of the soil alone were similar in the inter-elemental relationships for plants alone. In the present study, attempts have been made to compare the elemental composition in trees, shrubs and herbs growing at different sites (overburdens) in the mining area that were geologically and physiologically same, but differed in their mine spoil lithology and bioavailability.

The statistical data showed relationships among four heavy metals drawn with a view to study the heavy metal content of the soil and accumulation in leaf and stem of five selected tree species. From the study it was depicted that both positive and negative correlation coefficients were established between Cu, Fe, Al, and Cr in soil and in leaf and stem of *Trema orientalis*, *Haldina cordifolia*, *Diospyros melanoxylon*, *Ixora arborea* and *Tamarindus indica* (Table 1). Maximum positive corelation was observed in stem and leaf of *Trema orientalis* for copper. In *Haldina cordifolia*, chromium in stem showed relationship with chromium in leaf. In *Diospyros melanoxylon*, iron in stem and leaf had a positive relationship with a correlation coefficient study having (r = 0.886; P=0.05). In *Ixora arborea*, positive relationship was observed between chromium in stem and chromium in leaf. In *Tamarindus indica*, copper in the stem showed a positive correlation with copper in the leaf.

Here the result showed the relationship between elemental status of copper, iron, aluminium and chromium in soil and in leaf and stem accumulation of five selected shrub species. Correlation analysis revealed that there was no positive significant correlation marked between Cu, Fe, Al, and Cr and vegetative parts i.e, stem and leaf of *Chromalaena odorata, Calotropis gigantea, Woodfordia fruiticosa, Cassiaria elliptica and Phyllanthus reticulatus*. The data in the basis of bivariate correlation coefficient studies indicated that copper in stem had shown a significant positive correlation (r = 0.892; P=0.05) with copper in leaf of *Chromalaena odorata* (Table 2). Other metals, however did not show any significant relationship in other species like *Calotropis gigantea*, *Woodfordia fruiticosa, Cassiaria elliptica.* But in *Phyllanthus reticulatus*, chromium in stem had shown a positive correlation with chromium in leaf (r = 0.967; P = 0.05). Correlations for inter-elemental (Cu, Fe, Al, and Cr) analysis of whole plant of five selected herb species are presented in Table 3 and Table 4. The correlation coefficients analysis revealed that there was no significant correlation for copper, iron, aluminium, and chromium in whole plant of the species like Croton bonplandianum, Catharanthus roseus, Hyptis suaveolens, Solanum xanthocarpum and Tridax procumbens (Table-3).

Table 1: Correlations for inter-elemental variables between stem, soil and leaf in different tree species grown on coal mine overburden spoils of South Bolanda

Species	Element Corr. Coef. (r)	Stem vs soil Corr. Coef. (r)	Leaf vs soil Corr. Coef. (r)	Stem vs leaf Corr. Coef. (r)
Trema orientalis	Cu × Cu Fe× Fe Al × Al Cr × Cr	– 0.210 0.349 0.046 0.205	– 0.003 –0.018 0.466 –0.218	0.950* 0.803 0.167 –0.063
Haldina cordifolia	Cu × Cu Fe× Fe Al × Al Cr × Cr	–0.607 –0.558 0.275 –0.712	–0.658 0.752 0.529 – 0.598	0.636 –0.016 0.828 0.923*
Diospyros melanoxylon	Cu × Cu Fe× Fe Al × Al Cr × Cr	0.470 –0.032 0.328 –0.289	–0.305 –0.473 –0.085 0.629	0.251 0.886* 0.805 –0.224
Ixora arborea	Cu × Cu Fe× Fe Al × Al Cr × Cr	–0.187 0.789 –0.445 –0.114	0.695 0.268 0.042 –0.383	0.460 0.209 0.809 0.952*
Tamarindus indica	Cu × Cu Fe× Fe Al × Al Cr × Cr	–0.640 –0.693 –0.476 0.078	–0.486 –0.072 0.119 0.643	0.911* 0.629 0.686 0.750

Table 2. Correlation for inter elemental variables between soil, stem and leaf in different shrubs grown on coal mine overburden spoils of South Bolanda

Species	Element Corr. Coef. (r)	Stem vs soil Corr. Coef. (r)	Leaf vs soil Corr. Coef. (r)	Stem vs leaf Corr. Coef. (r)
Chromalaena odorata	Cu × Cu	0.575	0.244	0.892*
	Fe× Fe	0.010	0.213	0.433
	Al × Al	–0.480	0.697	0.784
	Cr × Cr	0.225	–0.647	0.330
Calotropis gigantea	Cu × Cu	–0.947	0.066	0.015
	Fe× Fe	–0.453	–0.898	0.631
	Al × Al	0.139	0.625	0.087
	Cr × Cr	0.075	– 0.421	–0.934
Woodfordia fruiticosa	Cu × Cu	0.299	– 0.379	–0.160
	Fe× Fe	0.393	0.421	0.827
	Al × Al	– 0.334	– 0.334	0.093
	Cr × Cr	0.100	0.603	0.228
Cassiaria elliptica	Cu × Cu	–0.453	–0.299	0.703
	Fe× Fe	–0.446	– 0.875	0.656
	Al × Al	–0.359	0.512	0.348
	Cr × Cr	0.487	0.019	0.726
Phyllanthus reticulatus	Cu × Cu	0.549	–0.188	0.206
	Fe× Fe	–0.173	–0.387	0.624
	Al × Al	0.387	–0.623	–0.068
	Cr × Cr	0.604	0.479	0.967*

Table 3.Correlation for inter-elemental variables between whole plants (herbs) grown on the coal mine overburden spoils of South Bolanda

Species	Element Corr. Coef. (r)	W. P vs W.P Corr. Coef. (r)
Croton bonplandianum	Cu × Fe	–0.626 –0.601
	Cu × Al	–0.609
	Cu × Cr	
	Fe × Al	–0.046
	Fe × Cr	–0.335
	Al × Cr	0.732
Catharanthus roseus	Cu × Fe	– 0.429 0.224
	Cu × Al	–0.283
	Cu × Cr	
	Fe × Al	0.217
	Fe × Cr	0.533
	Al × Cr	–0.671
Hyptis suaveolens	Cu × Fe	– 0.215
	Cu × Al	0.296
	Cu × Cr	0.576
	Fe × Al	0.856
	Fe × Cr	0.104
	Al × Cr	0.373
Solanum xanthocarpum	Cu × Fe	0.007
	Cu × Al	0.249
	Cu × Cr	0.533
	Fe × Al	0.774
	Fe × Cr	–0.323

	Al × Cr	–0.070
Tridax procumbens	Cu × Fe Cu × Al Cu × Cr Fe × Al Fe × Cr Al × Cr	–0.871 0.146 0.003 –0.168 –0.317 0.321

Table 4.Correlation for inter-elemental variables between whole plants (herbs) and soil grown on coal mine overburden spoils of South Bolanda

Species	**Element Corr. Coef. (r)**	**W. P vs soil Corr. Coef. (r)**
Croton bonplandianum	Cu × Cu Fe × Fe Al × Al Cr × Cr	–0.248 0.281 0.019 –0.344
Catharanthus roseus	Cu × Cu Fe × Fe Al × Al Cr × Cr	–0.401 –0.729 –0.159 0.833
Hyptis suaveolens	Cu × Cu Fe × Fe Al × Al Cr × Cr	0.364 –0.432 –0.667 0.047
Solanum xanthocarpum	Cu × Cu Fe × Fe Al × Al Cr × Cr	–0.247 0.615 0.103 0.339
Tridax procumbens	Cu × Cu Fe × Fe Al × Al Cr × Cr	0.794 0.065 0.537 0.273

Fig.1: Coalmine overburden of South Bolanda

Fig.2: Coalmine overburden with sparse vegetation (South Bolanda)

4. Discussion:

The overburden exhibited a poor vegetational cover with greater dominance of herbaceous members. The vegetation of old dumpsites were comparatively richer with the establishment of large number of shrubs and arboreous members with stunted growth .Similar type of vegetation distribution was observed in different coal mine sites and reported by several workers (Wali and Freeman1973, Glenn-Lewin, 1979, Jha and Singh, 1990). High amount of Fe, Mn, Ni, Mg, Al and Sulphate and poor supply of Ca, K, P and N resulted in sparse plant strands and retarded plant growth (Barnhisel and Massey, 1969). The coal mine wastes was generally acidic in nature having low water holding capacity was also noted in many coal mine spoils (Mays and Bengston, 1978, Pederson *et al*., 1980). Distribution, growth and sparse occurrence of plant species on coal mine spoil due to low nutrient and low water holding capacity was reported earlier (Deo, 1992). The natural occurring plant species exhibited some morphological abnormalities in some plant species due to sandy soil nature, low nutrient availability, presence of heavy metals and bituminous coal products of the South Bolanda coal mine spoils (Sahu *et al*., 1989).

Data on elemental composition in the plant species growing at different mine sites showed variation (Erdman and Gough, 1979, Gough and Severson,1989). The inter elemental relationships of the soil alone were similar in the inter-elemental relationships for plants alone.

Comparison of concentrations of different elements in plant and soil showed that some of the trees, shrubs and herbs could be useful in geochemical prospecting .The statistical data showed relationships among four heavy metals drawn with a view to study the heavy metal content of the soil and accumulation in leaf and stem of five selected tree species. Various interactions of heavy metals between plant and soil were studied. (James and Bartlett, 1984). The same trend was observed by (Gartside and McNeilly, 1974) studied plants differed remarkably in their metal contents on metal enriched soils. Accumulation of heavy metals by higher plants in metalliferous soils was also studied (Maywald and Weigel, 1997). Transport and accumulation of heavy metals in different plant species have been reported earlier in other mine spoils(Haritonidis and Malea,1995).

Elemental composition on the plant species growing at different mine sites showed variation (Munshower and Newman,1980; Erdman and Gough, 1979; Gough and Severson,1981). Here the result showed the relationship between elemental status of copper, iron, aluminium and chromium in soil and in leaf and stem accumulation of five selected shrub species. Similar trend of observation was reported (Lyon *et al*., 1968).The distribution of heavy metals in different plant parts were reported earlier (Bower and Melhuish, 1988). Uptake of heavy metals by various plant species (trees, shrubs and herbs) in chromite spoils were studied (Samantaray *et al.*, 1999) . From the correlation analysis it was concluded that there was no significant relationship in uptake of heavy metals from the soil to the vegetative parts of the plant. It might be due to the limited supply of heavy metals from soil to plant (Newman *et al* , 1985).The physiological mechanism of the effects of heavy metals on different plant species is still not clear, though there is evidence that most metals produce a similar kind of metabolic disturbance. A leaf necrosis appears which is specific to a particular metal, but there is also a general chlorosis of the younger leaves common to all metals (Bradshaw *et al* 1978*)*

From the five numbers of herb plant species the maximum correlation coefficient was observed in whole plant and soil for chromium in Catharanthus roseus (r=0.833; P=0.05) (Table 4). The distribution of heavy metals in different parts of plant species were reported (Lyon et al., 1968, Samantaray et al., 1999).

Thus among the various sample studied, there could be a range of genetically different plant species comprising of trees, shrubs and herbs which adapted to their own level of soil metal status or with a specific elemental uptake. It would appear that genetic variation was a minor factor where high concentration of an element was found. Cu and Fe were essential elements, and could have favourable growth; where as Al and Cr might be some concerned. From this study it was concluded that there was no correlation coefficient among the mine spoil and natural occurring plants. Overall the coal mine overburden soil is non toxic to plants. The success of reclamation schemes is greatly dependent upon the choice of species and their method of establishment. Many factors have to be considered in the choice of plant materials in particular the nature of the soil, the prevailing climate and the choice of eventual land use. So it is recommended that the plantation of suitable trees and shrubs could be come out successfully in the barren overburden of the coal mining area. The long term effects of the accumulation from the soil and their uptake by plants need further study.

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