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COAL-BASED SPONGE IRON INDUSTRY WASTE AND ASSOCIATED HEAVY METAL POLLUTION

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Abstract

Industrial and technological progress negatively affects the environment by polluting and degrading the soil. One such industry is sponge iron industry where sponge iron is made from reduction of iron in presence of coal as input material and is used as a raw material in making steel. The coal FA emitted from furnace of coal based sponge iron industry contains heavy metals like arsenic, cadmium, cobalt, copper, chromium, nickel, lead, zinc and mercury.Thus, deposition of FA in the surrounding environment of sponge iron plants leads to accumulation of heavy metals in the soil. The aim of the present investigation is to understand and get aware with the pollution, mainly heavy metal pollution of the study area (in and around the integrated coal based Bhushan sponge iron plant present at Rengali block of Samblpur district as experimental site and a nonindustrial site 28.1 km away from the experimental site as control) and the effect of the sponge iron industry waste particularly the bottom fly ash (FA). All the studied heavy metal concentrations were predominantly elevated in the soil samples of experimental site as compared to the control site indicating the negative influence of sponge iron plant and the soil pollution due to heavy metals present in it.

Key words- sponge iron, fly ash, environmental pollution, soil, heavy metal

Introduction

The recent population and industrial growth and development has led to increasing production of domestic, municipal and industrial wastes, which are indiscriminately dumped in landfill and water bodies without any pre-treatment (Sharma et al., 2013). Sponge iron is a rapidly growing industry in India. Undoubtedly, it has brought financial benefit to the nation; but at the same time it cause environmental pollution leading to adverse health impacts. In India, iron and steel industries are, among the 17 most polluting industrial sectors, identified by the Central Pollution Control Board (CPCB). Air emissions from Iron and steel industries are an important source of pollution (Liu et al., 2013; Rai et al., 2011). Most of the sponge iron plants in India are coal based and the major drawbacks of converting coal into useful form of energy is generation of high quantity of coal FA. In India comparatively more FA is generated per unit amount of coal because of low quality (Warren and Duddas (1984); Sen and Kumar (1995); Haque (2013); Padhy et al. (2016). The main reason of this problem with Indian sponge iron industry is that these are mostly coal based units. Coal based sponge iron industries are releasing large quantities of pollutants, directly or indirectly discharged to adjoining land areas, water bodies

such as stream, river, etc and also the atmosphere (Parida etal,2015). Odisha is one of the major producers of sponge iron in India and thus a victim of such pollution. Moreover, the eco-friendly methods of disposal are not enough to sustainable manage, dispose the vast mass of FA generated in Indian condition (Sen and Kumar, 1995) and those lies as unclaimed and burdened heaps near the plant premises.
The emitted FA is spread in and around the different sites and affects the physico-chemical parameters of soil and water as reported by Rai et al., (2011). According to Nayak (2015) soil pollution due to FA accumulation in the nearby power plants causes land degradation, soil erosion and loss of soil fertility. The coal FA emitted from furnace of coal based sponge iron industry contains heavy metals like arsenic, cadmium, cobalt, copper, chromium, nickel, lead, zinc and mercury (Llorent et al., 2001). Soils nearer to the FA emission source were more affected as compared to soil away from the source (Bashoff et al., 2014). FA is small enough to be carried with the gas; vapor and finer FA particles that escape from the stack system are blown by the wind and get deposited close to the sponge iron plant. Further, during transport of waste materials from the plant to the dumping site large amount of FA are deposited on the site close to the plant. In the sponge iron plant, during handling of iron ore and scrap iron large amount of heavy metals are released into the air and get deposited in the soil layers close to the steel making plant (Risk appraisal study of Raigarh District, 2006). Several workers reported that FA also contains significant amount of toxic metals such as As, Ba, Hg, Cr, Ni, V, Pb, Zn and Se (Adriano et al., 1980; Aitken et al., 1985; Mattigod et al., 1990).

FA carries the potential for environmental contamination during the disposal (Bilski et al., 2012) because FA contains multiple toxic elements and predominantly heavy metals. The mobilization of heavy metals in FA is reported to be a very slow process (Lokeshappa and Dikshit, 2011). However, the release of such metals during storage can have deleterious effect on the environment as well as on the human health (Yuan et al., 2009). Senapati (2011) proposed that all the heavy metals (Ni, Cd, As, Sb, Cr, Pb, etc.) generally found in FA are toxic in nature which can cause a number of health hazards. Soil is a slow moving medium and the heavy metals migrate in it slower than they do it in water and air; because of which these toxic pollutants increase gradually in the soil (Vladislav et al., 2003). The ecological problem of soil degradation due to sponge iron industry is of extreme importance in present global scenario (Sahoo et al., 2014).

Sampling Sites

The present study was confined to the area surrounding Bhusan Power and Steel Limited (BSPL), located in Rengali block of Sambalpur district of Odisha, India. The BSPL is the integrated steel (2.2 MTPA) and power plant (230 MW capacity).The experimental sites were selected within 2 km away from the stack of Bhusan Sponge Iron Industry. The control site (non-industrial area), Dhanupali, Sambalpur was located 28.1 km. away from the Sponge Iron cluster (Figure- 1).

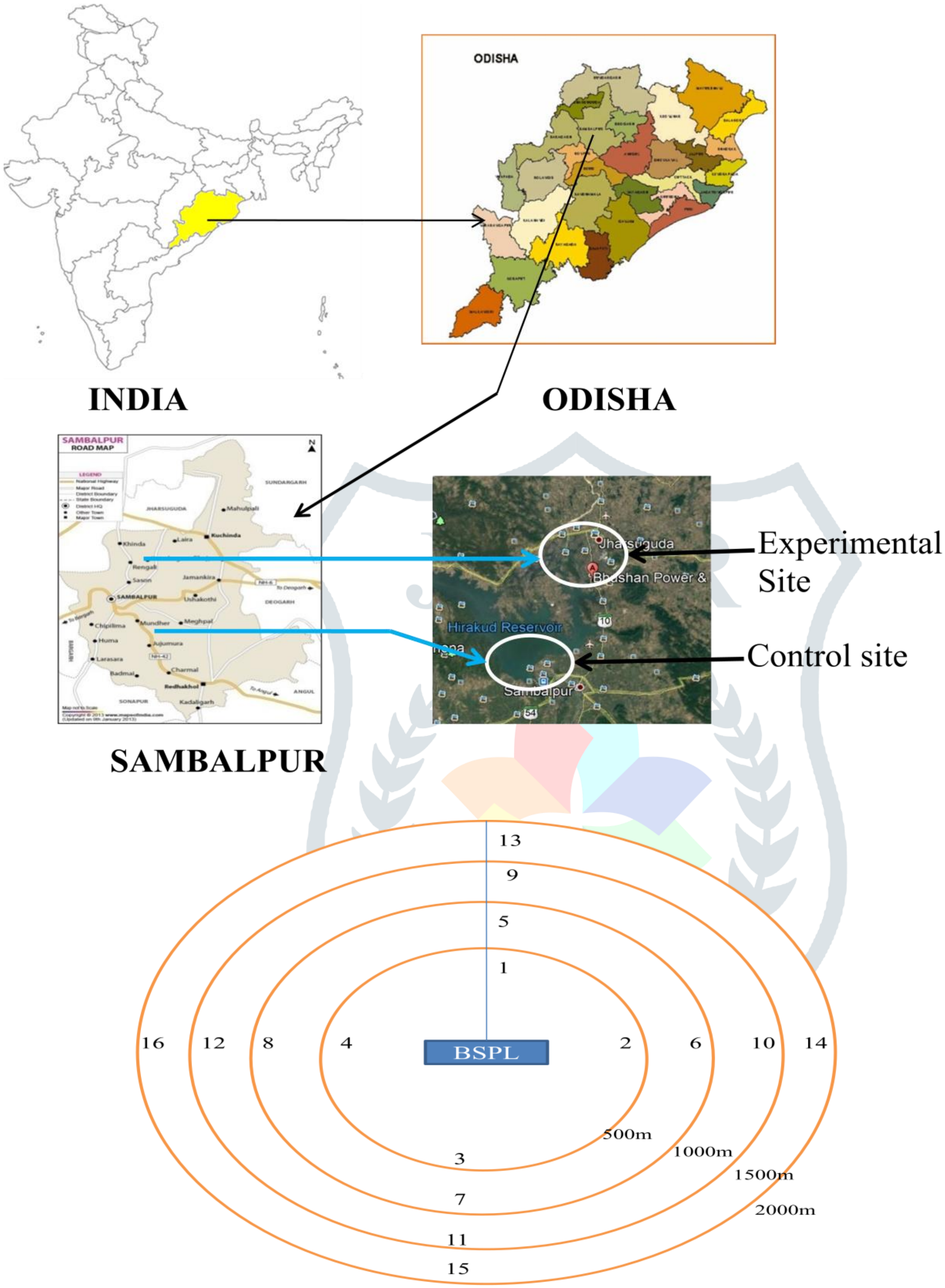

Figure -1: Soil sampling sites around the BSPL Rengali, Sambalpur, Odisha, India.

Collection of Soil Samples

For present study four different locations were chosen in four directions (east, west, north and south) and which corresponds to sites located at 0.5 km, 1.0 km, 1.5 km and 2.0 km distances from the stack of the sponge iron plant of experimental site(Figure -1) and control site. The soil samples from 0-10 cm depth were packed in plastic zipper bag, brought into the laboratory and stored at 4 ºC before analysis.

Materials and Methods

3.3.2 Heavy Metal Analysis

All the collected soil samples were oven dried (70°C). Dried soil samples were then ground and sieved through 1 mm mesh sieve. The powdered samples were digested with nitric acid-perchloric acid digestion method for analysis of heavy metal. 1 g dried soil sample with 10 ml of NHO_3, H_2SO_4 and $HClO_4$ mixture in 5: 1:1 ratio at 80°C. After filtration with whatman (no. 42) filter paper, metal contents were analyzed using atomic absorption spectrophotometer.

4 Statistical Analysis

Variation pattern examined graphically after the study of different heavy metals were subjected to one way ANOVA with replicates and two way ANOVA with replicates to find out the significance with respect to different sites and different seasons.

3.4 Results

3.4.1 Effects of FA on Heavy Metal Contents

The distance wise distribution of mean concentration of Cd, Pb, Ni, As and Cr in summer, rainy and winter season has been presented in Table-1. The results indicated that maximum concentrations of 6.4 mg / kg of Cd, 17.22 mg/kg of Pb, 430.56 mg / kg of Ni, 4.34 mg / kg of As and 1195.36 mg / kg of Cr were recorded at a distance of 0.5 km from sponge iron plant in winter season. The concentration of these heavy metals was found to decrease with increasing distance from the stack and lowest heavy metal concentrations were 5.67, 14.8, 405.83, 4.54, and 1136.92 mg/kg of Cd, Pb, Ni, As, and Cr respectively at 2 km away from the industry. The control soil showed significantly low concentration of heavy metals (0.27, 13.3, 27.88, 0.279, 59.95 mg/kg of Cd, Pb, Ni, As, and Cr respectively) in comparison to experimental sites in winter season.

During rainy season maximum concentrations of Cd, Pb, Ni, As, and Cr was recorded to be 5.66, 15.77, 420.25, 4.18, and 1170.16 mg/kg respectively at 0.5 km from the emission source. At 2.0 km distance minimum concentrations of all the studied heavy metals (5.16, 14.0, 395.01, 3.51, and 1113.9mg/kg of Cd, Pb, Ni, As, and Cr respectively) were recorded in rainy season. It was also noticed that the soil samples of control site showed low heavy metals in rainy season (0.2 mg/kg for Cd, 10.85 mg/kg for Pb, 24.59 mg/kg for Ni, 2.06 mg/kg for As, 49.41 mg/kg for Ni) in comparison to experimental site.

The present study revealed maximum concentration of 6.18 mg/kg of Cd, 16.22 mg/kg of Pb, 425 mg/kg of Ni, 4.22 mg/kg of As and 1188.53 mg/kg of Cr at a distance of 0.5 km from emission source in the experimental site. Further, at 2.0 km distance the data revealed minimum concentration of all the studied heavy metals during summer season (5.39, 14.22, 404.66, 3.75, 1127.4 mg/kg of Cd, Pb, Ni, As and Cr respectively). In summer season the soil samples of control site showed significantly low concentration of heavy metals (0.24 mg/kg of Cd, 24.48 mg/kg of Pb, 25.7 mg/kg of Ni, 0.26 mg/kg of As , 58.27 mg/kg of Cr) in comparison to experimental site.

Table -1 Heavy metal concentration in control and experimental sites near Bhusan Power and Steel Plant in different seasons

Distance	Seasons	Heavy metal content (mg/kg)				
		Cd	Pb	Ni	As	Cr
0-0.5 km	Summer	6.18 ± 0.03	16.22 ± 0.11	425 ± 3.67	4.22 ± 0.08	1188.53 ± 2.41
	Rainy	5.66 ± 0.01	15.77 ± 0.06	420.25 ± 6.87	4.18 ± 0.07	1170.16 ± 13.61
	Winter	6.4 ± 0.08	17.22 ± 0.1	430.56 ± 1.3	4.34 ± 0.07	1195.36 ± 2.91
0.5-1.0 km	Summer	6 ± 0.12	15.53 ± 0.08	413.78 ± 3.84	4.24 ± 0.08	1182.82 ± 3.36
	Rainy	5.6 ± 0.14	15.09 ± 0.07	404.33 ± 3.77	3.71 ± 0.16	1156.84 ± 18.96
	Winter	6.28 ± 0.06	16.47 ± 0.17	424.31 ± 3.72	4.3 ± 0.108	1179.03 ± 6.36
1.0-1.5 km	Summer	5.43 ± 0.05	14.74 ± 0.09	405.1 ± 4.29	4.12 ± 0.05	894.31 ± 18.87
	Rainy	5.25 ± 0.1	14.53 ± 0.1	397.56 ± 4.17	3.58 ± 0.08	1140.55 ± 4.5
	Winter	5.85 ± 0.04	15.29 ± 0.05	415.63 ± 3.56	4.28 ± 0.11	1165.99 ± 10.5
1.5-2.0 km	Summer	5.39 ± 0.06	14.22 ± 0.06	404.66 ± 2.32	3.75 ± 0.15	1127.4 ± 6.2
	Rainy	5.16 ± 0.04	14 ± 0.01	395.01 ± 3.3	3.51 ± 0.07	1113.9 ± 5.07
	Winter	5.67 ± 0.07	14.8 ± 0.03	405.83 ± 5.93	4.54 ± 0.04	1136.92 ± 2.84
Control	Summer	0.24 ± 0.005	24.48 ± 0.06	25.7 ± 0.24	0.26 ± 0.014	58.27 ± 0.33
	Rainy	0.2 ± 0.005	10.85 ± 0.28	24.59 ± 0.82	0.206 ± 0.0064	49.41 ± 6.61
	Winter	0.27 ± 0.008	13.3 ± 0.59	27.88 ± 0.64	0.279 ± 0.0062	59.95 ± 0.44
Safe limit for Indian soil		0.07-1.1	10-70[b]	75-150[a]	0.5[d]	65[c]

[a]Indian standard Awashthi and European Union, 2000; [b]FA O/WHO, codex general standard for contaminants and toxins in foods, 1996; [c]World Health Organization, 2000;[d]World Health Organization, 2004 (Tasrina et al .,2015).

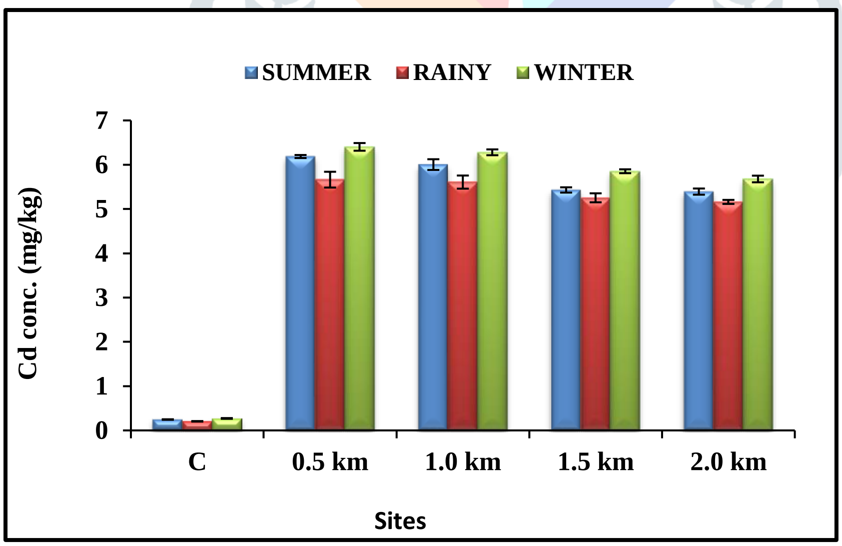

Figure -2 Concentrations of cadmium (mg/kg) in different study sites during different seasons

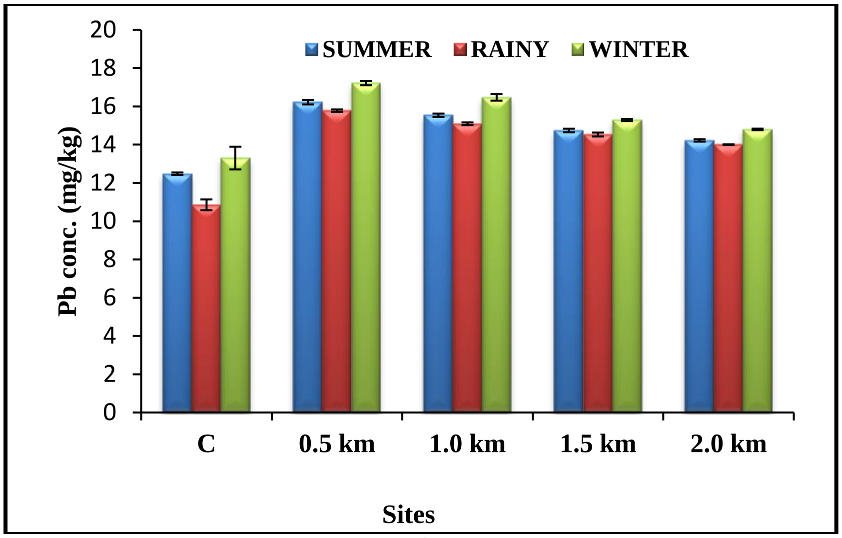

Figure- 3 Concentrations of lead (mg/kg) in different study sites during different seasons

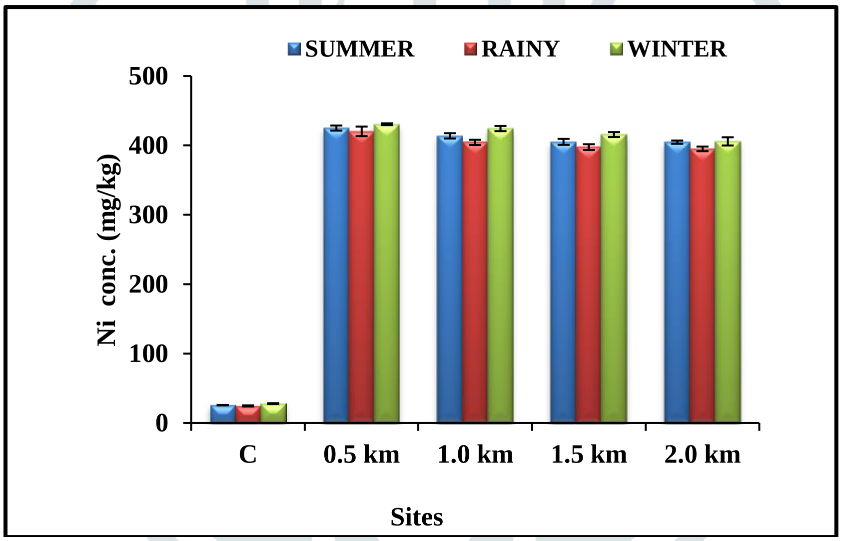

Figure -4 Concentrations of nickel (mg/kg) in different study sites during different seasons

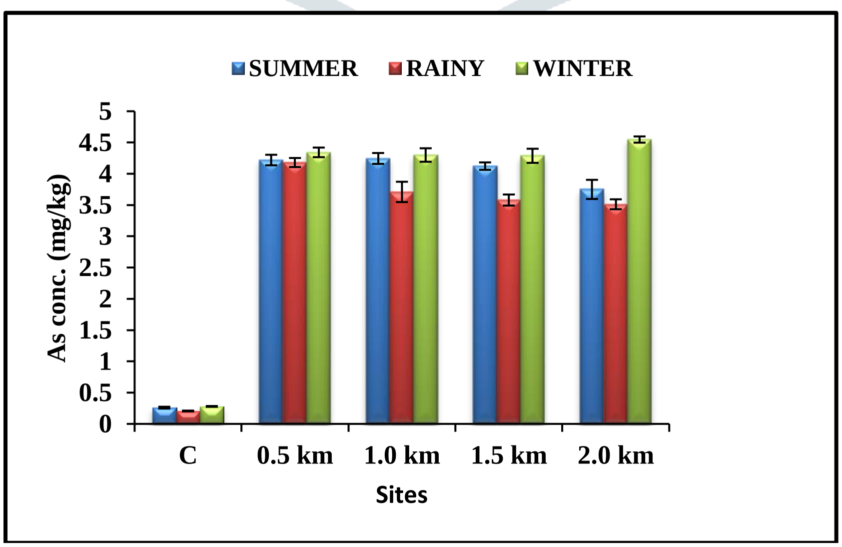

Figure -5 Concentrations of arsenic (mg/kg) in different study sites during different seasons

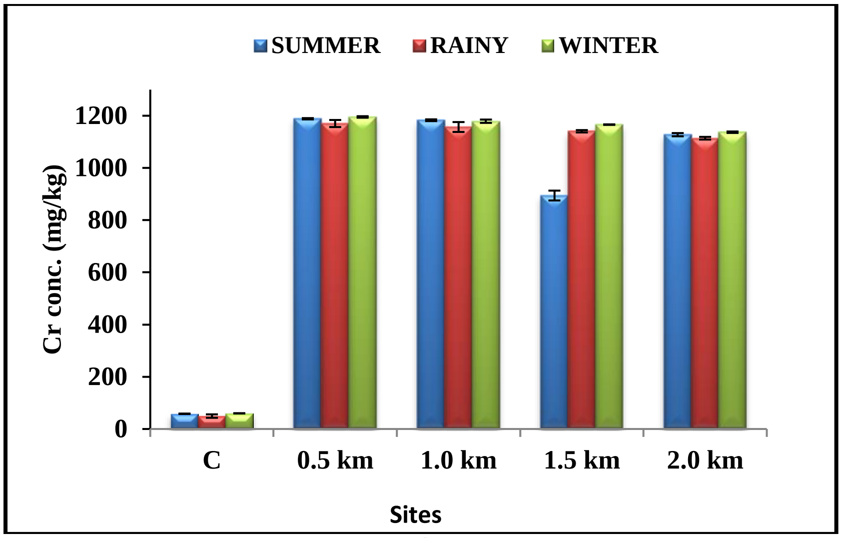

Figure -6 Concentrations of chromium (mg/kg) in different study sites during different seasons

Statistical Analysis for Heavy Metals: Two-Way ANOVA was carried out for each heavy metals separately to see the significance of difference between the seasons as well as between sites (Table-2). Two-Way ANOVA revealed that the seasonal variation affects the Cd concentration significantly (F=10051.14, p<0.001) along with significant difference among different sites (F=184.0, p< 0.001). For Pb the statistical analysis revealed the difference in lead concentration to be highly significant between seasons (F=859.86, p<0.001) as well as between different sites (F=261.34, p<0.001). Ni concentration showed significant difference in different seasons at P<0.001 (F=25997.37) and between different sites (F=261.34 at p<0.001). Arsenic concentration of soil also showed significant difference between seasons (F=623.17 at p<0.001) as well as between different sampling sites (F=212.96 at P<0.001). For Cr the two way ANOVA revealed highly significant difference between seasons as well as between different study sites (F=39680, p<0.01and F=31.8,p<0.05 respectively).To find out whether the distance wise variation of soil heavy metal contents in the experimental site were significant or not one way ANOVA (Table -3) was conducted. The analysis showed that concentrations of metals such as Cd, Pb, Ni, As decreased with increase in distance from the sponge iron plant, but the difference was not statistically significant. However, a significant variation in concentration of Cr was observed (F=3.13, p<0.05) in relation to distance. Thus, the study indicates that the distance has control over the increasing concentration of heavy metal close to the source of emission.

Table-2 Results of two way ANOVA for different heavy metal contents

Heavy metal contents (mg/kg)	*Source of Variation*	*df*	*F- values*
Cadmium	Seasons	4	10051.14***
	Sites	2	184**
	Interaction	8	11.61*
	Within	45	
	Total	59	
Lead	Seasons	4	859.86**
	Sites	2	261.34**
	Interaction	8	15.96*
	Within	45	
	Total	59	
Nickel	Seasons	4	25997.37***
	Sites	2	56.69*
	Interaction	8	3.75*
	Within	45	
	Total	59	
Arsenic	Seasons	4	4374.71***
	Sites	2	164.69**
	Interaction	8	26.76*
	Within	45	
	Total	59	
Chromium	Seasons	4	39680.22***
	Sites	2	31.8*
	Interaction	8	1.84^{NS}
	Within	45	
	Total	59	

* indicates significance at P<0.05,** indicates significance at P<0.001,
*** indicates significance at P<0.01, ^{NS} indicates not significant.

Table-3 One way ANOVA showing the distance wise variations of different heavy metal contents

Heavy metal contents (mg/kg)	*Source of Variation*	*Df*	*F- values*
Cadmium	Between distances	15	0.69^{NS}
	Within distances	16	
	Total	31	
Lead	Between distances	15	2.1S^{NS}
	Within distances	16	
	Total	31	
Nickel	Between distances	15	1.53^{NS}
	Within distances	16	
	Total	31	
Arsenic	Between distances	15	0.14^{NS}
	Within distances	16	
	Total	31	
Chromium	Between distances	15	
	Within distances	16	
	Total	31	3.13*

* indicates significance at $P<0.05$, ^{NS} indicates not significant

Discussion

The level of heavy metals in the soil of present was compared with the Indian Standard, Codex Alimentarious Commission (1996); Awasthi (2000); European Union (2000); WHO (2000). The guidelines identify ecological investigation levels (EILs) based on total metal concentration, considerations of phytotoxicity (Tasrina et al., 2015). The present study on heavy metal contents with respect to Cd, Pb, Ni, As and Cr in both the sampling sites revealed significantly higher concentration of all the elements in experimental sites in all the four directions as compared to control in three seasons i.e. summer, rainy and winter and there was a gradual decrease of the concentration of these heavy metals with the increasing distance from the stack of the steel making plant. Further, all the recorded toxic heavy metals content were found to be above the safe limit recommended by WHO/FAO (2007) in the experimental sites which is supposed to be due to continuous deposition of FA in the surrounding areas of the plant containing considerable amount of heavy metals in excess quantity. Rautray et al. (2003); Adriano et al. (1980); Singh et al. (2010); also recorded higher level of Fe, Cu, Mn, Zn, Cr, Ni, Pb and Cd in the soil contaminated with FA from a thermal power plant. Sahoo et al. (2014) also observed highly elevated levels of heavy metals in the soil nearer to sponge iron industry. The present study is thus is in conformity with above findings.

The investigation of heavy metals in the soil was essential since even slight change in their concentration above the acceptable levels, whether due to natural or anthropogenic factors, could result in serious environmental and subsequent health problems (Fangueiro et al., 2002; Sandroni and smith, 2002; Cobelo–Garcia et al., 2004). Due to increasing industrial activities, there is environmental pollution, decreasing soil fertility and adverse effects on soil micro organisms. Therefore, it is of great concern to study the degraded soil properties and function, and to utilize the waste for better crop production, simultaneously minimizing the soil pollution. It was recorded that all the metals at the industrial site (experimental site) were significantly higher than the control site in all the soil samples. The study thus demands to take appropriate steps to utilize the deposited FA and minimize the pollution in the surrounding areas of sponge iron industry. This was the reason for less fertile soil of the experimental sites particularly nearer to the source of emission (0.5 km distance). Generally, higher heavy metal concentration was recorded in the soil during summer season than rainy season. High rainfall is supposed to facilitate the leaching of the heavy metals down the soil profile during rainy season. In dry season open dumping of FA and deposition of atmospheric particulates loaded with heavy metals could have caused higher heavy metal contents in summer.

Conclusion:

The heavy metal pattern clearly indicating that the soil quality in the Rengali area is getting degraded with respect to heavy metal concentration which is a major point of concern. In Rengali area, the trend shows that the pollution is generated from the coal based sponge iron industries and getting dispersed. The present study on heavy metal contents with respect to Cd, Pb, Ni, As and Cr in both the sampling sites revealed significantly higher concentration of all the elements in experimental sites in all the four directions as compared to control in three seasons i.e. summer, rainy and winter and there was a gradual decrease of the concentration of these heavy metals with the increasing distance from the stack of the steel making plant. The heavy metal concentrations are higher at night during stable environmental conditions. Thus, deposition of FA in the surrounding environment of sponge iron plants leads to accumulation of heavy metals in the soil. Several workers demonstrated that the contamination of soil by heavy metals is a significant problem, which leads to negative influence on soil characteristics and limitations of productive and environmental functions. So proper care should be taken for the safe management and disposal of such pollutants to make the area a better place to live.

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