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Contribution of mining on the heavy metal load of soils-a case study in the iron ore belt of Bolani, Keonjhar district, Odisha, India

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Abstract

Soil heavy metal study is carried out in Bolani and surrounding areas to assess the soil contamination levels with respect to heavy metal loads. Sampling of soils is carried out in post-monsoon and pre-monsoon periods. Heavy metals were determined by Atomic Absorption Spectrophotometer. The heavy metal concentrations determined are Fe, Mn, Co, Zn, Ni, Cd, Pb, Cr and Cu. Value for Fe range from 5.03 to 48.03%, Mn range from 0.065 to 0.483 %, Cd varies from 2 to 120 µg/g, Co value range from 53 to 160 µg/g, Cu varies from48 to 100µg/g, Ni varies from 38 to 105µg/g, Pb range from 15 to 25 µg/g, Zn varies from 55 to 230µg/g in pre monsoon period. The post monsoon heavy metals concentrations show higher values in comparison to pre monsoon period. Remedial steps may be taken to prevent soil contamination from mining in rainy season.

Keywords: soil, heavy metal, pre and post monsoon, mining, bolani

1. Introduction

Several investigations carried out on soils (Hren *et al.*, 2001; McGregor *et al.*, 1998; Lin and Herbert, 1997; Bullock and Bell, 1997; Clark *et al.*, 2001; and Gabler and Schneider, 2000) [11, 14, 3, 6, 9, 10] reveal that the soils and the sediments of the nearby mining area are severely contaminated by heavy metals in most part of the world.

Any mining activity involves removal of vegetal cover and burring of hill slopes or land surface. This enhances the surface run-off component of the hydrological cycle into an increased load of particulate and eroded material. Opencast mining generates huge amount of solid wastes in the form of overburden material and tailings dumped in the vicinity of mine sites. The washouts from the mine wastes and mine effluent waters contaminate the surrounding soils. Natural slopes and vegetations of the region are destroyed by accelerated weathering and erosion processes due to mining activities. Mining generally involves excavation, drilling, blasting, loading and transport of ores. Also the ores undergo beneficiation to meet the demand for specific metallurgical plants. This involves crushing, screening, blending and washing of ores. There is a tendency that elements introduced with solid waste material are less stably bound than those in natural systems. Even at relative small proportion of these materials, therefore, mobilization (and subsequent transfer to biota) of potentially toxic elements by acidity, complexing agents or redox charges may be significantly increased (Forstner, 1986) [8]. Materials from the overburden dumps and tailings are transported in air as suspended particulate matter (SPM) and water, and contaminate the surrounding soil. They serve as feeder for the increased load of heavy metal content of soil.

The concentration of heavy metals in soil depends on: (i) release of metals from parent material by weathering and (ii) their translocation and accumulation in soil constituents which absorb metals such as clays, hydrous oxides and organic matter. Hence soils serve as ultimate sink for heavy metals. Heavy metal contents of soils are generally modified by anthropogenic activities such as mining and industry.

To assess the heavy metal contents of soils in the mining town of Bolani, samplingwere carried out in pre-monsoon and post-monsoon periods and their heavy metal variations were studied.

2. Geology of the area

Bolani area is surrounded by iron deposits. The parent rocks of these ore deposits are Banded Iron Formations (BIF) as they occur in the form of iron and silica bands. The iron-rich bands mainly comprise of hematite, martite, magnetite, specularite and goethite, where as silica-rich bands consist of quartz or jasper (Chakraborty and Majumdar, 1986 and 2002) [4]. This area comprises of weakly metamorphosed volcano-sedimentary sequence of rocks of Precambrian age forming the storehouse of iron and manganese ore deposits. The BIF along with the volcanic-sedimentary rock pile constitutes the Iron Ore Group (IOG), more precisely, the Banded Hematite Jasper (BHJ) or Banded Hematite Quartzite (BHQ) and ferruginous shales. The rock types of iron ore groups comprise of lower phyllite shales with acid tuffs, Banded Hematite Jasper with iron ore, ferruginous quartzites, shales with volcanics, manganese ore, dolomite and mafic lavas. The regional structure is a low NNE plunging synclinorium overturned towards southeast, which is commonly known as horse-shoe synclinorium (Jones, 1934 and Saha, 1994) [12, 15].

3. Materials and Methods

Soil samples are collected from 12 locations (Fig. 1) during pre- and post-monsoon periods covering the Bolani region during 2012-14. From each location about 2 Kg sample is collected in polythene packets. Then they are dried and sieved. Coarse materials are removed. Then less than 200 mesh size fraction is taken for heavy metal analysis, as it is a known fact that heavy metals are found in the finer fraction of soil. Then the soils are acid digested (HCl: HNO3 = 1:1 mixture). After this, the concentration of heavy metals is determined by an Atomic Absorption Spectrometer (Perkin-Elmer-3100). In the present work heavy metals Fe, Mn, Co, Zn, Ni, Cd, Pb, Cr, and Cu are analysed for their concentrations. The pre monsoon and post monsoon variation of heavy metal content in soils are given in Figures 2-9.

4. Results and Discussion

Heavy metals are those, which have atomic density more than $6g/cm^3$. Heavy metals are also classed as trace elements because they occur in concentration of less than 1% and frequently below 0.01% in the rocks of earth's crust. Variations of concentration of heavy metals such as Fe, Mn, Co, Zn, Ni, Cd, Pb, Cr, and Cu in soils of pre-monsoon and post-monsoon periods from Bolani region are given in Fig. 2. The ranges and mean values of these elements in the collected samples, and the standard values of soils are given in Table-1 and 2.

Although the relative toxicity of different metals to plants can vary with different plants, the metals those are the most toxic to plants and micro-organisms are Cu, Ni, Pb, Co and Cd.

4.1. Iron

Among the heavy metals iron is the most dominant one present in soil and its concentration in natural soil varies from 0.7% to 4.2% (Adriano, 1986) [1]. The background level of iron in soil is reported to be 3.2% (Forstner, 1986; Solomons and Forstner, 1984) [8, 16].

Mechanism for solubility of iron is the release of hydrogen ions by the root, which lowers the pH in the root zone. Availability of iron to the root of plants is influenced by the iron content of soil but also by its pH and phosphate content. Although iron is a nutrient for plants. Iron concentration exceeding 10 to 200 mg/l of nutrient solution have been found to be toxic to plants. It leads to chlorosis and stunted growth.

The acidic soils aggravate iron toxicity in plants, which may result in chlorosis and stunted growth in plants. Soil capacity for elements are strongly correlated with free iron oxide in soil (Korte *et al.*, 1976). However, under anaerobic conditions, Fe^{+3} is reduced to Fe^{+2}, which is readily absorbed by plants. Therefore, in flooded soils such as those constitute paddy fields, Fe toxicity can be a serious problem even if the soil does not contain excess Fe levels (Fernandes and Henriques, 1990) [7].

The iron content of soils of Bolani varies from 5.03 to 48.03% in pre-monsoon and 10.61 to 60.87 % in post-monsoon periods. The post-monsoon iron content in soil is distinctly higher than pre- monsoon soils due to mixing of wash outs from over burden dumps and tailings in the soils. Soils nearer to mines show higher iron content in comparison to soils away from mines. The Variation of Iron in pre monsoon and post monsoon soil samples is given in Fig-2.

4.2. Manganese

In surface soils, manganese is highest in A- horizon, reaches a minimum in the B-horizon and then generally increases in the C-horizon of soil. Soils of low pH generally has the highest amount of water soluble, exchangeable organic Mn where as soils with high pH contain large amounts of reducible Mn. 75% Mn in soil is found in oxide form. Secondary Mn oxides can occur in soils in several forms including concretions, pans, coatings and mottles and they constitute considerable part of the soil.

The average Mn content in soils is 550 ppm. The manganese concentration in plant is normally between 20 and 200 ppm. An excess of Mn in plants causes chlorosis. In well-drained soils manganese toxicity is generally found in soils having pH below 5.5. Manganese concentration in soils of the area varies from 0.065 to 0.483 % in pre-monsoon and 0.05 to 0.8 % in post-monsoon. Manganese toxicity in plant is reflected by chlorosis, necrosis of leaves, stunted growth and depressed yield. Variation of Manganese in pre monsoon and post monsoon soil samples is given in Fig-3.

4.3. Trace elements: Lead, Chromium, Copper, Cadmium, Cobalt, Nickel, Zinc

Copper toxicity makes poorly developed root system, leaf cholorosis and stunted growth. Copper concentration in soils of the area varies from 48 to 100μg/g in pre-monsoon and 28 to 80μg/g in post-monsoon. The average copper value reported for soils of the world is 30μg/g and copper toxicity is associated with soils having Copper content more than 150μg/g. Variation of Copper in pre monsoon and post monsoon soil samples is given in Fig-4.

Zinc is an essential micronutrient for plants. The average value of zinc reported for soil is 60μg/g. Zinc content more than 100 ppm in soil is related to yield depression in plants. Zinc content in soils of the area varies from 55 to 230μg/g in pre-monsoon and 40 to 120μg/g in post-monsoon. Variation of Zinc in pre monsoon and post monsoon soil samples is given in Fig-5.

Cadmium is hazardous heavy metal in soil and their average content in soils of the world is 1μg/g. Cadmium toxicity leads to zinc deficiency in plants manifested in the form of retardation of growth. Cadmium content in soils of the area varies from 2 to 120 μg/g in pre-monsoon and 140 to 160 μg/g in post-monsoon. Such higher content of cadmium in post monsoon soil samples may be due to mixing of wash outs from shaly overburden which are rich in cadmium. Cadmium toxicity leads to zinc deficiency in plants manifested in the form of retardation of growth. Variation of Cadmium in pre monsoon and post monsoon soil samples is given in Fig-6.

Nickel content in soils of the area varies from 38 to 105μg/g in pre monsoon and 140 to 260μg/g in post monsoon. Average nickel content in soils of the world is reported to be 50μg/g. Nickel content in soil shows the similar toxicity as cadmium. Variation of Nickel in pre monsoon and post monsoon soil samples is given in Fig-7.

Cobalt presence in soils, sometimes as lower as 0.1 ppm can produce adverse effect on many crops. Toxicity due to excess cobalt exhibit chlorosis and necrosis and soil acidity increases the bioavailability of cobalt percentage. Cobalt content soils of the area varies from 53 to 160 μg/g in pre monsoon and 80 to 180 μg/g in post-monsoon. The world average cobalt content in soil is very low and is reported to be 8μg/g. Hence, higher cobalt values in soils of the area could be due to mining activity in the region. Variation of Cobalt in pre monsoon and post monsoon soil samples is given in Fig-8.

Lead content soils of the area varies from 15 to 25 μg/g in pre-monsoon and 5 to 40 μg/g in post-monsoon. The average lead content in world soil is reported to be 35μg/g and the lead content in non-contaminated rural soil varies from 10 to

30µg/g. Pb-toxicity is dependent on its phyto-availability. Lower the pH, higher the extractable Pb from soils. More than 30 mg/l in nutrient solution was found to toxic to plants. Toxicity effects include growth retardation in plants. Variation of Lead in pre monsoon and post monsoon soil samples is given in Fig-9.

Chromium content in soils of the area varies from 100 to 230 µg/g in pre monsoon and 200 to 1200 µg/g in post monsoon. Such high content of chromium in soils of post monsoon samples may be mixing of washouts from volcanic tuffs and ferromagnesian minerals in the mining overburden materials which are known to be rich in chromium content. Chromium toxicity in plants gives depressed yield. Chromium may prove to be toxic to plants at about 5 ppm in nutrient solution.

Variation of Chromium in pre monsoon and post monsoon soil samples is given in Fig-10.

In general, the post-monsoon heavy metal contents in soils are higher than the pre-monsoon values. The heavy metal contents in soils near to iron and manganese mines are higher than other locations. Heavy metal content in most of the locations exceeded the average heavy metal content reported for the soils of the world. Shales, tuffs, and iron & manganese ores are the source of these heavy metals. Toxicity of most of the heavy metals revealed in growth of plants and depressed yield of crops.

Table 1: Heavy metal constituents of pre monsoon soil samples from Bolani {standard reported values (* Solomons and Forstner, 1984; Alloway, 1990) for soils. Fe and Mn are in % and the rest are in □g/g.}

Sample No.	Fe	Mn	Cu	Zn	Ni	Co	Cr	Pb	Cd
	%	%	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g
1	8.38	0.103	60	56	83	65	100	15	2
2	5.03	0.160	50	95	55	80	160	15	2
3	10.05	0.205	95	230	80	160	160	15	2
4	8.94	0.065	70	180	88	80	160	15	2
5	13.96	0.100	100	130	73	100	180	15	2
6	12.29	0.170	50	85	63	53	140	15	2
7	18.43	0.483	70	83	78	130	198	15	2
8	9.49	0.143	80	160	80	100	180	25	2
9	11.17	0.170	80	93	105	110	210	15	2
10	35.19	0.070	48	55	38	78	180	15	2
11	13.96	0.100	100	130	73	100	180	15	2
12	48.03	0.085	80	190	80	130	230	20	120
Mean	16.24	0.154	74	124	75	99	173	16	12
Range	5.03	0.065	48	55	38	53	100	15	2-120
	-48.03	-0.483	-100	-230	-105	-160	-230	-25	
Standard	3.2*	0.1	30	60	50	8	70	35	70

Table 2: Heavy metal constituents of post monsoon soil samples from Bolani {standard reported values (* Solomons and Forstner, 1984; Alloway, 1990) [16] for soils. Fe and Mn are in % and the rest are in □g/g.}

Sample No.	Fe	Mn	Cu	Zn	Ni	Co	Cr	Pb	Cd
	%	%	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g
1	10.61	0.124	45	70	171	80	200	10	140
2	24.57	0.185	65	85	190	95	425	10	150
3	18.40	0.220	65	55	160	180	371	30	140
4	13.96	0.800	55	65	260	100	260	10	140
5	29.32	0.170	57	85	140	120	700	10	150
6	21.22	0.160	47	100	140	90	360	10	150
7	21.20	0.175	80	120	160	140	400	40	150
8	21.70	0.137	62	75	140	110	480	10	150
9	13.90	0.170	77	80	150	120	250	12	150
10	58.92	0.080	31	40	190	90	1200	5	160
11	43.50	0.050	37	60	210	120	930	17	150
12	60.87	0.069	28	40	190	140	1180	7	160
Mean	28.18	0.195	54	73	175	115	563	14	149
Range	10.61	0.05	28-80	40-120	140	80	200	5-40	140-160
	-60.87	-0.8			-260	-180	-1200		
Standard	3.2*	0.1	30	60	50	8	70	35	70

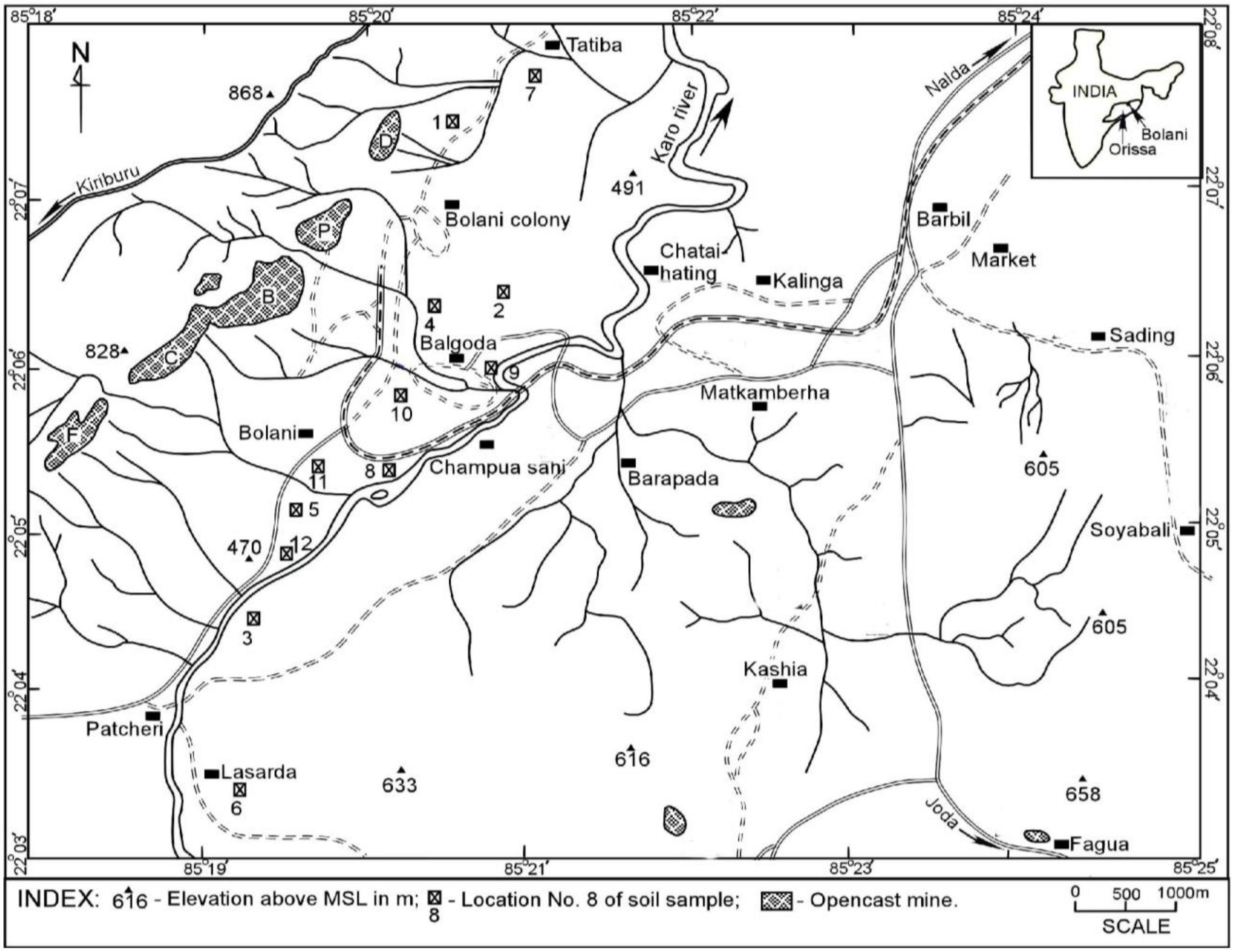

Fig 1: Location map of soil samples

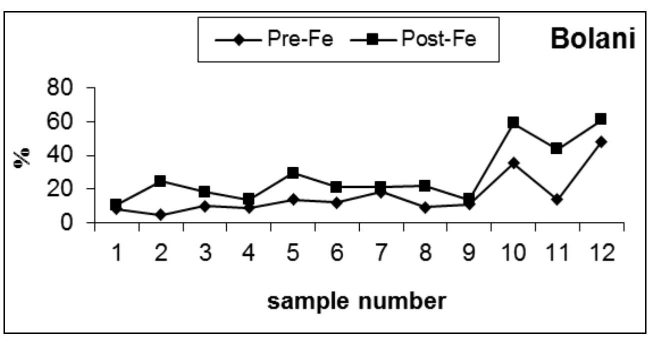

Fig 2: Variation of Iron in pre monsoon and post monsoon soil samples

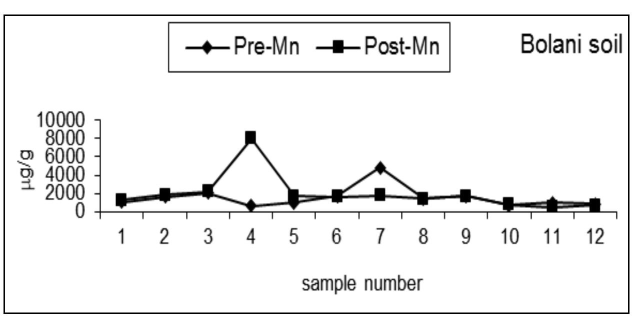

Fig 3: Variation of Manganese in pre monsoon and post monsoon soil samples

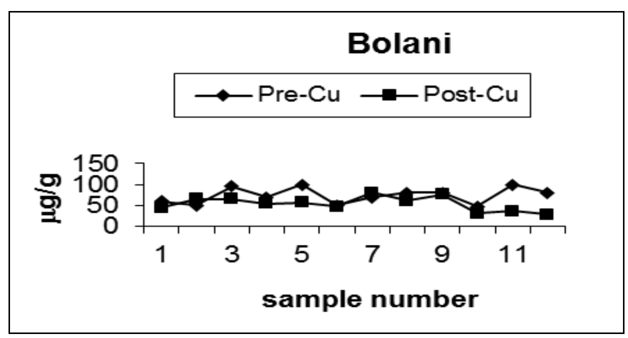

Fig 4: Variation of Copper in pre monsoon and post monsoon soil samples

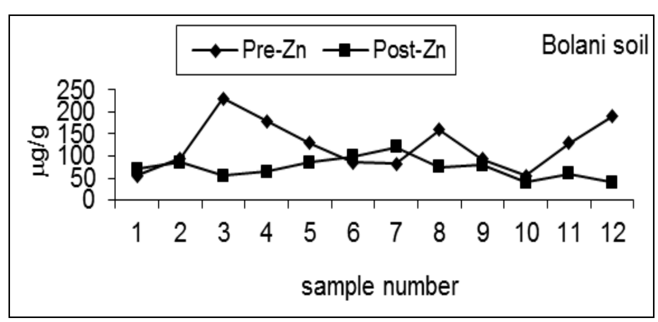

Fig 5: Variation of Zinc in pre monsoon and post monsoon soil samples

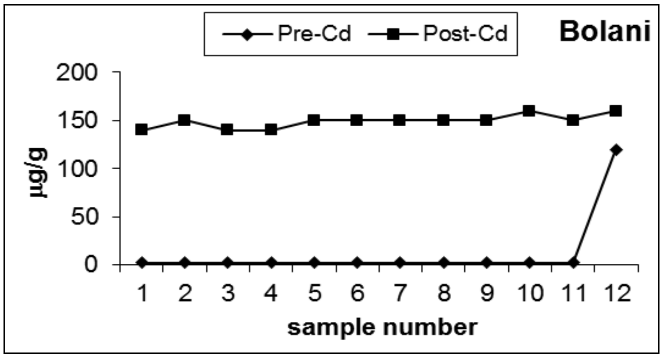

Fig 6: Variation of Cadmium in pre monsoon and post monsoon soil samples

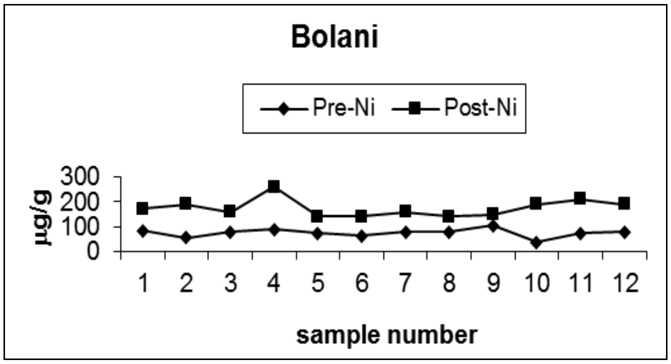

Fig 7: Variation of Nickel in pre monsoon and post monsoon soil samples

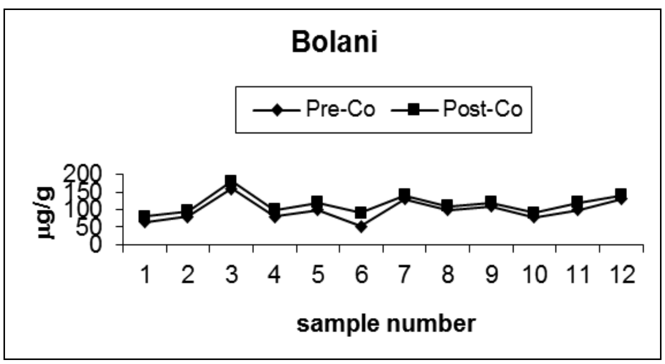

Fig 8: Variation of Cobalt in pre monsoon and post monsoon soil samples

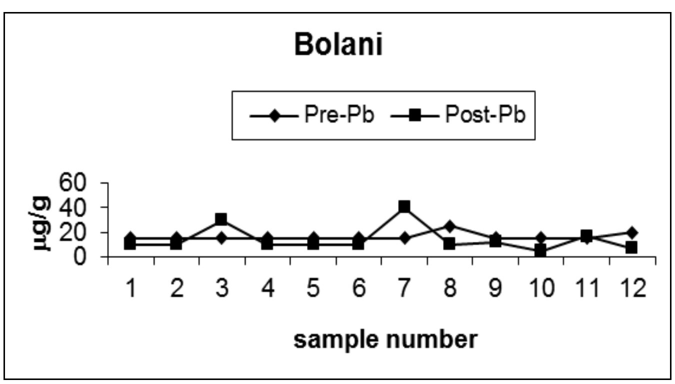

Fig 9: Variation of Lead in pre monsoon and post monsoon soil samples

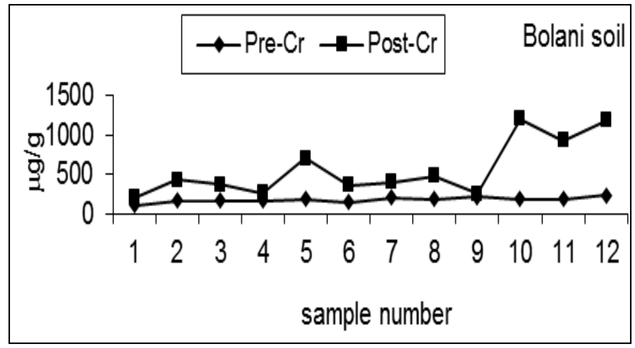

Fig 10: Variation of Chromium in pre monsoon and post monsoon soil samples

5. Conclusions

From the present study there are indications that the soils are contaminated with the heavy metals triggered by mining and industrial activities in the region. Also the post-monsoon concentrations of heavy metals are higher than the pre-monsoon concentration. Such heavy metal contamination may lead to phytotoxicity for which further work is needed. Hence, appropriate remedial steps may be taken to prevent contamination of the soils from mining and industrial activity in rainy season.

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