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Research Paper

Heavy Metal Content and Physico-Chemical Characteristics of Soils in Open Forest and Crop Fields Near Bhusan Sponge Iron Plant in Sambalpur District of Odisha, India

Environment

KEYWORDS : Heavy metal, Physico-chemical properties, Top soil, Availability of heavy metals

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ABSTRACT

The present study assessed heavy metal contents in the soil with special reference to Cr, Ni, Cd and investigated the soil physico-chemical properties in the neighborhood of a sponge iron plant (open forest and crop fields). Standard laboratory procedures were adopted in analyzing the soils and the data obtained were subjected to analysis of variance and correlation analysis. The experimental sites showed improvement in terms of clay fraction, bulk density and water holding capacity. However the contents of heavy metals were significantly higher in these sites when compared to unpolluted control site. The highest metal contents were 6.45ppm and 6.17ppm for Cd, 435.0ppm and 427.5ppm for Ni, and 1297.5ppm and 1192.5ppm for Cr at 1.5 km distance in the top soil of both open forest and crop fields respectively. In the control site the Cd, Ni, and Cr contents were 0.12, 13.48, and 28.75 respectively. Though high in potassium and phosphorus, the experimental sites were poor in organic carbon and total nitrogen. Highly positive correlation was observed between heavy metals and clay, organic carbon and pH of the contaminated soil indicating easy availability of the heavy metals for the vegetation. Thus it is highly essential to take immediate remediation measure in order to protect the health of flora and fauna in these areas.

INTRODUCTION

Sponge iron is a product made from reduction of iron and is used as a raw material in making steel. Most of sponge iron plants in India are coal- based and are concentrated in the central eastern belt of the country including Odisha because of the easy availability of iron and coal. This industry is considered as polluting industry due to emission of dust and gas to the atmosphere containing significant amount of nickel, hexavalent chromium, cadmium, arsenic, manganese and copper which ultimately reaches to soil and surface water (Khan and Khan 1996). Right from raw material yard to dispersal of final product of sponge iron, at every step of its handling there is pollution due to dust and gas emission with significant content of toxic metals (Bandopadhaya et al. 2005). The coal fly ashes occupy more space in the premises of industrial plants and are mixed with water to discharge into fly ash settling ponds or land fills. Large quantities of coal fly ashes are stored in the form of waste heaps or deposits, whose contamination poses a serious threat to the environment as a major source of inorganic pollution. The behaviour of many metal pollutants and the release of such metals during storage can have deleterious effects on the environment as well as on human health (Yuan et al., 2009). Metals present in the ashes are originated from the composition of the coal used in combustion, combustion conditions, removal efficiency of air pollution control device and method of coal fly ash disposal (Carlson and Andriano, 1993).

The ecological problem of soil degradation due to sponge iron industry is of extreme importance in present global scenario. Metals entering the soil constitute a more lasting form of pollutants due to their accumulation in soil. Once the metal enters the soil, there is uptake by the plants, some amount is immobilised in the soil matrix and rest moves with water to ground water sources (Hapke, 1991; Dudka et al. 1994). Most problems of soil pollution are associated with large amount of heavy metals deposited on it through disposed waste. These metals which are not biodegradable are accumulated in living organisms when released into the environment. Although trace quantities of certain heavy metals are essential to animals and plant growth, they are of considerable environmental concern due to their toxicity and cumulative behaviour (Perkins, 1974). The contamination of soil by heavy metals thus negatively influences the soil characters and environmental functions. The study of heavy metals in soil is of great concern not only for their toxicity to soil biota but also their immobilisation with different organic and inorganic colloids. In the immobilised form they can persist for long time before being again available to living organisms including plants (Nanipieri et al. 1997). Soil is a slow moving medium and the heavy metals migrate in it slower than they do it in water air; because of which these toxicants increase gradually (Vladisalv et al. 2003). Toxic heavy metals in the air like Cr, Cd, Ni are human carcinogens that manifest after several year of exposure (Jena M, 2010) Therefore the present investigation aimed at analysing the physico-chemical properties of soils in neighbourhood of sponge iron industry and quantifying the heavy metal contents in these soils with special reference to Cr, Ni and Cd.

MATERIALS AND METHODS

Study area

The present study was confined to the areas in the neighbourhood (open forests and crop fields) of Bhushan steel industry. The site is located between latitude $21^0 44'$ to $21^0 46'$ N and longitude $84^0 01'$ to $84^0 03'$ E at Rengali Block of Sambalpur district of Odisha. The mean annual rainfall is 1460.8mm and most of its fall during monsoon season which lasts from June to September. The relative humidity varies from 21 to 87%. The major prevailing wind direction is north- east.

The soil sampling was carried out in premonsoon (April) and postmonsoon (October) period of 2010. As the predominant wind direction in April and October was north- east, east and south -east, the sampling sites were chosen in these directions. The distances between the emission sources and sampling sites along with land use systems of the sampling sites are shown in table 1 and figure 1. All these sites(Open forest at 1km and 1.5km, crop field at 1.5km, 2.0 k, and 2.5 km) are considered as experimental sites in the present study. As there was intermingling of pollutants released from the stacks of other industries and that of the Bhushan sponge iron industry beyond 3km, the sampling sites were selected up to 2.5km away from the emission source. The control site was open forest and crop fields present at Burla which was present at 32 km distance away from Bhushana sponge iron plant and free from the impact of sponge iron industry waste.

Soil sampling
Soil samples were collected from top soil (0-10cm) at four points from each site, air dried, gently crushed and sieved through 2mm sieve and then used for different analysis.

Laboratory analysis
The laboratory analyses were conducted for soil texture by using hydrometer (Bouyoucos 1962), bulk density and water holding capacity following the method prescribed in TSBF hand book (Anderson and Ingram 1992), soil pH by pH meter using 1:2 soil water suspension, the organic carbon content by Walkely and Black's titration method (Walkely and Black 1934), total nitrogen (TN) by Kjeldhal method (Jackson 1973), available potassium and sodium by flame photometer using ammonium acetate method (Hanway and Heidel 1952), the total phosphorus by Bray and Kurtz (1945). The heavy metal content in the soil samples were analysed by AAS (Perkin Elemer-3110) after digesting the samples with conc. Hydrochloric acid, Perchloric acid and nitric acid. Soil physical properties and heavy metal study was done during premonsoon period.

Data analysis
The generated soil data were subjected to one way analysis of variance (ANOVA) and means were separated using least significance difference (LSD) at 5% probability level. The heavy metals were correlated and regressed against selected soil properties and their correlation coefficient was obtained. All these statistical analyses were carried out using Microsoft Office Excel, 2007.

RESULTS AND DISCUSSION
Heavy metal contents
Heavy metal contents in respect to Cd, Ni, and Cr in control and experimental sites are illustrated in Table 2 and Table 3 respectively. The data revealed significantly high Cd, Ni and Cr content in experimental sites than control sites ($p < 0.001$). The highest metal contents were 6.45ppm and 6.17ppm for Cd, 435.0ppm and 427.5ppm for Ni, and 1297.5ppm and 1192.5ppm for Cr at 1.5 km distance both in open forest and crop fields respectively. However LSD analysis indicated no significant difference between different experimental sites. As per WHO/FAO (2007) and Awashthi (2000), different heavy metal contents in the experimental fields were much more than Indian standards for safe limits of heavy metals in soil (3-6ppm for Cd, 75-150ppm for Ni) though for Cr safe limits has not yet been determined. As per European Union Standards (EU 2002) the safe limit for Cr is 150ppm. Pradhan (2008) reported maximum Cd content of 0.3 ppm, and Cr contents of 67.9 ppm in crop field soil surrounding areas of an aluminium industry at Hirakud town of Sambalpur district which is also a coal-based industry and the amount was much less than the present experimental sites which is also coal-based . In the present study highest heavy metal contents were seen at 1.5km distance from the emission source.

Physical properties of soil
The textural composition of soils collected from open forest and crop fields in the neighbourhood of Bhushana sponge iron industry are presented in table 4. The clay percentage was 9.19%, 9.72% at 1 km and 1.5 km distance respectively in the open forest which was significantly higher than control (7.5%) at $p < 0.001$. In crop fields highest clay content of 9.69% was found at 1.5 km of the experimental sites in comparison to control (8.0%). However the differences of clay contents of control and experimental crop field soil was not significant. The textural composition of natural forest and the soil collected from neighbourhood areas of Bhushan steel plant was loamy sand type. However, significantly high clay content in the experimental soil is supposed to have been contributed by considerable amount of fly ash deposition in these areas. Soil bulk density ranged from 1.28-1.32 in open forest and 1.29-1.32 in crop field soil. Comparatively low level of soil bulk density at 1.5 km distance might be due to reduction of soil compactness contributed by development of soil micro pore space which in turn contributed by highest level of clay fraction in these sites and there by achieving highest water holding capacity.

Chemical characteristics
Results of some selected chemical properties of open forest and crop field soil in premonsoon and postmonsoon period are presented in Figures 2 and Figure 3. The pH of control forest soil was moderately acidic in premonsoon (5.42) and postmonsoon (5.62) while in experimental sites the pH was moderately alkaline ranging from 7.6 (at 1km) to 8.2 (at 1.5km) in premonsoon and 8.4 (at 1km) to 7.6 (at 1.5km) during postmonsoon period. The difference between control and experimental sites as well as between different distances was found to be significant (LSD = 0.61). The soil pH of the control crop field soil was found to be slightly alkaline (7.48) both in premonsoon and postmonsoon in contrast to the pH of three experimental sites which were moderately alkaline ranging from 8.21 to 8.26.The pH of the three experimental crop field sites were significantly higher than control (LSD =1.64), though between experimental sites the difference was not significant. However during postmonsoon, slight alkalinity was recorded in both control and experimental sites but the difference was not significant. Rain usually leaches basic elements from soil and thus lowers the pH during postmonsoon period. Plank and Martens (1974) reported that the pH of fly ash generated from coal combustion varies from 4.5 to 12 depending on the sulphate content of the parent coal and the type of coal used for combustion. This indicates the alkaline nature of fly ash deposited in the vicinity of sponge iron plant which is supposed to be responsible for higher pH level in these areas. The organic carbon (OC) content of open forest soil at 1 km (0.78g %) and 1.5km (1.06g %) distance from the source of emission was found to be significantly lower than natural forest soil (1.87g %) during premonsoon as well as postmonsoon (1.97g %, 0.998g % and 1.07g % in natural forest, in 1km and 1.5 km distance respectively). In crop field soil the OC content was significantly lower at 2km (0.99 g %) and 2.5km (0.99g %) distance than the control (1.06 g %) during premonsoon. However during postmonsoon the OC content of different sites was not significant. In both land use systems significantly high total nitrogen (TN) was recorded in control site (1688mg/kg and 2011mg/kg in open forest and 1206mg/kg and 1304mg/kg in crop fields during premonsoon and postmonsoon respectively). In experimental sites TN content of soil ranged from 207mg/kg in crop field at 2.5km to 357mg/kg in crop field at 1.5 km distance. Hodgson and Hollyday (1966) reported that the oxidation of OC and TN during combustion of coal drastically reduces their quantity in the flyash. Thus the low OC and TN content in the experimental sites indicate substantial deposition of fly ash in these areas. Na contents were least in experimental sites (275.5ppm and 221.5ppm at 1km and 1.5km distance during premonsoon, 102ppm at 1km and 120.9ppm at 1.5km during postmonsoon in open forest) when compared to control (625.07 and 478.9 during pre- and postmonsoon period respectively). In crop fields the difference in Na content between control and experimental sites was insignificant. The low Na content during postmonsoon than premonsoon in all sites might be due to leaching of the base during rainfall and low Na content in experimental sites might be due to low Na content in fly ash. Significantly high K was found in all the experimental sites ranging from 787ppm to 4707.25ppm indicating the fly ash to be a rich source of K. Page et al. (1979) reported that the coal fly ash was rich in K ranging from 1500ppm to 35000ppm. Highest K content in crop fields was supposed to be contributed by fertilizer application in those fields in addition to fly ash deposition. Significantly high ($F = 9.88$, $p < 0.01$) total phosphorus (TP) was recorded in experimental open forest soil (303.8ppm at 1km and 297.5ppm at 1.5 km) in comparison to control soil (193ppm) during premonsoon. However during the postmonsoon the TP level of control site (366.7ppm) was significantly more ($F = 39.92$, $p < 0.001$) than the experimental sites (128ppm and 115.7ppm at 1km and 1.5km distance respectively). In crop fields the difference was insignificant. Considerably high TP in crop fields during postmonsoon might be due to release of phosphorus by decomposition of organic matter and comparatively low TP during premon-

soon reflects the left over phosphorus after crop uptake and harvest. Reverse condition in open forest i.e. high TP during premonsoon might be contributed by substantial quantity of fly ash deposition as fly ash contains appreciable amount of TP (Sharma and Kalra, 2006). Low TP content in open forest soil during postmonsoon indicated activated decomposition process and higher uptake rate by the vegetation.

Cr, Ni and Cd availability in relation to selected soil properties in experimental soil

Alloway (1995) reported that clay minerals, organic carbon, and pH are likely to be the most important factors affecting heavy metal adsorption by soils. YiFan et al. (2009) observed a significant positive correlation between heavy metals like Cu, Zn, Ni, Pb, Cr and Cd with clay content, CEC and organic carbon in soils. Therefore an attempt was made in the present study, to find out the relationship between Cr, Ni, and Cd with clay percentage, organic carbon and pH. As highest contents of heavy metals in this study were found at 1.5 km (Table 3) distance from the stack of Sponge Iron Industry in open forest, the correlation was done taking the data of different parameters from this site and presented in the figure 4. The results indicated highly positive correlation of heavy metals with clay fraction, organic carbon and pH of soil. Salmasi and Tavasoli (2006) explained that heavy metals remained in top soil layer as a result of chemical reaction between heavy metals and organic matter and firm binding with these components. The correlation observed in the present study could be attributed to the fact that heavy metals remains in top layer as a result of chemical reaction between heavy metals and organic matter and firm binding with these components as reported by Salmasi and Tavasoli (2006) at South of Teheran.

CONCLUSION

Low OC, TN, available Na and significantly high heavy metals like Cr, Ni, Cd above the safe limit for Indian soils near the Bhushan Sponge Iron Industry indicates that the emission and deposition of fly ash from the stacks of the industry have adverse effects on the soil at these areas. Though improvement of soil condition by fly ash addition has been well documented by several authors (Maiti et al. 1990; Grewal et al. 2001; Garg et al. 2003), yet, besides rich in several nutrients, the fly ash also contains toxic heavy metals. The present study indicated improved soil physical properties in terms of increased clay content and water holding capacity in the experimental sites. However, the heavy metals showed positive correlation to clay, organic carbon and pH of top soil indicating that these parameters were responsible for heavy metal retention in the top soil. This process contaminates the neighbourhood areas of this industry. Further, the deposition of coal dust and fly ash on leaves was observed at a distance of 1 to 2 km away from the emission source which suggests that prodigious volume of such dust and ash have been deposited on soil over time. Thus there is the need for remediation of the contaminated soils in order to protect the health of vegetation and human beings in these areas.

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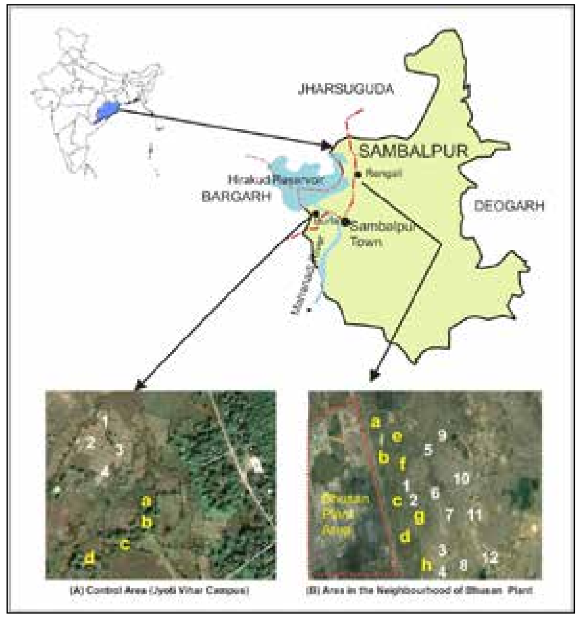

Fig. 1 (a) Control area at Jyoti Vihar Campus where a, b, c, d represent sampling points of open forest and 1, 2, 3, and 4 represent sampling points of crop fields (b) Area in the neighbourhood of Bhushan Plant where a, b, c, d represent sampling points of open forest area at1 km. and e, f, g, h represent sampling points of open forest area at 1.5 km distance from the stack. 1, 2, 3, 4 represent the sampling points of crop fields at 1.5 km, 5, 6, 7, 8 represent that at 2 km and 9, 10, 11, 12 represent the sampling points of crop fields at 2.5 km away from the stack of Bhushan Plant

Fig. 2 Chemical characteristics of open forest top soil at 1.0 km 1.5 km distance away from the stack of sponge iron plant during premonsoon and postmonsoon period

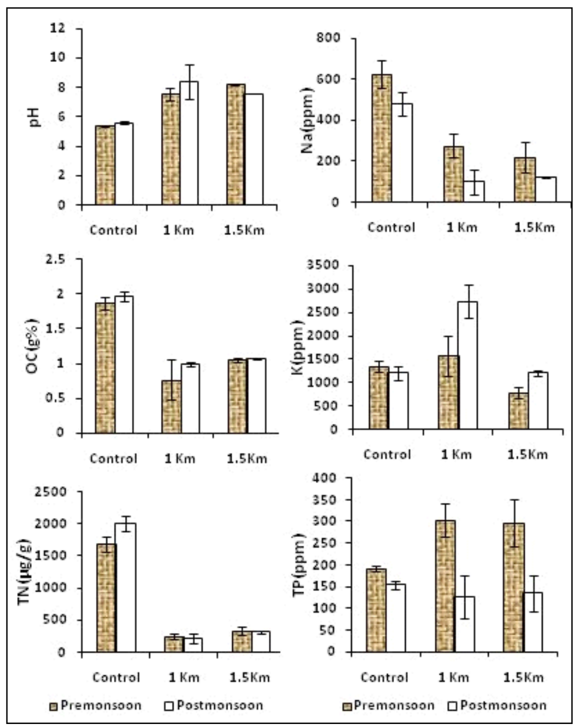

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Fig. 3 Chemical characteristics of crop field top soil at 1.5, 2.0, 2.5 km distance away from the stack of sponge iron plant during premonsoon and postmonsoon period.

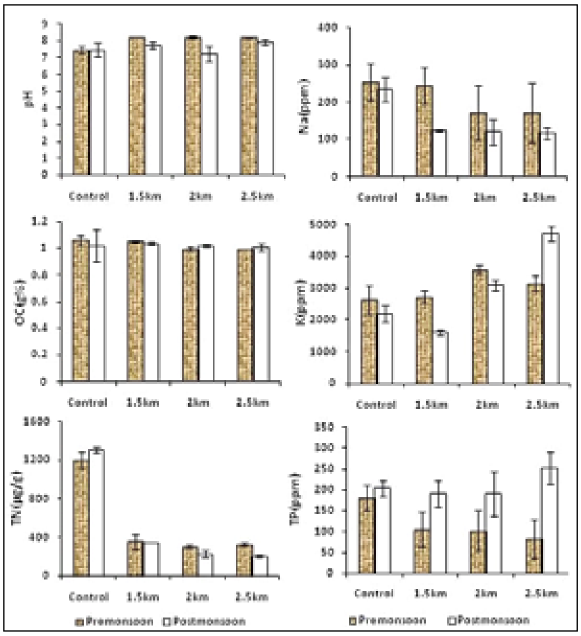

Fig. 4 Correlations of Cr, Ni, Cd with clay, organic carbon, and pH of soil at 1.5 km distance from the stack of sponge iron plant

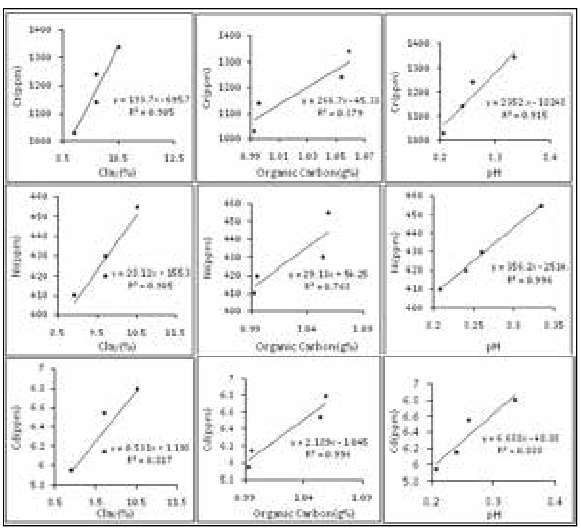

Table 1: Descriptions of the experimental sites

Land use systems	Experimental sites	Distance of experimental sites from emission source	Wind direction
Open forest	I	1km	NE, E, SE
	II	1.5km	NE & SE
Crop fields	I	1.5km	NE & E
	II	2km	NE & E
	III	2.5km	NE & E

Table 2: Heavy metal concentrations in soil collected from open forests present at 1 and 1.5km away from the stack of Bhusana sponge iron factory

Depth	Distance	Heavy metal content (ppm)		
		Cd	Ni	Cr
0-10cm	Control	0.12±0.04	13.48±3.9	28.75±5.89
	1.0km	6.36±0.38	428.75±19.3	1187.5±133.0
	1.5km	6.45±1.2	435.0±28.3	1297.5±60.1

Table 3: Heavy metal concentrations in soil collected from crop fields present at 1.5, 2 and 2.5km away from the stack of Bhusana sponge iron factory

Depth	Distance	Heavy metal content (ppm)		
		Cd	Ni	Cr
0-10cm	Control	0.19±0.09	15.67±3.77	58.77±7.5
	1.5km	6.17±1.6	427.5±3.5	1192.5±35.35
	2.0km	5.7±0.4	417.5±5.0	1170.0±48.8
	2.5km	5.6±0.68	115.0±24.8	1076.3±203.7

Table 4: Some physical properties of control and experimental sites

Land use pattern	Sites	Sand (%)	Silt (%)	Clay (%)	Bulk density(g/cc)	WHC[a] (%)
Open forest	Control	86.1	6.4	7.5	1.41	38
	1.0km	86.1	3.71	9.19	1.32	42
	1.5km	87.57	3.71	9.72	1.28	44
Crop fields	Control	80.6	11.4	8.0	1.38	39
	1.5km	87.1	3.21	9.69	1.29	43
	2.0km	88.0	2.39	9.61	1.32	41
	2.5km	87.9	2.5	9.6	1.32	40

[a] Water Holding Capacity, n = 4

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