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Assessment of Contamination of Soil due to Heavy Metals around Coal Fired Thermal Power Plants at Singrauli Region of India

Prashant Agrawal · Anugya Mittal · Rajiv Prakash · Manoj Kumar · T. B. Singh · S. K. Tripathi

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Abstract In the present study, an attempt was made to measure contamination of soil around four large coal-based Thermal Power Plants. The concentration of Cadmium, Lead, Arsenic and Nickel was estimated in all four directions from Thermal Power Plants. The soil in the study area was found to be contaminated to varying degrees from coal combustion byproducts. The soil drawn from various selected sites in each direction was largely contaminated by metals, predominantly higher within 2–4 km distance from Thermal Power Plant. Within 2–4 km, the mean maximum concentration of Cadmium, Lead, Arsenic and Nickel was 0.69, 13.69, 17.76, and 3.51 mg/kg, respectively. It was also observed that concentration was maximum in the prevalent wind direction. The concentration of Cadmium, Lead, Arsenic and Nickel was highest 0.69, 13.23, 17.29 and 3.56 mg/kg, respectively in west direction where wind was prevalent.

Keywords Power Plant · Fly ash · Soil · Metal

Thermal power plants consume a large amount of coal to generate electricity. Due to this coal combustion, a significant quantity and variety of trace elements, some of them potentially toxic, is transferred to the surrounding environment through different pathways (Goodarzi et al. 2008; Reddy et al. 2005; Baba 2002; Llorens et al. 2001). The importance of this transfer can be inferred from the fact that a conventional power plant of 1,000 MW consumes 12,000 tonnes (t) of coal per day and produces about 1,000,000 t of wastes per year.

During the combustion process, trace elements are released to the environment through two main pathways: (1) atmospheric emissions via the stack, including elements which are volatilized and those which are condensed and enriched in fine particles that escape from the particulate retention devices, and (2) leaching of combustion by-products (fly and bottom ashes) once these are ponded or landfilled, when these materials cannot be marketed for a wide variety of applications such as construction, ceramics and soil amendments (Llorens et al. 2001). The purpose of this work was to estimate the concentrations of Cadmium (Cd), lead (Pb), Arsenic (As) and Nickel (Ni) in soil around coal fired power plants in Singrauli region of India.

Materials and Methods

This study was based on the quantitative estimation of the toxic heavy metals (Cd, Ni, Pb and As) present in soil samples around coal fired Thermal power Plants (TPPs) in "Singrauli area". This area includes part of Singrauli District, of state Madhya Pradesh, and the adjoining southern part of the state of Uttar Pradesh (Sonebhadra District) and popularly known as "Energy Capital of India". The Singrauli region in India is one of the most polluted industrial sites of Asia. It encompasses 11 open cast coal mines and five coal based Thermal power Plants

P. Agrawal (✉) · A. Mittal · M. Kumar · S. K. Tripathi
Department of Forensic Medicine, Institute of Medical Sciences, Banaras Hindu University, Varanasi, India
e-mail: prashantagrawala@gmail.com

R. Prakash
School of Material Science & Technology, Institute of Technology, Banaras Hindu University, Varanasi, India

T. B. Singh
Department of Community Medicine, Institute of Medical Sciences, Banaras Hindu University, Varanasi, India

having capacity to generate about 9,000 MW (about 10% of India's total installed generation capacity) electricity. Thermal power Plants represent the main source of pollution in Singrauli region, emitting six million tonnes of fly-ash per annum.

In present study four Thermal power plants were chosen, two of them belongs to NTPC viz. Singrauli and Vindhyachal Super Thermal Power Plants (SSTPP & VSTPP), and two others Anpara and Renusagar Thermal Power Plants (ATPP & RTPP) belong to Uttar Pradesh state Government and private sector of Birla group respectively.

The present study was carried out for 3 years from March 2005 to February 2008. During this study period 256 soil samples were collected from different selected sites within the studied area (Fig. 1). In India there are three seasons in a year i.e., summer (March–June), monsoon (July–October) and winter (November–February). Sampling was done in summer and winter seasons of each year. Therefore, season wise it is categorized into Pre Monsoon Season (summer) and Post Monsoon Season (winter). Soil samples were collected at an interval of 2 months in respective season i.e., four times in a year.

For the collection of soil samples, the study area is divided into two Site I and Site II. Site I is the area surroundings of Anpara & Renusagar Thermal power plants whereas site II is surrounding area of Shaktinagar & Vindhyanagar Thermal power plants. The two power plants of each site are very close to each other. Each site is further divided into sub sites along a transect, assuming the power plants at centre, up to a distance of 8 km from Thermal power plants in all four east, west, north and south directions. Each sub site was spaced out at 2 km intervals for each transect. Therefore, a total four sub sites were selected for each site at the distances of 2, 4, 6 and 8 km from Thermal power plants in each direction. Each sub site was further divided into micro sites. Soil samples were collected randomly from the region of each selected micro site to determine elemental contamination from fly ash dispersal around the power plants.

Soil samples of about 100 g were randomly collected in polyethylene bags from each selected micro site. The collection of samples was considered from the surface soil as well as up to 30 cm beneath the soil surface. Collected all three replicate samples were mixed together in laboratory to prepare a pool sample of one micro site to minimize the chances of error during sampling. Pool sample was air dried at room temperature for 2–3 days, ground with a pestle and mortar and finally dried at 50°C. Dried samples

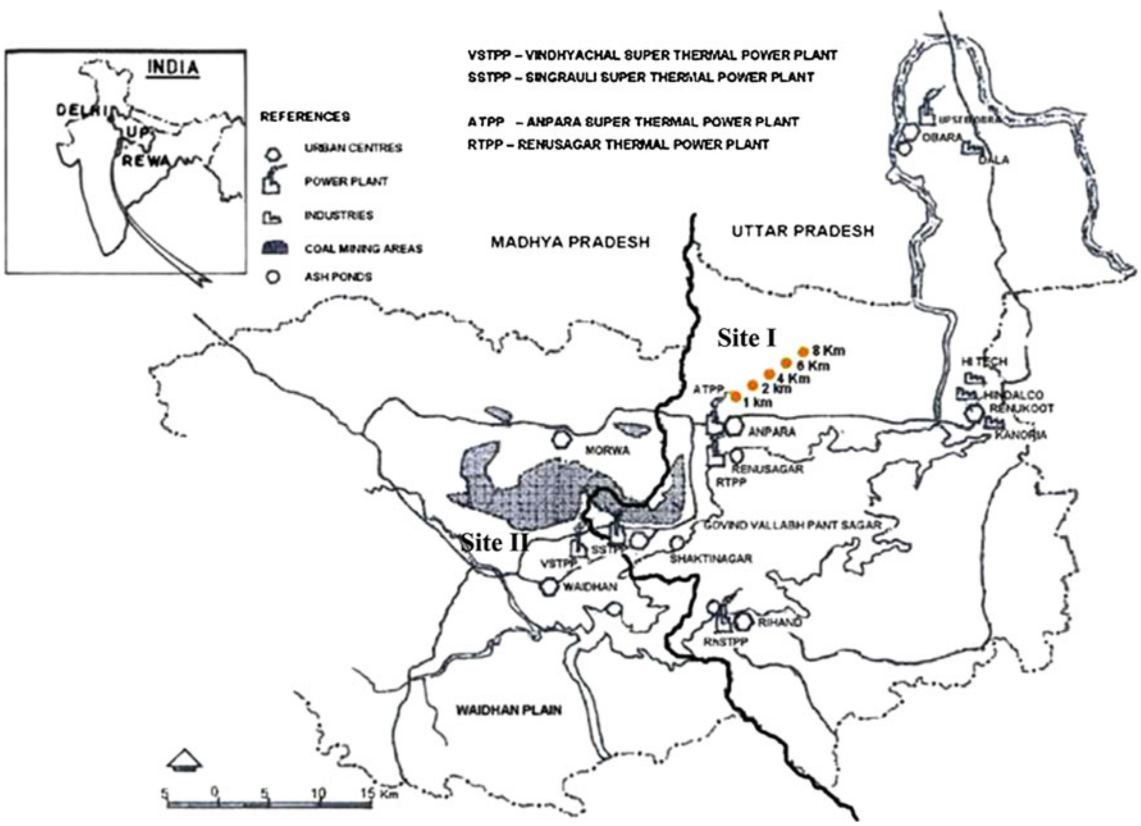

Fig. 1 Map of Singrauli region showing thermal power plants

were sieved using 70-mesh plastic sieves size (Mehra et al. 1998).

Take 1 g (dry weight) of soil to a digestion vessel in triplicate. 10 mL of concentrate Nitric acid (HNO_3) is added and leave it overnight. Next day, put the sample on preheated hot plate at 90°C and reflux without boiling until 1–2 mL of the sample is left. Allow the sample to cool, add 5 mL of digestion mixture (6 part conc. HNO_3 and 1 part $HClO_4$) and reflux for further 30 min. Repeat this step over and over until no brown fumes are given off by the sample. Filter through Whatman No. 41 filter paper. Rinse the digestate samples (all three replicates) with 1% Conc. HNO_3 and transfer the sample in separate graduated centrifuge vials and make the volume up to 10 mL (Nakadaira et al. 1995; Pip 1991).

Digestate samples were analyzed by Atomic Absorption Spectrophotometer (AAS, Model Elico SL 194 double beam). An average of the readings of all three replicates is noted as final. The results of both the sites (site I & site II) were clubbed together and statistical analysis is done to know the influence of all four Thermal Power plants in Singrauli region. The detection limits of AAS for Cd, Ni, Pb and As were 0.02, 0.1, 1.0, and 0.01 mg/L respectively. Analysis was done in Toxicology laboratory, Department of Forensic Medicine, Institute of Medical Sciences, Banaras Hindu University, Varanasi.

Results and Discussion

The Distance wise distribution of mean concentrations of Cd, Ni, Pb and As in pre and post monsoon season (Tables 1, 2) revealed that the maximum concentration (0.69, 13.69, 17.76, and 3.51 mg/kg, respectively) was found at distance of 2–4 km from Thermal power Plants in pre monsoon season. Similar Pattern was found in post monsoon seasons with maximum concentration 0.77, 13.45, 17.91 and 3.87 mg/kg, respectively.

Further at onward distances up to 8 km, concentration was found with decreasing trend (0.35, 11.39, 15.44, and 2.49 mg/kg, respectively). It was also noticed that at both sites near the Thermal power Plants (0–2 km), concentration was found lesser in pre monsoon (0.46, 11.99, 16.33 and 1.72 mg/kg, respectively) and post monsoon seasons (0.55, 12.0, 16.53 and 2.07 mg/kg, respectively) than the maximum concentration at distance 2–4 km. Further observation revealed that the mean concentration of Cd, Ni and Pb pollutants was minimum at 6–8 km distance (0.35, 11.39, 15.44 mg/kg, respectively in pre monsoon and 0.39, 11.91, 15.42 mg/kg, respectively in post monsoon season) but in As the pattern was reverse i.e., the minimum concentration (1.72, 2.07 mg/kg) was recorded at near distance 0–2 km from Thermal power Plants in pre and post monsoon season respectively. Study also revealed that in post monsoon seasons the concentration of all heavy metals was found higher than pre monsoon seasons depicting a direct seasonal effect.

Cicek et al. (2001) stated that with the increase in the use of coal, especially in Thermal power Plants, combustion products has become very important contributors to pollution, due to toxic heavy metal contents. As fly ash is small enough to be carried with the flue gas, vapor and the finer fly ash particles that escape from the stack system and that are blown by the wind, enter the atmosphere. Praharaj et al. (2003) made an attempt to delineate soil contamination around the ash pond of a coal-based thermal power plant in Orissa. The topsoil in the study area was found to be contaminated to varying degrees from ash disposal. The soil drawn from various profiles was largely contaminated by ash fall out, predominantly in the prevalent wind direction.

Mehra et al. (1998) observed a classical distribution pattern distance wise in the elemental concentrations of Al, alkali and alkaline earth metals in soils and found that the concentrations are generally seen to be higher in concentrations up to a distance of 4 km as compared with concentrations at 6 and 8 km from the power stations and Cu, Mn, Pb and Zn levels decrease to some extent 4 km south of the power plants. Concentrations of all elements decrease after 4 km east of the power plants. Almost similar pattern has been found in present study.

Table 1 Mean concentrations (mg/kg) of metals in soil around thermal power plants at varying distances in pre monsoon seasons (n = 128)

Distance from thermal power plants	No of samples (n)	Cd Mean ± SD	Ni Mean ± SD	Pb Mean ± SD	As Mean ± SD
0–2 km	32	0.46 ± 0.14	11.99 ± 1.19	16.33 ± 1.55	1.72 ± 0.37
2–4 km	32	0.69 ± 0.1	13.69 ± 2.09	17.76 ± 1.16	3.51 ± 0.72
4–6 km	32	0.5 ± 0.13	12.13 ± 0.85	16.52 ± 1.2	2.79 ± 0.56
6–8 km	32	0.35 ± 0.11	11.39 ± 1.79	15.44 ± 0.92	2.49 ± 0.62
(ANOVA) p value		<0.001***	<0.001***	<0.001***	<0.001***

*** $p = <0.001$

Table 2 Mean concentrations (mg/kg) of metals in soil around thermal power plants at varying distances in post monsoon seasons (n = 128)

Distance from thermal power plants	No of samples (n)	Cd Mean ± SD	Ni Mean ± SD	Pb Mean ± SD	As Mean ± SD
0–2 km	32	0.55 ± 0.14	12.0 ± 1.33	16.53 ± 1.12	2.07 ± 0.71
2–4 km	32	0.77 ± 0.11	13.45 ± 1.81	17.91 ± 1.16	3.87 ± 0.97
4–6 km	32	0.56 ± 0.12	12.05 ± 1.07	16.39 ± 1.03	3.33 ± 0.96
6–8 km	32	0.39 ± 0.12	11.91 ± 2.78	15.42 ± 0.9	2.83 ± 1
(ANOVA) p value		<0.001***	<0.001***	<0.001***	<0.001***

*** p = <0.001

Padmanabhamurty and Gupta (1977) have reported that generally the total particulate deposition from Indraprastha Power station in Delhi is higher in the winter months from October to March i.e., in post monsoon season. Reddy et al. (2005) studied emission characteristics of trace metals from coal and fuel oil fired power plants located in western India. A study of trace metal emissions from a 220 MW coal fired power plant and a 6 MW fuel oil based power plant was carried out. Potential toxic trace elements As, Cd, Cu, Co, Cr, Hg, Fe, Mn, Ni, Pb, Se and Zn are distributed in the flue gas from coal as well as from oil-fired power plants.

Sushil and Batra (2006) investigate the heavy metal content of fly ash and bottom ash from three major power plants in North India. The ashes were analyzed for the presence of Cr, Mn, Pb, Zn, Cu, Ni and Co and detectable levels of all were found in both fly ash and bottom ash (Goodarzi et al. 2008).

Mandal and Sengupta (2005, 2006) studied the extent of soil contamination around one of the largest thermal power plants of India located at Kolaghat, West Bengal India. Chemical analysis of the top soils and the soils collected from the different depth profiles surrounding the ash ponds show that the top soils are enriched in the trace elements. Mo, As, Cr, Mn, Cu, Ni, Co, Pb, Be, V, Zn heavy metals show maximum enrichment in the top soils collected from all the soil profiles. These elements are also enriched in the pond ash. Since there are no other sources of industrial effluents, it can be said that the enrichment of the trace elements (Mn, Co, Mo, Cr, Cu, Pb, Zn, As, Ni, Be, V) is attributed to their input from ash from the disposal pond (Gulec et al. 2001).

The Direction wise distribution of mean concentrations of Cd, Ni, Pb and As in pre and post monsoon season (Tables 3, 4) revealed that maximum concentration of all the heavy metals (0.53, 12.94, 17.29 and 3.12 mg/kg, respectively) was in west direction from the Thermal power Plant of Singrauli area in pre monsoon season. Similarly in post monsoon season the maximum concentration was found in west direction (0.69, 13.23, 17.03 and 3.56 mg/kg, respectively). The distribution of minimum concentrations of above mentioned pollutants direction wise was found in east direction from Thermal power Plants in pre monsoon season and it was 0.48, 11.04, 15.41 and 2.26 mg/kg, respectively. In post monsoon season also it was minimum in east direction (0.52, 12.07, 15.23 and 3.11 mg/kg, respectively).

The direction wise distribution pattern in Singrauli area may be dependent on topographic situation i.e., the studied site is located on hill surrounded plateau. Due to its topographic situation, the wind direction is prevalent round the year in west direction, therefore the maximum concentration of pollutants was observed in west direction from Thermal power Plants.

Keegan et al. (2006) studied the dispersion of As and heavy metals around coal-burning power station in central

Table 3 Mean concentrations (mg/kg) of metals in soil around thermal power plants in pre monsoon seasons direction wise (n = 128)

Distance from thermal power plants	No of Samples (n)	Cd Mean ± SD	Ni Mean ± SD	Pb Mean ± SD	As Mean ± SD
East	32	0.48 ± 0.21	11.04 ± 1.78	15.41 ± 1.46	2.26 ± 0.86
West	32	0.53 ± 0.14	12.94 ± 1.6	17.29 ± 1.84	3.12 ± 0.72
North	32	0.49 ± 0.18	11.97 ± 1.30	15.82 ± 1.04	2.47 ± 0.68
South	32	0.51 ± 0.15	12.25 ± 2.16	16.53 ± 1.07	3.02 ± 1.05
(ANOVA) p value		0.779	0.108	<0.001***	0.029*

*** p = <0.001

* p = <0.05

Table 4 Mean concentrations (mg/kg) of metals in soil around thermal power plants in post monsoon seasons direction wise (n = 128)

Distance from thermal power plants	No of Samples (n)	Cd Mean ± SD	Ni Mean ± SD	Pb Mean ± SD	As Mean ± SD
East	32	0.52 ± 0.22	12.07 ± 0.88	15.23 ± 1.06	3.11 ± 1.26
West	32	0.69 ± 0.17	13.23 ± 1.85	17.03 ± 1.86	3.56 ± 0.76
North	32	0.57 ± 0.18	12.76 ± 1.28	16.13 ± 1.13	3.29 ± 1.21
South	32	0.59 ± 0.16	12.35 ± 3.07	16.85 ± 1.12	3.23 ± 0.96
(ANOVA) *p* value		0.405	0.545	0.016*	0.001***

*** $p = <0.001$

* $p = <0.05$

Slovakia. Coal samples were taken from the power station and analysed to determine concentrations of As, Zn, Pb, Cu, Cr, Ni and Cd. Concentrations of soil As were substantially raised in the near vicinity of the plant but decreased within 5 km to concentrations similar to those in the rest of the district. Concentrations in coal of all six heavy metals tested (Cd, Cr, Cu, Ni, Pb and Zn) were slightly raised. Topsoil concentrations of Cr, Cu, Pb and Zn decreased with distance from the plant.

Cicek and Koparal (2004) studied the quantities of sulfur and heavy metals, resulting from the Tuncbilek Thermal Power Plant (TPP) in Turkey in tree leaves and soil samples within a 10 km radius of the plant. A preliminary study was conducted at a total of 28 locations, 7 locations for each principal direction. As a result of the analysis it was found that the southern locations to the Thermal power Plant, and where the prevailing winds are directed, had the highest level of pollutant concentrations. Leaf and soil samples obtained from northern, eastern and western locations of the Thermal power Plant, outside the impact zone of dominant winds, had relatively less sulfur and heavy metal concentrations.

Mehara et al. (1998) worked the elemental concentrations of Cd, Co, Cr, Cu, Mn, Ni, Pb and Zn in soils around the thermal power stations in Delhi, India and observed that the distribution of concentrations of pollutants has some relation with the distance and directions from Thermal power Plants i.e., Concentrations of all elements decrease after 4 km east of the power plants and they drop substantially at site W4 (8 km west of the power stations), whereas Cd levels are the lowest, indicating a reduction in Cd levels in this direction which is in the opposite direction to the prevailing winds. No trends can be observed in elemental concentrations in soils north of the power stations.

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