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Heavy Metal Translocation in Soil Near to the Effluent Discharge Channel of Industrial Complex, West Bengal, India

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Abstract: The present study focuses on the heavy metal translocation and its potential impact on soil contamination near to the industrial effluents discharge channel. Metal concentrations in contaminated soil are considerably higher than background levels and decreases with increasing depth and distance from effluent channel. A significant correlation between heavy metals and soil physical factor was observed in both vertical and lateral direction. The enrichment of heavy metals in vertical direction are Fe > Cr > Mn > Cd > Cu > Pb > Zn > Ni whereas in lateral direction Fe > Cr > Mn > Pb > Cu > Zn > Ni > Cd. Concentration factor (CF) was very high for Fe and Cr compared to other metals. Pollution Load Index (PLI) of soil samples shows highest metal accumulation at surface soil, nearest to wastewater channel. Fe, Cr, Mn and Zn were found to be present in greater amounts in comparison to Pb, Cu, Cd and Ni. The results indicate that heavy metal concentration in surrounding soil is highly influenced by discharge of untreated effluents from sponge iron industries which is expected to increase with time due to geoaccumulation.

Key words: Soil contamination, industrial wastewater, concentration factor, Pollution Load Index.

Introduction

Industrial wastewater is recognized to have a direct impact on physico-chemical properties of soil and may also lead to accumulation of heavy metals in the soil. Heavy metals in soil are of great environmental concern due to their toxicity, bioaccumulative tendency, threat to human life and environment (Igwe and Abia, 2003). Metals added in small concentrations find specific adsorption sites in soil where they remain very strongly, either on inorganic or organic colloids (Sauve et al., 2000). General observation shows that there is a significant increase in the total content of the heavy metal in soil closer to the source, which clearly decreases with increasing depth (Jaradat et al., 2005; Iwebue et al., 2006) and distance (Kashem et al., 1999; Gupta et al., 2007). Metals present in wastewater not only remain in the effluent channel but they are distributed into the soil due to the wastewater leaching and heavy metals movement. The amount of heavy metals mobilized in a soil environment is a function of pH, clay content, organic matter, CEC (cation exchange capacity) and other soil properties (Kimberly and William, 1999). It also depends on the metal concentration in wastewater and their comparative-synergistic effects on each other.

Sponge iron industries are one of the most profitable industries due to its nature of manufacturing process. But a rapid increase of sponge iron and ferro alloy industries particularly in the eastern region of India, in state West Bengal, leads to deterioration of local environment. These

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industries do not have proper effluent treatment measures and discharge their effluent through a commonly united unlined effluent channel to adjoining land. A number of studies were performed on the effects of industrial effluents on soil quality and heavy metal contamination (Sharma et al., 2007; Rusan et al., 2006; Gupta et al., 2007). The present investigation deals with the accumulation of metals in soil near to industrial effluent discharge channel and their subsequent vertical and lateral translocation through the soil.

Materials and Methods

Study Area

The field study (Figure 1) has been done on Mangalpur industrial complex (Latitude 23°37′N and Longitude 87°08′E) comprising a number of sponge iron and ferro alloy industries, located at the eastern part of West Bengal. This area is under lateritic soil zone with coal mining activities in the past; with the end of mining the surrounding land has been converted into industrial estate. This industrial complex has been on a run for last nine years using iron ore as major ingredients for manufacture of sponge iron containing major elements, like, oxides of Fe (57–59%), Cr (0.6–0.7%) and Mn (0.2–0.4%).

Sampling Strategy

The wastewater samples are collected from different sites of effluent channel on monthly interval basis in plastic bottles; wastewater preservation and analysis are done as per standard method (APHA, 1998). Twelve soil samples were collected at different sites (Figure 1) along the effluent discharge channel. Soil samples were collected laterally, that is, L1 (0–10 cm, i.e., in contact with wastewater), L2 (10–30 cm), L3 (30–60 cm) and L4 (60–100 cm) from both the sides of effluent channel. Vertical sampling was also done along the depth of; V1 (0–5 cm), V2 (5–15 cm), V3 (15–30 cm) and V4 (30–50 cm). Plastic spatula was used throughout the collection and analytical procedure to avoid metal contamination. Soil samples were collected in polythene bags, air dried, pulverized and sieved with 0.25 mm sieve for further physico-chemical analysis. As there were no previous recorded background values for soil parameters, uncontaminated soil samples were collected at near by area (Figure 1), which do not receive any wastewater or industrial emissions and considered as background values.

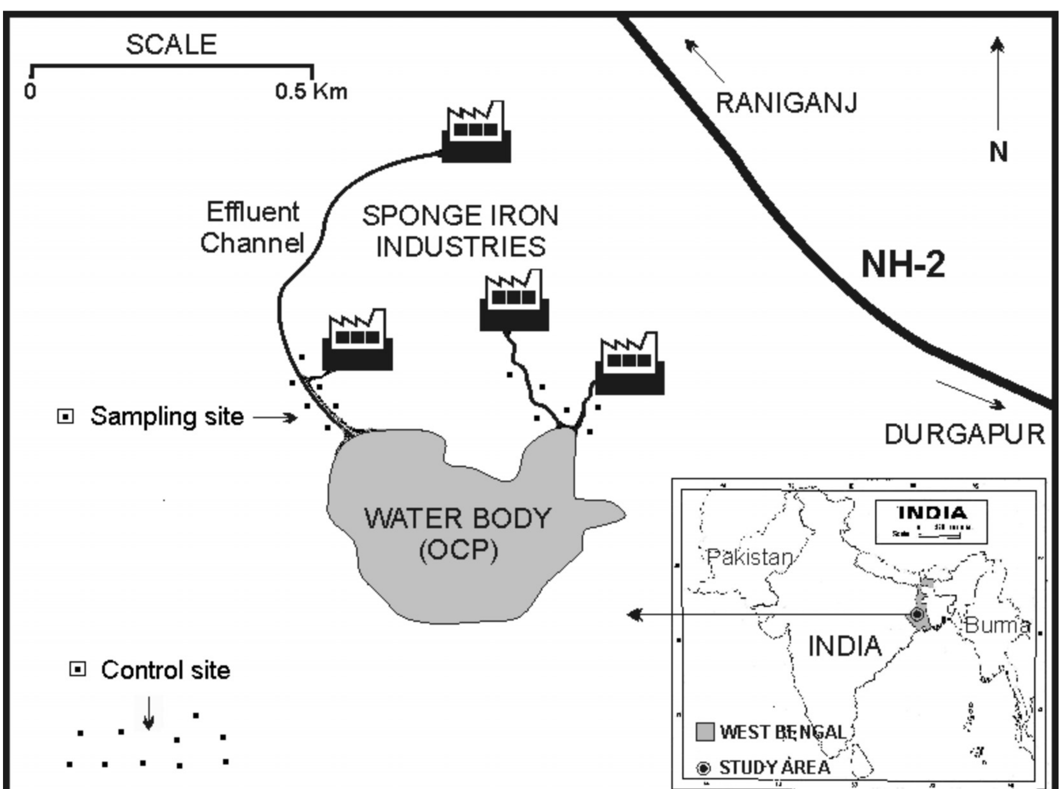

Figure 1: Locational setup of study area.

Analytical Methods

Soil samples were analysed for pH and electrical conductivity (EC) in 1:5 ratio of soil-water suspension (Rhoades, 1982). Total organic matter (OM) was determined by wet oxidation using Walkey and Black's method. Cation exchange capacity was carried out as the total basic cations extracted with 1 (M) CH_3COONH_4 (Reeuwijk, 1995). Soil texture was determined by using hydrometer (Gee and Bander, 1986). Heavy metal concentration were estimated from digested soil samples (1g of soil with a mixture of concentrated $HNO_3 : HClO_4 = 5:1$) (Barman and Lal, 1994). The solution was filtered, diluted to 50 ml with distilled water and analysed by atomic absorption spectrophotometer (GBC, Avanta) to determine cadmium (Cd), chromium (Cr), copper (Cu), manganese (Mn), zinc (Zn), nickel (Ni), lead (Pb) concentration in soil. Iron (Fe) concentration was determined spectrophotometrically at 510 nm.

Index for Assessing Soil Contamination

Pollution load index (PLI) has been calculated to determine the pollution load of different soil zone at contaminated site. The PLI was defined by Tomilson et al. (1980). The index is based on the concentration factor (CF) of each metal present in the soil. Concentration factor has been calculated by using the formula

$$CF = \frac{\text{Concentration of metal in contaminated site}}{\text{Concentration of metal at uncontaminated or control site}}$$

whereas PLI is represented as geometric mean of CF value of n number of metals estimated at contaminated site. A PLI value close to one indicates heavy metal load near to background value while PLI value above one indicates soil pollution (Cabrera et al., 1999). PLI >1 <1.5 slightly polluted, PLI >1.5 <2 moderately polluted and PLI >2 is highly polluted.

Statistical Analysis

The Pearson correlation (r) and test of significance were performed between metals with various soil parameters. Factor analysis is used as a numerical method of discussing variables and identifying geochemical processes. Principal Component Analysis (PCA) along with varimax rotation was performed for heavy metals and other soil parameters to establish significant interrelationship at different soil zones. Statistical calculations are carried out by SPSS software system (version 10).

Results and Discussion

Characterizations of raw wastewater and soil samples along the effluent discharge channel have been studied in order to assess the heavy metal translocation and its impact on soil quality of the surrounding environment.

Characterization of Wastewater

Physicochemical analysis of raw wastewater (Table 1) shows that it is slightly alkaline in nature with very high amounts of total suspended solids (TSS). Wastewater shows very low value for chemical oxygen demand (COD), but total hardness of wastewater is higher than the IS discharge limits (IS 2490 Part I, 1981). Heavy metal concentration except iron (Fe) and lead (Pb) are within the IS discharge limits, which is similar with earlier findings by Gupta et al., 2007. These metals (Fe, Cr, Mn, and Ni) are used in high quantity for manufacturing of alloy with sponge iron. Some of the metals are present in iron ore which is ultimately mixed with effluent water.

Table 1: Characterization of raw wastewater from effluent channel

Parameters	*Raw wastewater*	*Indian standard (IS 2490 Part I: 1981)*
pH	8.2	5.5-9
EC	16.83	-
TSS	1076	100
COD	210	250
Hardness	782	600
Fe	7.93	3
Cu	0.87	3
Cr	0.72	2
Pb	0.34	0.1
Ni	0.07	3
Cd	0.2	2
Mn	0.74	2
Zn	0.63	-

Except pH, EC all the values are in mg/L
- Standard not mentioned.

Vertical and Lateral Translocation of Heavy Metals along with Physico-chemical Parameters

The analysis of soil near effluent channel (Table 2) reveals that pH of surface soil is slightly acidic due to deposition of acid forming particles and pH increases with increasing depth. In lateral direction, wastewater adjacent soils (L1) shows slightly greater pH value because of the alkaline nature of effluents. EC is highest at surface soil nearest to effluent channel due to presence of more soluble salts and decreases with increasing depth and distance from effluent channel. Surface soil shows highest OM content and decreases with increasing depth, but the trend is reverse for lateral direction as industrial wastewater does not contribute significantly. The CEC also follows the similar trend like EC and OM.

Soil samples collected along vertical depth (Table 3) reveals very high concentration of Fe and Cr followed by Mn, Zn and Pb; while Cu, Cd and Ni show lower concentrations. V1 shows the highest metal content followed by V2, and V3; while in V4 most of the metals are same as their background level, similar with earlier findings where 30–100 cm is considered as the depth at which background values are reached. Other studies also show surface soil has the highest metal content and it decreases with increasing depth (Jaradat et al., 2005; Iwebue et al., 2006). Due to their low solubility, heavy metals tend to accumulate in surface soil (McGrath et al., 1994) and are capable of forming insoluble complex compounds with soil organic matter (Sauve et al., 2000). This decrease in metal concentrations with increasing depth is accompanied with decrease in EC, OM, CEC and increase in pH. Soil samples collected in lateral distance from effluent channel (Table 4) shows Fe and

Table 2: Analytical results of soil physical parameters along vertical and lateral distance from effluent channel

	pH	*Ec µs at 25.5ºC*	*Org - M*	*CEC*	*Sand*	*Silt*	*Clay*
Vertical Depth							
0-5 cm	5.74	222	5.56	159.6	87.8	10.1	2.1
5-15 cm	5.9	134	3.66	132.4	64.5	24	11.5
15-30 cm	6.03	118	3.47	87.6	60.5	16	23.5
30-50 cm	6.01	101	2.89	86.2	60.7	19.2	20.1
Lateral Distance							
0-10 cm	5.8	327	3.96	129.4	78.5	12	9.5
10-30 cm	5.57	237	4.76	131.6	80.2	17.4	2.8
30-60 cm	5.6	128	5.98	119.5	84.1	4.7	11.2
60-100 cm	5.64	116	5.36	121.5	82.5	8.5	9

OM (organic matter), sand, silt, clay content are in % value.

Table 3: Vertical distribution of heavy metals in soil along with CF factor and PLI index

n = 12		*0-5 cm*	*5-15 cm*	*15-30 cm*	*30-50 cm*	*Average CF factor*
Cd	C_{soil}	38.5 ± 1.62	28 ± 1.44	16 ± 1.22	14.5 ± 0.85	
	B_{value}	18	17.5	15.6	15	1.43
Cr	C_{soil}	517 ± 17.03	309 ± 16.79	117.5 ± 11.04	117 ± 9.98	
	B_{value}	102	98	96.5	94	2.66
Ni	C_{soil}	28.56 ± 1.94	17.64 ± 0.89	16.4 ± 1.06	13.6 ± 1.36	
	B_{value}	19.26	16.24	15.58	14.2	1.14
Fe	C_{soil}	519.03 ± 16.28	446.94 ± 12.73	360.44 ± 10.69	344.61 ± 7.90	
	B_{value}	108.56	104.5	103.82	101.05	3.98
Cu	C_{soil}	83.16 ± 1.87	56.84 ± 1.72	32.16 ± 2.02	30.05 ± 1.50	
	B_{value}	42.5	34.67	30.86	30.42	1.41
Pb	C_{soil}	117 ± 9.98	78 ± 9.03	65 ± 6.35	59 ± 4.45	
	B_{value}	46	45.3	42	40.2	1.39
Zn	C_{soil}	189.3 ± 5.65	135.8 ± 5.11	108.6 ± 8.26	108.9 ± 8.47	
	B_{value}	127.62	118.46	109.2	108.5	1.16
Mn	C_{soil}	201.26 ± 6.00	170.76 ± 6.19	132 ± 4.09	131.38 ± 2.78	
	B_{value}	109.5	105.32	101.24	98.6	1.53
PLI value		2.30	1.78	1.27	1.24	

n = number of soil samples; C_{soil} = contaminated soil; B_{value} = background value; concentration of metals is in µg g^{-1}.

Table 4: Lateral distribution of heavy metals in soil from effluent channel along with CF factor and PLI index

n = 12	0-10 cm	10-30 cm	30-60 cm	60-100 cm	Average B_{value}	Average CF factor
Cd	34 ± 3.56	25.5 ± 2.78	18.5 ±1.76	16.5 ±2.01	18	1.28
Cr	451 ± 4.89	301.5 ± 5.04	230 ± 4.58	218 ± 5.07	102	2.94
Ni	33.31± 3.88	24.21 ± 3.52	23.85 ± 3.67	19.56 ± 2.25	19.26	1.31
Fe	749.71 ± 5.82	619.95 ± 5.56	475.78 ± 8.01	444.89 ± 4.17	108.56	5.27
Cu	86.37 ± 4.00	69.03 ± 3.75	42.79 ± 4.13	40.23 ± 3.90	42.5	1.41
Pb	126 ± 5.12	83 ± 6.00	70 ± 6.91	52 ± 5.22	46	1.54
Zn	201.2 ± 7.54	179.2 ± 6.70	163.7 ± 5.40	161.6 ± 6.07	127.62	1.36
Mn	248.42 ± 5.22	181.22 ± 5.88	155.2 ± 6.18	156.4 ± 6.41	109.5	1.69
PLI value	2.50	1.91	1.54	1.43		

n = number of soil samples; B_{value} = background value; metal concentrations are in µg g^{-1}.

Cr are present in very high concentrations. Mn, Zn, Pb and Cu content ranges from high to moderate, whereas Cd and Ni shows relatively low concentrations at contaminated site. Investigation reveals that L1 have high concentration for all the metals followed by L2 and L3; whereas for L4, metal concentrations were near to the background value. This indicates that heavy metals mainly accumulated in soils adjacent to wastewater and decreases with the increasing distance from the source (i.e., effluent channel), consistent with the earlier findings (Kashem et al., 1999; Gupta et al., 2007). Decrease in metal concentrations in lateral distance is associated with decrease in pH, EC and CEC and increase in OM content.

Texture composition of vertical soil samples shows high sand percentage in surface soil with little amounts of silt and clay; silt and clay content become more evident with increasing depth which acts as impermeable barrier for downward movement of metals. In lateral direction sand, silt and clay contents does not exhibit much variation as all the soil samples are collected from surface level.

Statistical Interpretation

Statistical interpretation of heavy metals along the vertical depth shows EC, CEC and OM are positively correlated with the metals ($r > 0.9$) while pH and clay content shows negative correlation with metals ($r > 0.9$). Among the metals significant correlation exists between Cd and Cu ($r = 0.998$, $p = 0.002$), Mn and Cd ($r = 0.999$, $p = 0.001$), Cu and Mn ($r = 0.998$, $p = 0.002$), Fe and Cu ($r = 0.996$, $p = 0.004$), Cr and Cu ($r = 0.999$, $p = 0.001$). In lateral direction, soil pH, EC and CEC shows positive correlation with the metals ($r > 0.6$) while a strong negative correlation ($r > 0.9$) is observed between OM and metals. Significant correlation is also found between Cd and Fe ($r = 0.998$, $p = 0.002$), Cd and Zn ($r = 0.997$, $p = 0.003$), Cr and Zn ($r = 0.996$, $p = 0.004$), Cr and Mn ($r = 0.996$, $p = 0.004$) and Fe and Cu ($r = 0.997$, $p = 0.003$); ($p < 0.005$ is highly significant at 5% level). These significant correlations between the metals were probably due to their similar kind of distribution pattern.

Factor analysis (PCA) between heavy metals with other soil parameters in both the directions considered only two factors. Factor loading (after varimax rotation) in vertical direction together comprising 99.48% of total variance of a data set. Elements, specially metals are in close association with first principal component (F1) represents significant loading of 73.74% of total variance, whereas for second principal component (F2) loading is relatively low (25.74% of total variance). The results of PCA in lateral direction considered two principal components explained 97.88% of total variance, of which the first principal components (F1) covering 71.58%, and second principal component (F2) represent 26.31% of total variance. In both the cases, heavy metals shows very close affinity with first principal components and explained considerably high of total variance of data set, which confirms that anthropogenic activity (here wastewater discharge) is the most determining factor for the origin and distribution of heavy metals in soil.

Assessment of Pollution Load and Metal Enrichment in Contaminated Soil

Pollution Load Index is a good indicator of pollution level of any contaminated site. Vertical assessment (Table 3) shows surface soil (V1) has the highest PLI value followed by V2, while soil samples V3 and V4 have very low PLI value almost reaching background level. Lateral assessment reveals (Table 4) wastewater adjacent soil (L1) is highly polluted followed by L2 and L3 (moderately polluted), while L4 shows lowest PLI value.

The average concentration factor (CF) (Table 3) of metals in vertical depth are Fe > Cr > Mn > Cd > Cu > Pb > Zn > Ni which is similar to lateral direction (Table 4) Fe > Cr > Mn > Pb > Cu > Zn > Ni > Cd except Cd and Cu. In both the direction, Fe and Cr show very high CF in comparison to other metals. This can be attributed to their relatively higher concentration in wastewater which facilitates subsequent leaching into the soil, whereas CF of Mn, Pb, Zn, Cu, Cd and Ni are relatively low indicating their less enrichment in soil.

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