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CIVIL & ENVIRONMENTAL ENGINEERING | RESEARCH ARTICLE

Heavy metal contamination of groundwater due to fly ash disposal of coal-fired thermal power plant, Parichha, Jhansi, India

Chanchal Verma¹, Sangeeta Madan^{1*} and Athar Hussain²

Abstract: The present study focused on the groundwater contamination due to fly ash disposal of coal-fired thermal power plant into a non liner ash pond. Six villages were selected as study site around ash pond of Parichha thermal power plant, Jhansi. Groundwater samples were collected on seasonal basis; winter season (January 2015), pre monsoon season (May 2015), and monsoon season (August 2015) using composite sampling method. Five heavy metals (Pb, Ni, Cr, Mn, and Fe) were detected in coal, fly ash, and groundwater samples. Heavy metal concentration in coal and fly ash was assessed by Energy Dispersive X-ray Fluorescence, while AAS was used for groundwater assessment. Heavy metal concentration in groundwater was ranged as Pb (0.170–0.581 ppm), Ni (0.024–0.087 ppm), Fe (0.186–11.98 ppm), Cr (0.036–0.061 ppm), and Mn (0.013–0.178 ppm). The observed results revealed the exceeding value of heavy metals prescribed by WHO for groundwater.

Subjects: Environmental Health; Pollution; Water Science

Keywords: groundwater; fly ash; thermal power plant; ash pond; heavy metal; environmental sustainability engineering

1. Introduction

Heavy metal contamination in air, soil and water is a global problem that is a growing threat to human beings. There are hundreds of sources of heavy metal pollution, including coal combustion in thermal power plants (Khan, Din, Ihsanullah, & Ahmad, 2011). Fly ash produced during the combustion of coal contains several toxic heavy metals like lead (Pb), nickel (Ni), zinc (Zn), manganese (Mn), etc. The extent of heavy metals in fly ash depends on both the mineralogy and particle size distribution of the raw material being burnt and combustion temperature. Fly ash is found to be more enriched with several toxic elements as compared to its parent coal (Baba, Gurdal, Sengunalp, & Ozay, 2008) because many of trace elements present in parent coal is vaporized during the combustion.

Coal-based thermal power plants contributing to 61% of total installed capacity, are the major source of electricity generation in India (Tiwari, Bajpai, Dewangan, & Tamrakar, 2015). Thermal

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PUBLIC INTEREST STATEMENT

The present work has highlighted the groundwater contamination with heavy metal due to uncontrolled fly ash disposal from thermal power plant and possible health impacts on the population residing in the vicinity of power plant, those are consuming groundwater for drinking purpose.

power plants generate a large amount of fly ash as solid waste material from coal combustion. Currently, the generation of fly ash from coal-based thermal power plants in India is about 131 million tons per annum (Singh, Gupta, & Guha, 2014). Disposal of such a huge quantity of fly ash is a major environmental concern. Much of the ash is disposed off in the settling ponds with effluent outlets that enter into local water ways. If the ash pond is unlined, then a significant volume of the ash leachate percolates underground to the underlying water table (Praharaj, Powell, Hart, & Tripathy, 2002).

Water quality around ash pond is altered due to the leaching of soluble ions present in fly ash. The leaching potential of heavy metals from an open system (ash pond) is expected to be greater due to diurnal and seasonal variation in temperature, moisture, and other parameters. Movement of water through materials containing soluble components significantly influences the surrounding soil, groundwater, and surface water. Due to leaching characteristics of fly ash, the soluble heavy metals gradually percolate downward to contaminate nearby groundwater aquifers. This raises the potential threat of percolation of hazardous elements from fly ash to groundwater and subsoil degradation from the ash pond (Singh et al., 2014).

Parichha thermal power plant is a coal-fired power plant in Jhansi, India. Fly ash produced as a byproduct in power plant is being disposed in form of ash slurry into a non liner ash pond. Ash slurry water contains toxic heavy metals leached from fly ash and percolates downward through soil strata and may contaminate groundwater. The objective of present study is to assess the heavy metal concentration in coal, fly ash, and groundwater in surrounding of ash pond.

2. Materials and methods

2.1. Sample collection

Coal and fly ash samples were collected from Parichha Thermal power plant, Jhansi, India. Groundwater samples were collected from villages around ash pond of Parichha thermal power plant using composite sampling method. Sampling of groundwater was carried out in winter season (January 2015), pre monsoon season (May 2015), and monsoon (August 2015). Groundwater samples were acidified with nitric acid. Three ml of nitric acid was added in one liter of sample to stabilize heavy metals (Figure 1).

2.2. Sample preparation

Fine powder of coal and fly ash samples was mixed with boric acid to make separate pellets. The mixture of sample and boric acid is filled in a ring-shaped cup and pressed with a press machine. Boric acid was used as a binding material. The process is known as pelletization. Compressed pellet, shown in Figure 2, is used for Energy Dispersive X-ray Fluorescence (EDXRF) analysis.

Figure 1. Study area map with sampling sites.

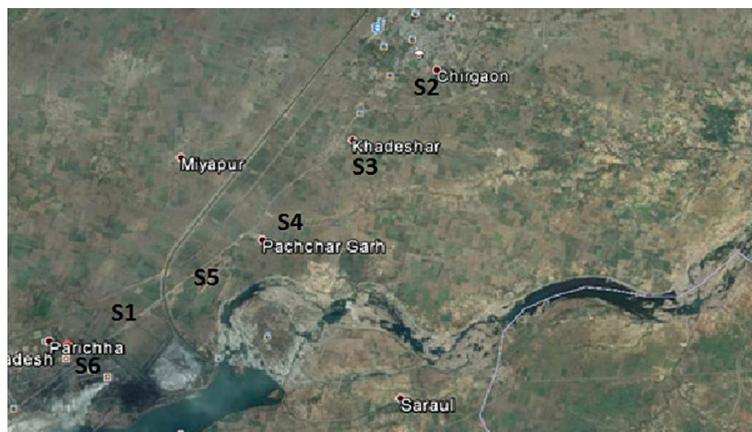


Figure 2. Pellet used in EDXRF.



Table 1. Different wavelengths used for heavy metal detection on AAS

Element	Wavelength (nm)
Pb	217
Ni	232
Fe	248.3
Cr	357.9
Mn	279.5

Groundwater samples were digested with nitric acid. Five ml nitric acid was added to 100 ml of water sample. Sample was heated at a very low temperature until 10–20 ml was left. The sample was cooled and filtered with Whatmann 42 filter paper and the final volume was made up to 100 ml (American Public Health Association, 2005).

2.3. Sample analysis

Heavy metals like lead (Pb), nickel (Ni), iron (Fe), chromium (Cr), and manganese (Mn) were assessed in coal, fly ash and groundwater samples. EDXRF technique was used for coal and fly ash samples and atomic absorption spectrophotometer was used for groundwater samples. The detection wavelengths of heavy metals on atomic absorption spectrophotometer are given in Table 1.

3. Results and discussion

Fly ash is normally considered hazardous to living organisms. Heavy metals in coal can be emitted into the atmosphere with flue gas during combustion process (Yuan, 2009). Heavy metal concentration obtained in coal, fly ash and groundwater samples are presented in Tables 2 and 3 respectively.

3.1. Heavy metal concentration in coal and fly ash

Coal is carbon-rich combustible material containing organically bound mineral matter. This organic material is released during coal combustion to form an ash residue (Zandi & Russell, 2007). Various factors that control the concentrations of trace elements in the coal and ashes include element

Table 2. Heavy metal concentration in coal and fly ash samples

Heavy metal	Coal (ppm)	Fly ash (ppm)
Pb	4.117	34.809
Ni	18.695	51.609
Fe	1,929.48	2,635
Cr	7.976	64.772
Mn	35.084	286.205

Table 3. Heavy metal concentration in groundwater samples

Heavy metals	Season	S1	S2	S3	S4	S5	S6	Average	WHO Permissible limit (ppm)
Pb	Pre Monsoon	0.411	0.507	0.438	0.509	0.435	0.477	0.463	0.01
	Monsoon	0.534	0.581	0.501	0.511	0.533	0.501	0.527	
	Winter	0.17	0.263	0.307	0.273	0.316	0.301	0.272	
Ni	Pre Monsoon	0.061	0.073	0.074	0.079	0.04	0.024	0.059	0.02
	Monsoon	0.064	0.081	0.083	0.087	0.058	0.028	0.067	
	Winter	0.056	0.046	0.052	0.077	0.029	0.028	0.048	
Fe	Pre Monsoon	0.291	0.352	9.8	0.374	0.63	0.205	1.942	0.3
	Monsoon	0.297	0.67	11.98	0.539	0.845	0.292	2.437	
	Winter	0.25	0.348	4.59	0.35	0.426	0.186	1.025	
Cr	Pre Monsoon	0.048	0.053	0.054	0.048	0.046	0.039	0.048	0.05
	Monsoon	0.049	0.061	0.059	0.05	0.05	0.042	0.052	
	Winter	0.048	0.051	0.053	0.043	0.041	0.036	0.045	
Mn	Pre Monsoon	0.016	0.145	0.175	0.121	0.089	0.027	0.096	0.1
	Monsoon	0.027	0.162	0.178	0.142	0.091	0.034	0.106	
	Winter	0.013	0.067	0.111	0.092	0.047	0.017	0.058	

sources, modes of element occurrence, combustion conditions, volatilization–condensation mechanism, and particle size of the ash (Ram et al., 2015). Concentration of heavy metals in coal was observed as Pb (4.117 ppm), Ni (18.695 ppm), Fe (1929.48 ppm), Cr (7.976 ppm), and Mn (35.084 ppm). Concentration of heavy metals in fly ash sample was found as Pb (34.809 ppm), Ni (51.609 ppm), Fe (2635 ppm), Cr (64.772 ppm), and Mn (286.205 ppm).

Heavy metal concentration in fly ash was found to be higher than feed coal. It is due to loss of organic components during volatilization and enrichment of inorganic heavy metals. Cao et al. (2008) has reported that fly ash is a fine particle having more surface area for condensation which shows high affinity with trace elements.

3.2. Heavy metal contamination in groundwater

Amount of heavy metals released from fly ash in groundwater from stock piles of fly ash depends largely on the pH, bonding between the element and fly ash, its chemical form, and physicochemical properties of water (Fulekar & Dave, 1991; Pandey, 2014). The heavy metal concentration assessed in groundwater samples near ash pond are as follows.

3.2.1. Lead

Lead is a dangerous element; it is harmful even in small amount and enters the human body in many ways. High concentration of lead in the body can cause death or permanent damage to the central nervous system, the brain, and kidneys (Jennings, Sneed, & Clair, 1996; Mandour, 2012). The permissible limit of lead in drinking water prescribed by WHO is 0.01 ppm although in present study concentration ranged from 0.17 ppm to 0.581 ppm. Lead concentration in all groundwater samples around ash pond was observed exceeding the prescribed limit of WHO (Figure 3).

3.2.2. Nickel

Nickel is regarded as essential trace metal but toxic in large amount to the health. Concentration of Ni in groundwater was observed from 0.024 ppm to 0.087 and it was above the prescribed permissible limit (0.02 ppm) by WHO. Drinking contaminated water causes hair loss and can be related to dermatotoxicity in hypersensitive human (Hanaa, Eweida, & Farag, 2000) (Figure 4).

Figure 3. Average concentration of lead (Pb) in groundwater samples at different sites.

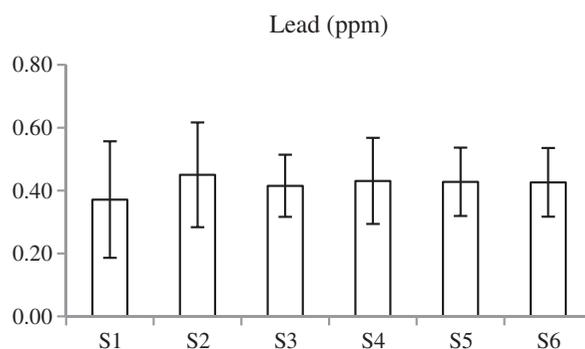


Figure 4. Average concentration of Nickel (Ni) in groundwater samples at different sites.

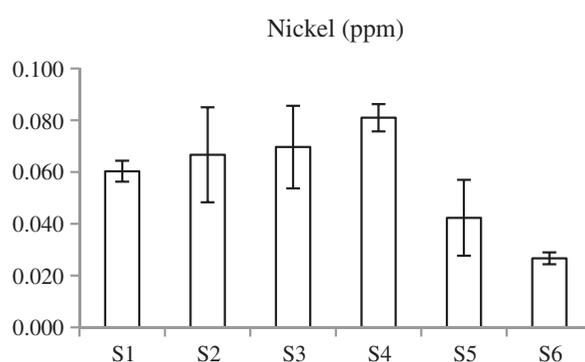
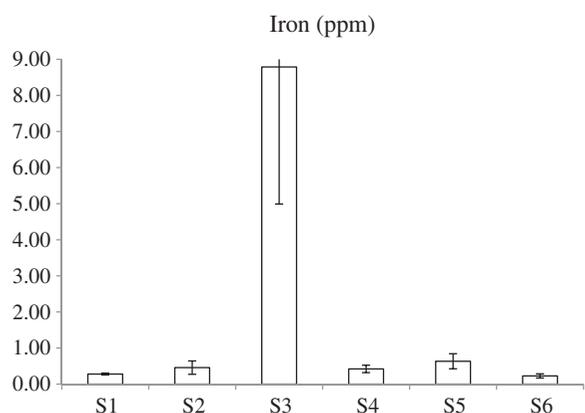


Figure 5. Average concentration of Iron (Fe) in groundwater samples at different sites.



3.2.3. Iron

Iron is readily found in soil and water. Coal and pond ash are also a rich source of iron into groundwater. Concentration of iron in groundwater samples was observed from 0.186 ppm to 11.98 ppm. Prescribed limit of WHO for iron in drinking water is 0.3 ppm while in most of the sample of groundwater it is exceeding the limit. Liver cirrhosis is found to be related to drinking water contaminated with iron (Mandour, 2012) (Figure 5).

3.2.4. Chromium

Maximum permissible limit of WHO in drinking water for chromium is 0.05 ppm but the concentration estimated in groundwater samples near ash pond ranged from 0.036 ppm to 0.061 ppm. This is showing higher concentration than prescribed value in more than 50% of samples. Chromium in excess amount can be toxic especially the hexavalent form. Long-term exposure of chromium can

Figure 6. Average concentration of Chromium (Cr) in groundwater samples at different sites.

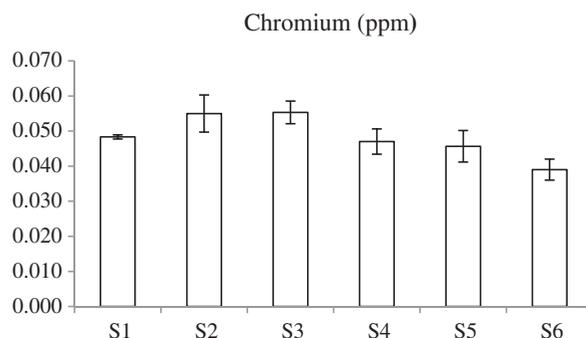
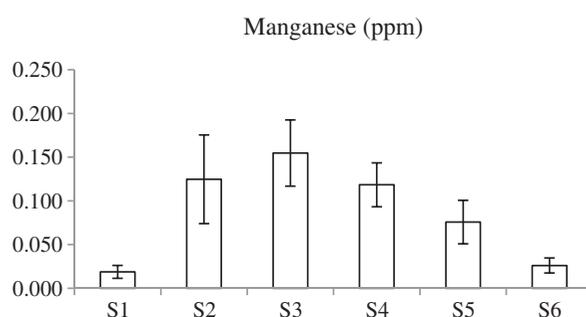


Figure 7. Average concentration of Manganese (Mn) in groundwater samples at different sites.



cause kidney and liver damage and can damage too circulatory and nerve tissue (Hanaa et al., 2000) (Figure 6).

3.2.5. Manganese

Manganese concentration in groundwater samples ranged from 0.013 ppm to 0.178 ppm while the permissible limit is 0.1 ppm (WHO). Only one-third of the samples were exceeding the prescribed limit and rests of the samples were within the limit. Higher concentration of manganese in drinking water is reported to cause neurological impairment and manganism (Figure 7).

The results obtained above have showed high concentration of heavy metals in groundwater surrounding the ash pond of thermal power plant. Groundwater is the only source of drinking water in the region of thermal power plant which is being contaminated due to fly ash disposal. The presence of heavy metals in drinking water sources is a serious matter of concern due to health damaging effects.

4. Conclusions

Fly ash is observed to be enriched with various heavy metals. Fly ash in slurry form may be a major source of groundwater contamination into an unlined pond. As hydraulic water of ash slurry infiltrates through soil, heavy metals dissolve and percolate out of soil and reach the groundwater. Heavy metal concentration assessed in groundwater around ash pond was found to be exceeding the prescribed permissible values of WHO in almost all samples. This may cause significant health effects on population depending on groundwater only for drinking purpose. The heavy metal concentration was observed maximum in rainy season into groundwater. The heavy metal leaching from ash pond mainly depends on pH not and on the amount present in fly ash. Heavy metal release from ash slurry increases with decreasing pH. Lowering of pH in ash lagoon is caused due to SO₂ which may be adsorbed on the surface of fly ash or reach through atmosphere. Rain water is already found to have acidic pH up to 5.5 and dissolved atmospheric SO₂ in the surrounding of thermal power plant further lowers pH. This makes more acidic conditions into ash pond and heavy metal release from ash slurry into groundwater increases.

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