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Mobility Assessment of Heavy Metals with Seasonal Variation in an Industrial Region of Chhattisgarh

Manoj Kumar Tiwari†*, Samir Bajpai and Umesh Kumar Dewangan****
*Department of Civil Engineering, SSTC, Bhilai, India
**Department of Civil Engineering, National Institute of Technology, Raipur, India
†Corresponding author: Manoj Kumar Tiwari

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ABSTRACT

Heavy metals are a source of pollution affecting the whole environment. The concentration of heavy metals in a soil sample, collected from an adjoining area of steel slag dump yard, Bhilai, was investigated for pre and post monsoon seasons, up to a depth of one meter. Concentration profiles of selected metals are presented with the distances and depths to assess the migration. The Mn has transported from soils in pre-monsoon (7.763 mg/kg) and been retained in higher concentration (9.08 mg/kg) in post-monsoon, at moderate depths (0.5 m). The metal mobility order in the pre-monsoon was Mn>Cr>Fe>Pb>Zn; while for the post-monsoon the order was Mn>Cr>Fe>Zn>Pb. The distance and vertical mobility of selected metals were higher in post-monsoon.

INTRODUCTION

The release and transport of metals into the environment through industrial activities is of a great concern. This is very evident that the urban areas are always associated with various types of industrial activities that release a considerable amount of heavy metals into the atmosphere and soil (Shallar et al. 1998, Bilos et al. 2001, Senthilkumar et al. 2005, Rainer et al. 2007 and Ozan et al. 2008). Worldwide, soil pollution by heavy metals is a substantial environmental concern (Alloway 1995), due to urbanization and industrialization (Mireles et al. 2012, Wei & Yang 2010, Yaylali-Abanuz 2011). Some sources of these metals in the soil are dust fall (Cyrys et al. 2003, Gray et al. 2003, Naim et al. 2004 and Emanuela et al. 2006), fly ash (Schulze et al. 1997), slag (Patterson 1971) and other industrial solid wastes.

Production of steel is associated with a significant amount of various kinds of solid wastes and are a centre of attention with respect to its environmental impact. The steel industry sector in Chhattisgarh, including 86 iron-ore based industries (http://chhattisgarhmines.gov.in) and 130 steel re-rolling mills, produced a total capacity of 15 million tonnes of steel (MSMEDI 2015).

The solid waste generation, presently in Indian steel industry is in the range of 450-550 kg/t of crude steel (Ambasta et al. 2016). Bhilai steel plant (BSP) is undergoing expansion to increase hot metal production from 5.5 MTPA to 7.5 MTPA by 2015-16. (BSP, SAIL 2015). During the year 2015-16, 88.96% of blast furnace (BF) slag and 78.0% of basic oxygen furnace (BOF) slag were utilized (Sail Annual-Report-2015), leading to huge slag dumps.

Major issues of concern for steel slag wastes in Chhattisgarh are their huge generation, lower utilization, and unscientific open dumping on sites surrounding the populated areas. Steel slag may create an environmental hazard due to the release of the heavy metals bearing leachate severely affecting the surrounding soil and water and in turn human health (Carlson & Adriano 1993, El-Fadel et al. 1997). This necessitates the study of leachate from these waste dumps and study of the possible transport of the heavy metals from the leachate in the surrounding soil to evaluate their possible impacts along with the influence of monsoon season.

MATERIALS AND METHODS

Description of study area: The selected study area is enclosed by two different major industries; one is Bhilai Steel Plant with a capacity of 3.153 MT of saleable steel (IMYB 2015) generating about 2.1 million tonnes of slag every year, of which 81 per cent is blast furnace air-cooled and granulated slag (Kumar 2007) and the other is NSPCL coal-based thermal power plant of 74 MW capacity.

A large amount of industrial solid wastes is generated from these industries as fly ash (1.03 MT/year) and steel slag (2675 T/year), and after utilization a huge amount re-

Fig. 1: Location of the study area.

mains in the form of uncontrolled dumping (about 60% of fly ash and 40% of steel slag of generated amount) at the sites in the vicinity of industry areas, close to the adjoining population.

Sampling: The Fig. 1 indicates the surrounding area of the sampling. To assess the potential transport of the selected heavy metals (Cr, Fe, Mn, Pb, Zn) through the leachates from the waste dumps to the soil and water bodies in the surrounding areas, 80 soil samples (pre monsoon and post monsoon samples) were collected from the downstream side of dumps based on the direction of slope of the natural ground. The samples were collected up to a horizontal distance of 1.5 km (as after 1.5 km there are barriers of roads, railways and earthen fill) and as moving away from landfill locations. Prasad & Mondal (2008) reported that leachate migration to a long distance has not been seen from disposal sites for slag and fly ash. Also, according to Salami et al. (2013), the concentration of contaminants decreases with distance from the source and any impact of leachate will be negligible at such a distance.

Significant metal enrichment in the top layers of soils (0-20 cm) and exponential reduction in metal concentration in the lower soil depths has been reported (Liang et al. 2011). In another study the soil heavy metal content did not show changes in concentration below 100 cm depth (Wenji & Shan-ming 2016). Thus, at each sampling location, soil samples up to maximum 1 m depth were collected at every 25 cm intervals at different vertical depths from the surface, totalling 4 vertical samples at each location. Samples were collected from 10 such locations, totalling 40 samples for each season.

Soil digestion: The samples were ground with wooden roller, air dried and placed in electric oven at a temperature of 40°C approximately for 30 minutes. They were then homogenized and sieved through stainless steel IS sieve of 2 mm mesh. 0.1g sample was weighed out and transferred to the reaction vessel. 2.0 mL of concentrated nitric acid and 5.0 mL of concentrated hydrochloric acid were then added to each vessel. Vessels were then placed in the rotor and the rotor was microwaved. The vessels were allowed to cool for a minimum of 25 minutes before removing them from the microwave system. The vessels were carefully uncapped and the digests were filtered through Whatman No. 41 filter paper and the filtrate was collected in a 100 mL volumetric flask, the volume was adjusted to 100 mL with 0.5% HNO_3 (Tiwari et al. 2015).

Heavy metals analysis: The digested soil extract was analysed for heavy metals using the atomic absorption spectrophotometer (AAS), VARIAN GTA-120, AA240 model. Prior to the analysis, the samples were diluted with 2% 1N nitric acid solution to bring the pH to below 2.0. The AAS could detect the presence of heavy metals such as Cr, Fe, Mn, Pb, and Zn in the soil around the slag dumping site (Table 1).

RESULTS AND DISCUSSION

The concentrations of the heavy metals were significantly different between each sampling location. Assessment of average data of heavy metal concentration indicated that all the metals were within the permissible limit with Mn showing higher values. In depth-wise pre-monsoon soil analysis, the higher metal concentrations were present near the topsoil (0.25 m); while, in post-monsoon samples, the higher metal concentrations were present between 0.25 m and 1.0 m depth. Also, the metal concentrations varied significantly at sampling locations at various distances, for both the seasons.

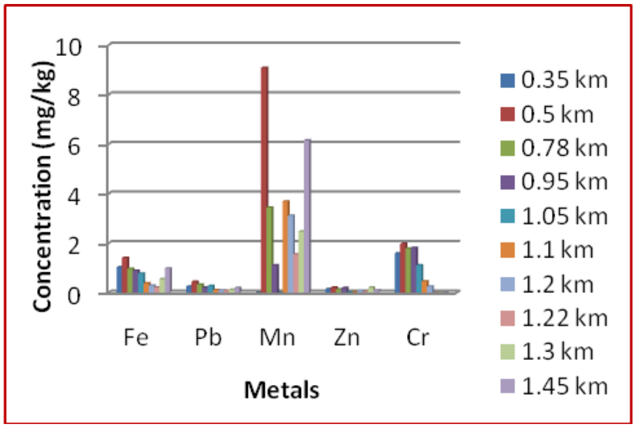
The higher heavy metal concentrations near the subsoil and a significant increase was observed in the post-monsoon season. This increase may be due to rainfall and more leachate release from dumps of industrial solid wastes.

It shows the higher heavy metal concentrations near the topsoil (Rais 2005), but no significant increase was observed in heavy metal concentrations in the subsoil. The results clearly show that the maximum concentration of heavy metals was observed near the dumpsite. The concentrations of heavy metals also decreased as the soil sampling distance from the dump increased. This was in accordance with other studies (Chinwe et al. 2010, Ipeaiyeda & Dawodu 2008, Oyedele et al. 2008, Sobolev & Begonia 2008 and Bada et al. 2001).

The maximum concentrations of heavy metals were observed at a distance of 500 m in pre-monsoon, whereas from 350 m to 950 m in the post monsoon season, from the dump location. The metal mobility in the pre-monsoon soil samples, for both depth and distance, was in the order:

Table 1: Operating conditions of AAS.

Instrument Condition	Lead	Chromium	Iron	Manganese	Zinc
Lamp			Hollow Cathode		
Slit	4	3	3	4	4
Wavelength	283.3 nm	358.3 nm	248.3 nm	279.8 nm	670.8 nm
Fuel			Acetylene		
Oxidant	Air	Air	Air	Air	Air
Type of flame	Oxidizing	Reducing (slightly yellow)	Oxidizing	Oxidizing	Oxidizing



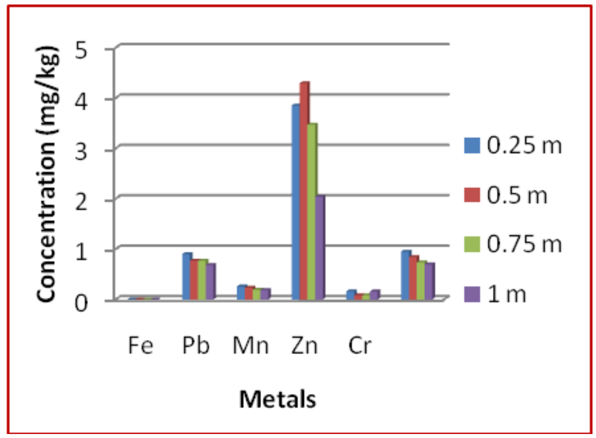


Fig. 2: Average concentration (mg/kg) distance and depth-wise.

Table 2: Average metals concentration in soil (mg/kg).

Samples	Cr	Fe	Mn	Pb	Zn
Blank Sample	2.051	19.87	21.63	6.37	5.863
Pre-monsoon	1.984	1.416	9.08	0.453	0.214
Post-monsoon	2.042	1.68	6.07	0.509	0.604

Table 3: Maximum and minimum metal concentration.

Metals	Pre-monsoon concentrations (mg/kg)		Post-monsoon concentrations (mg/kg)	
	Max	Min	Max	Min
Cr	2.938	0.088	3.358	0.034
Fe	2.004	0.182	2.442	0.156
Pb	0.59	0.09	0.69	0.009
Mn	7.763	0.0	9.08	0.05
Zn	0.745	0.013	0.706	0.004

Mn>Cr>Fe>Pb>Zn; while for the post-monsoon soil samples the order was Mn>Cr>Fe>Zn>Pb (Tables 2 & 3, Figs. 2 & 3).

In a study, it was reported that the heavy metals (Pb, Cd, Zn, Cr, Ni) in soils at various depths and distances away from the dumpsite in the wet and dry seasons were higher in the dry season when compared with the wet season, which can be attributed to the leaching of the cations down the profile by rainfall (Olafisoye et al. 2013, Alloway & Ayres 1997, Chinwe et al. 2010).

Correlation studies of heavy metals: The analysed metals indicated a significant, both, positive and negative correlation (Table 4). Thus, no definite correlation could be observed, both, for the pre-monsoon and post-monsoon samples metal concentration with respect to the distance from the dump site. The same was substantiated by the p-values as well.

CONCLUSION

The major issues of concern for fly ash and steel slag wastes in study area are their huge generation, lower utilization, and unscientific open dumping on sites surrounding the populated areas. The study reveals that heavy metal concentration of topsoil is significant in the study area. In depth-wise pre-monsoon analysis, the higher concentrations were present near the topsoil (0.25 m); while, in post-monsoon samples, the same were present between 0.25 m and 1.0 m depth, indicating a mobility to lower soil layers.

The maximum concentrations of heavy metals were observed at a distance of 500 m and from 350 m to 950 m in pre and post monsoon season respectively. The metal mobility for both, depth and distance, was in the order of Mn>Cr>Fe>Pb>Zn and Mn>Cr>Fe>Zn>Pb in both the

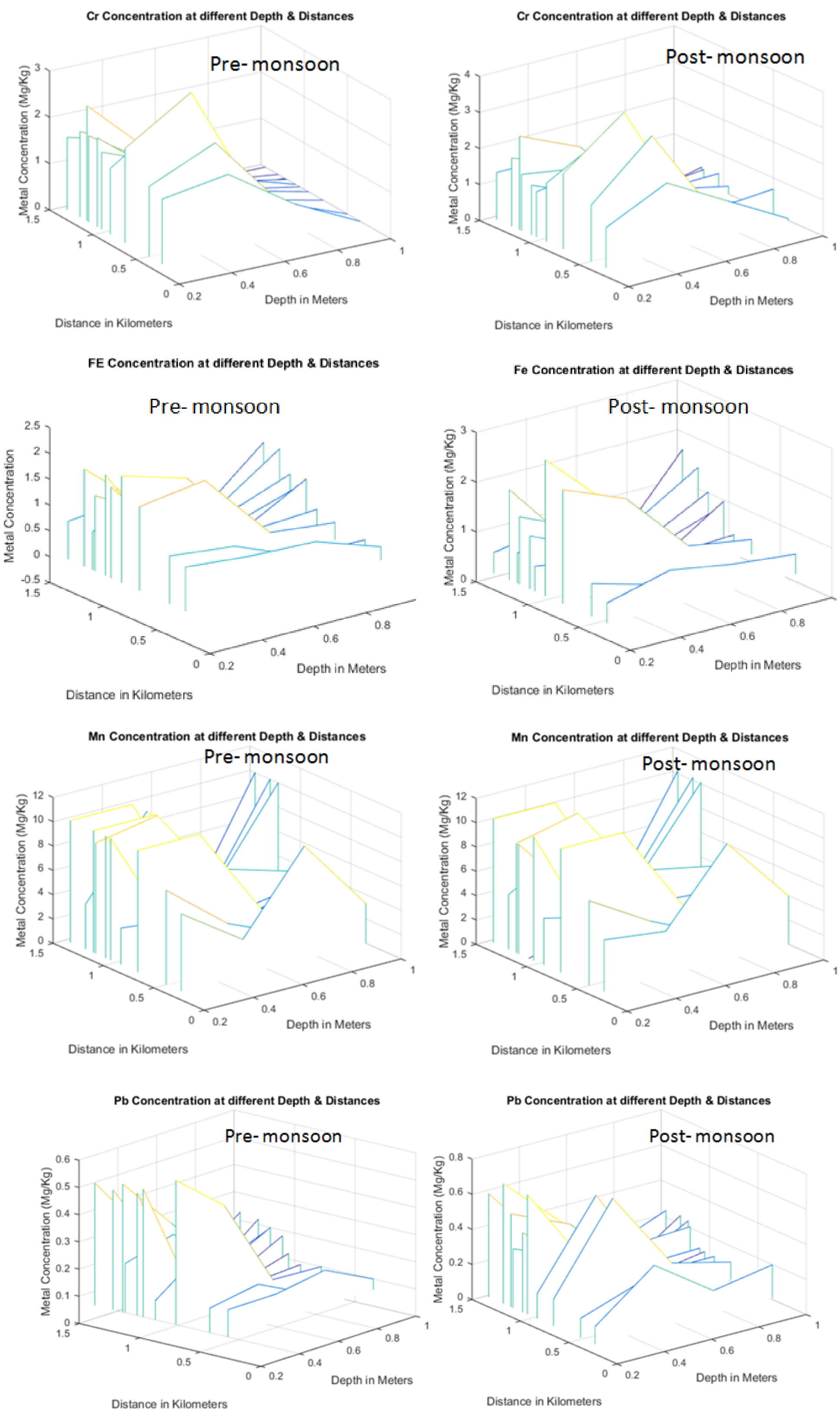

Cr Concentration at different Depth & Distances
Pre- monsoon
Metal Concentration (Mg/Kg)
Distance in Kilometers
Depth in Meters
Cr Concentration at different Depth & Distances
Post- monsoon
Metal Concentration (Mg/Kg)
Distance in Kilometers
Depth in Meters
FE Concentration at different Depth & Distances
Pre- monsoon
Metal Concentration
Distance in Kilometers
Depth in Meters
Fe Concentration at different Depth & Distances
Post- monsoon
Metal Concentration (Mg/Kg)
Distance in Kilometers
Depth in Meters
Mn Concentration at different Depth & Distances
Pre- monsoon
Metal Concentration (Mg/Kg)
Distance in Kilometers
Depth in Meters
Mn Concentration at different Depth & Distances
Post- monsoon
Metal Concentration (Mg/Kg)
Distance in Kilometers
Depth in Meters
Pb Concentration at different Depth & Distances
Pre- monsoon
Metal Concentration (Mg/Kg)
Distance in Kilometers
Depth in Meters
Pb Concentration at different Depth & Distances
Post- monsoon
Metal Concentration (Mg/Kg)
Distance in Kilometers
Depth in Meters

Fig. 3 cont....

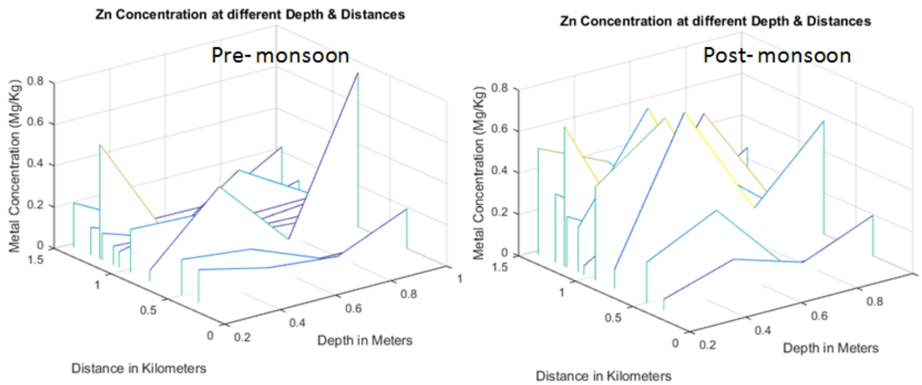


Fig. 3: Metal concentration in pre and post-monsoon seasons.

Table 4: Correlation analysis and p-value results.

Distance (km)	Metal	Post-monsoon		Post-monsoon	
		Pearson Correlation	p-value	Pearson Correlation	p-value
0.00 to 0.35	Fe	0.964	0.036	0.957	0.043
	Pb	0.204	0.796	0.868	0.132
	Mn	- 0.661	0.339	- 0.371	0.629
	Zn	0.046	0.954	0.788	0.212
	Cr	0.254	0.746	0.660	0.340
0.35 to 0.50	Fe	- 0.863	0.137	0.201	0.799
	Pb	- 0.246	0.754	- 0.507	0.493
	Mn	0.258	0.742	0.896	0.104
	Zn	0.831	0.169	0.925	0.075
	Cr	0.880	0.120	0.886	0.114
0.50 to 0.78	Fe	- 0.863	0.137	0.201	0.799
	Pb	- 0.246	0.754	- 0.507	0.493
	Mn	0.258	0.742	0.896	0.104
	Zn	0.831	0.169	0.925	0.075
	Cr	0.880	0.120	0.886	0.114
0.78 to 0.95	Fe	0.096	0.904	- 0.891	0.109
	Pb	- 0.398	0.602	- 0.912	0.088
	Mn	- 0.170	0.830	0.090	0.910
	Zn	0.830	0.170	- 0.336	0.664
	Cr	0.863	0.137	- 0.999	0.001
0.95 to 1.05	Fe	0.096	0.904	- 0.588	0.412
	Pb	- 0.398	0.602	- 0.018	0.982
	Mn	-	-	- 0.105	0.895
	Zn	0.830	0.170	0.819	0.181
	Cr	0.863	0.137	- 0.255	0.745

seasons. Also the metal concentrations in soil samples varied significantly at each sampling location at various distances, for both the seasons. To reduce the heavy metal pollution within safe limits, an anticipatory remedial action possibly will be essential on the identified dumpsite surroundings, in addition to other measures.

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