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Research Paper

IDENTIFICATION OF CONTAMINATED ZONES USING DIRECT CURRENT RESISTIVITY SURVEYS IN AND AROUND ASH PONDS NEAR KOLAGHAT THERMAL POWER PLANT, WEST BENGAL, INDIA

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Lack of proper insulation at the bottom of the ash disposal ponds enhances the chances of groundwater contamination. In this study, direct current (dc) resistivity survey, employing Schlumberger configuration, was undertaken to identify the local subsurface and to estimate the depth of contamination around ash ponds near a thermal power plant in Eastern India. A continuous conductive zone with resistivity < 5 Ωm was identified throughout the studied region at a depth of about 2–10 m indicating the presence of water with higher ionic concentration. This can be due to the leached soluble species that percolate downwards with the slurry water in the form of leachate. The continuity of this zone from inland towards the river can pose a threat to the groundwater as well as the overall health of the river ecosystem. Geophysical method utilized in this study is fast, efficient and cost-effective in delineating the extent of the probable contamination zone(s).

Keywords: Ash pond, Groundwater contamination, Thermal power plant, Vertical electrical sounding, Leachate

INTRODUCTION

Global energy sector (in the form of electricity) is largely dependent on fossil fuel, especially coal. In 2009, 30% of the total energy was generated from coal (IEA, 2013). By 2035, the coal demand is projected to be 25% more than that of in 2009 (IEA, 2011). Most of the developing economies like India, China and other Asian countries have coal based energy as their backbone for growth (IEA, 2013). However, in the long run, coal based energy generation can accrue considerable environmental cost due to the release of solid, liquid and gaseous wastes. Solid waste is generated in the form of fly and bottom ash. The finer ash particles are released in the environment and coarser ash particles are collected at the bottom of the stack through electrostatic precipitators. The coarse grained ash, also known as bottom ash, is then disposed into ash ponds in the form of slurry. After deposition, the ash is stored there for some time for drying, and then removed for further use in other industries (mostly

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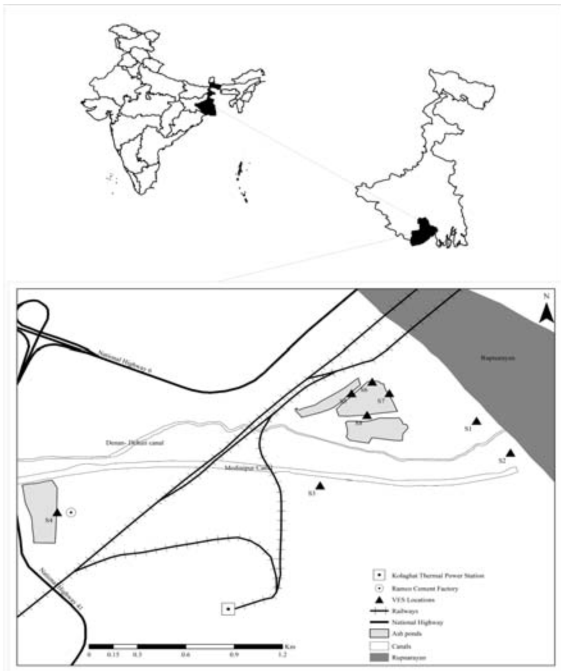
cement and brick manufacturing). The fly ash from the thermal power plants is reported to contain several toxic metals and radionuclides (Bhangare *et al.*, 2011; Papastefanou, 2008; Mondal *et al.*, 2006; Mandal and Sengupta, 2006, 2005; Flues *et al., 2*002; Bem *et* al., 2002; Xu *et al.*, 2003). Lack of proper insulation at the bottom of the ash pond often allows the water of the slurry to leach these toxic elements and enhance the probability of contamination of groundwater aquifer or potable water sources of the locality (Jambhulkar and Juwarkar, 2009; Sushil and Batra, 2006) . In India, about 70% of the total electricity is generated from coal (Mishra, 2004). In Eastern India, coal alone accounts for about 86% of the total energy generation. However, as mentioned earlier, the greatest concern with coal based energy is its impact on environmental health. The Indian coal, used for thermal power generation, is generally characterized by low sulphur and high ash content (5 - 50%). This leads to generation of a huge amount of ash per unit of electricity production by its combustion (Mandal and Sengupta, 2003). At present, ash generation rate is 160 million tons per annum and is projected to reach 300 million tons per annum by 2016-2017 (Singh *et al.*, 2011). Continuous dumping of ash in the ponds over the years with a very low reuse percentage causes a build-up of the toxic elements in the dumps. These can percolate into the local groundwater flow with time. In addition to that, heavy to extreme precipitation and favorable local geochemistry will facilitate the contaminants to enter into the aquifer, and thus exposing a large population at risk. In order to identify the extent and severity of the problem, proper monitoring and study is required. Geophysical methods offers cost-effective, time effective and non-invasive solution to such cases (Samouëlian *et al*., 2005; Tabbagh *et al.*, 2000). The non-invasive nature of these methods also provide the scope of studying temporal variation of the scenario. Of the various geophysical methods, dc resistivity surveys had been extensively used by various researchers to study the environmental contamination (Ekeocha *et al.,* 2012; Sundararajan *et al*., 2012; Olofsson *et al*., 2006; Ahmed and Sulaiman, 2001; Mukhtar *et al.*, 2000; Stierman and Brady, 1999). Application of electrical resistivity in contamination study in and around waste dumps assigns high resistivity to dry and comparatively less contaminated zones and considerably low resistivity to water saturated and contaminated layers. In the present study, the dc resistivity method was used to identify the subsurface and depth of contamination around ash dumping sites near the Kolaghat thermal power plant.

The Kolaghat thermal power plant is the third largest power plant in West Bengal, India, with a generation capacity of 1260 MW (after Mejia Thermal power plant (2340 MW) and Farraka thermal power plant (2100 MW)). The coal used in this plant is of Gondwana type and known for its high ash content. Around 18000 tons of coal is burned to operate six units of the plant generating about 7500 - 8000 Mt of ash every day (Dasgupta and Paul, 2011). The study area being densely populated, a considerable section of the population is vulnerable to the effect of groundwater contamination from the ash leachates. A study by Mandal *et al.* (2007) was carried out with the aim to identify whether the area was contaminated or not. In the present study the objective was to study the spatial distribution of the contaminants from the ash ponds to the nearby areas. The specific sounding locations in Mandal *et al.* (2007) were completely different from the present study. Whereas, Mandal *et al*. (2007) performed all the soundings on the ash ponds; the present study was carried out on ash ponds (S4 to S8) as well as areas away from ash ponds (S3) and close to the river (S1 and S2). An improved interpretation method is used in the present study compared to the study by Mandal *et al*. (2007). In the present study, we have used interpretation procedure by Sharma (2012) which is more robust and accurate as compared to the interpretation procedure of Sharma and Kaikkonen (1999) used in Mandal *et al.* (2007). Sharma (2012) interpretation is based on statistical distribution of good fitting models (several thousand) in the selected model space. However, Sharma and Kaikkonen (1999) interpretation method was based on mean model computed from the 10 best fitted models only. Hence present interpretation approach is better.

STUDY AREA AND METHODOLOGY

The present study area, shown in Figure 1, is located on the right bank of Rupnarayan River. It lies 80 km southwest of Kolkata and 50 km northwest of Haldia and extends from 2222°24'44'' to 22°26'22'' N and 87°51'17'' to 87°53'50''E. The major water bodies in this region are Denan-Dehati canal, Medinipur canal and the tributaries of Rupnarayan River. The area is densely populated and the localities are situated very close (within 2 km) to the ash ponds. There are five ash ponds present for the ash disposal covering an area of 325 acres of land (Dasgupta and Paul, 2011). Two large ash ponds 4A and 4B, situated to the northeast and northwest of the power plant respectively, are studied.

Figure 1: Map Showing The Study Area and Sounding Locations



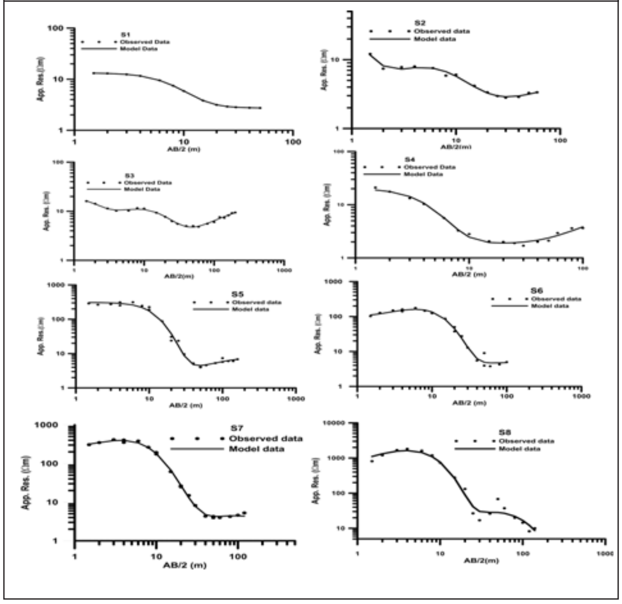
Vertical Electrical Sounding (VES) measurements using Terrascience resistivity meter were conducted at eight locations across the study area as shown in Figure 1. Out of these, five soundings were in the vicinity of the two ash ponds and three soundings were located within a radius of 1 km from the ash disposal sites. The Schlumberger electrode configuration was employed for the study. To achieve greater depth of penetration, longest possible profile at every location was selected. The maximum electrode spacing in the eight soundings were varied between 100 m to 400 m. The maximum profile length measured was at VES-S3. The measurements were carried out during winter and spring season to avoid the interferences due to rain.

In resistivity sounding, current (I) is injected into ground through a pair of metal electrodes and the potential difference (ΔV) is measured by another pair of electrodes (potential electrodes). The placement of these two pairs of electrode determines the array configuration. According to Ohm's law, the ratio of the potential difference to the current injected estimates the resistance. The apparent resistivity is estimated using Ohm's law and the geometric factor corresponding to a particular array configuration (equation 1).

$$\rho_a = G.(\Delta V/I) \qquad ...(1)$$

where 'G' is the geometric factor due to the array configuration, 'ΔV' is the potential difference between the two potential electrodes and 'I' is the current supplied. A detail discussion can be found in Telford *et al.* (1990). Greater the current electrode separation, greater is the depth of penetration. For Schlumberger electrode configuration the depth of penetration is about one-third of the profile length.

Figure 2: Fitting Between the Observed Field Data and Model Data for VES-S1 to VES-S8



The resistivity sounding data were interpreted using 1-D very fast simulated annealing (VFSA)

Table 1: Layer Parameters (Resistivity and Thickness) Obtained After Performing Global Optimization on the VES Data

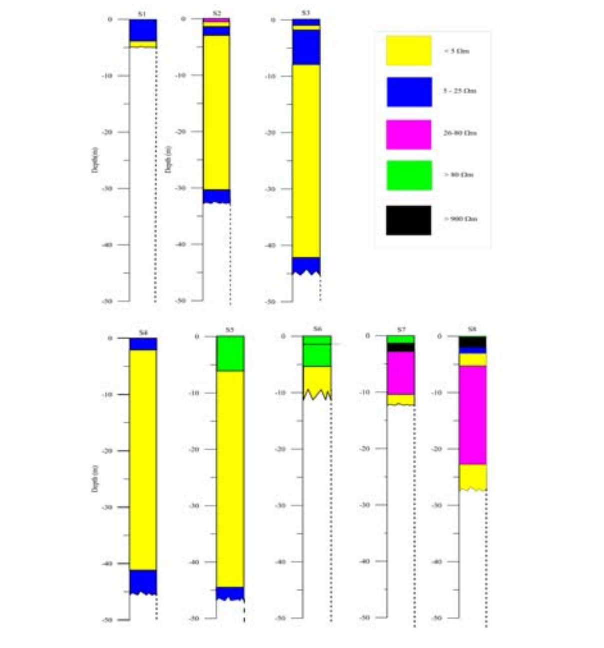
Parameters	S1	S2	S3	S4	S5	S6	S7	S8
ρ1 (Ωm)	13.2	40.8	20.5	20.1	307.5	100.1	268.9	139.8
ρ2 (Ωm)	2.7	3.5	4.7	1.8	3.7	280.4	923.6	4229.7
ρ3 (Ωm)	-	20.2	15.0	20.0	8.6	4.5	27.3	16.3
ρ4 (Ωm)	-	2.5	3.4	-	-	-	3.5	4.3
ρ5 (Ωm)	-	5.8	15.1	-	-	-	-	68.9
ρ6 (Ωm)	-	-	-	-	-	-	-	0.5
h1 (m)	3.8	0.5	1.0	2.1	6.0	1.4	1.1	0.2
h2 (m)	∞	0.9	0.8	39.1	38.4	3.9	1.7	1.8
h3 (m)	-	1.5	6.1	∞	∞	∞	7.6	1.0
h4 (m)	-	27.3	34.3	-	-	-	∞	2.2
h5 (m)	-	∞	∞	-	-	-	-	17.5
h6 (m)	-	-	—	-	-	-	-	∞
Misfit	1×10^{-3}	5.6×10^{-4}	2.4×10^{-4}	1×10^{-3}	5×10^{-3}	5.7×10^{-3}	1×10^{-3}	2.0×10^{-3}

global optimization technique (Sharma, 2012). The VFSA global optimization technique was applied to each sounding data to estimate the layer parameters, namely the apparent resistivity and the thickness of each layer. The measured and calculated apparent resistivity was plotted (in logarithmic scale) against half of the current electrode separation (AB/2) in meter and is shown in Figure 2 (VES-S1 to VES-S8). The computed apparent resistivity was plotted to fit the observed data. The process was repeated for all sounding locations. The interpreted model parameters for all the sounding locations are shown in Table 1.

RESULTS AND DISCUSSION

The interpreted subsurface lithology at each sounding location is shown in Figure 3. Resistivity is an intrinsic property of a given material. Dry and granulated materials are characterised by high resistivity and water saturated materials exhibit low resistivity.

Figure 3: Interpreted Lithology of Locations VES-S1 to VES-S8



The model results, provided in Figure 2 and Table 1, show that different numbers of layers were present at each sounding location due to difference in their respective profile length (Figure 2 and Table 1). Based on the models, the interpreted resistivity values were classified into five groups as (i) < 5 Ωm (ii) 5 - 25 Ωm (iii) 26 - 80 Ωm (iv) > 80 Ωm (v) > 900 Ωm to achieve better correlation among the different sounding locations. For discussion purpose, the eight sounding locations were broadly divided into two groups: i) VES located away from the ash ponds and ii) VES located on or near the ash ponds.

VES Located away from the Ash Ponds

VES-S1 to VES-S3 were located away from the ash ponds. They were located to the northeast of the thermal power plant within a radius of 1 km from the nearest ash pond. The interpretation of the sounding data appearing in Figure 3, show two layers at VES-S1 and five layers at VES-S2 and VES-S3. Due to small profile length, the depth of investigation at VES-S1 was very small and only the depth of the first layer could be obtained. In VES-S1 to VES-S3, the top most layer resistivity ranged between ~ 13 – 41 Ωm. From field observations, the top soil at VES-S1 was observed to be exposed with coarse saturated sand mixed with ash and clay; however, top soil at VES-S2 and VES-S3 were observed to be made up of clay with fine to coarse sand. At VES-S2 the surface was observed to be made up of loose sand, which is why the top layer at VES-S2 was showing higher resistivity than the top layers at VES-S1 and VES-S3. At VES-S2 and VES-S3 the resistive top layer was followed by a thin conducting layer (< 5 Ωm) at a depth 0.5 m and 1 m, respectively. A similar conducting but considerably thick layer (< 5 Ωm) was also observed at these locations starting at a depth of

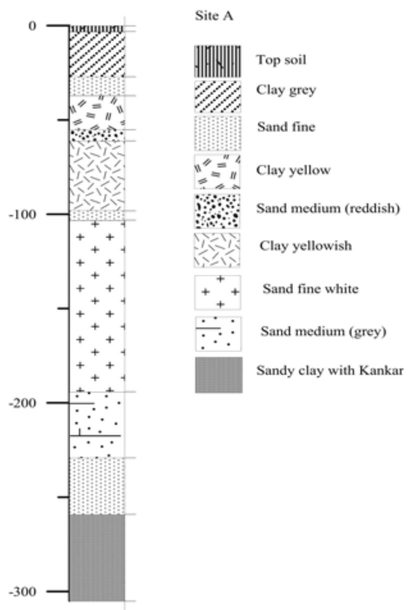
~ 3 m and 8 m, respectively. In both the locations, the second conducting layer of clay was flanked by resistive layers on either side.

VES Located Near the Ash Ponds

VES-S4 to VES-S8 were located on the periphery of the active ash ponds 4A and 4B. VES-S4 was located along the eastern periphery of ash pond 4A and VES-S5 to VES-S8 were located along the four sides of the ash pond 4B. The interpretation of the sounding data, provided in Figure 3, showed three layers at VES-S4, VES-S5 and VES-S6; four layers at VES-S7; six layers at VES-S8 (a very thin top layer). At VES-S4, a very thick (~ 39 m) conducting layer was observed (from 2.1 m – 41.1 m depth) in between two coarse saturated sand layers (20 Ωm). The top layer at locations VES-S5 to VES-S8 showed a highly resistive (> 80 Ωm) top layer of thickness varying between 0.2 m to 6 m. At VES-S5, the resistive top layer was followed by a thick (~ 38 m) conducting layer (< 5 Ωm). At VES-S6 to VES-S8 the top layer was followed by another highly resistive layer. The conducting zone at VES-S6 was present beneath the two resistive layers (100.1 and 280.4 Ωm). At VES-S7, the conducting layer was observed under three resistive layers of resistivity 268.9 Ωm, 923.6 Ωm and 27.3 Ωm, respectively. At VES-S8, two conducting zones were observed at a depth of 3 m and ~ 23 m, respectively. At VES locations, VES-S7 and VES-S8, highly resistive layer is due to the presence of rocks and boulders used for fortifying the embankments of the ash ponds.

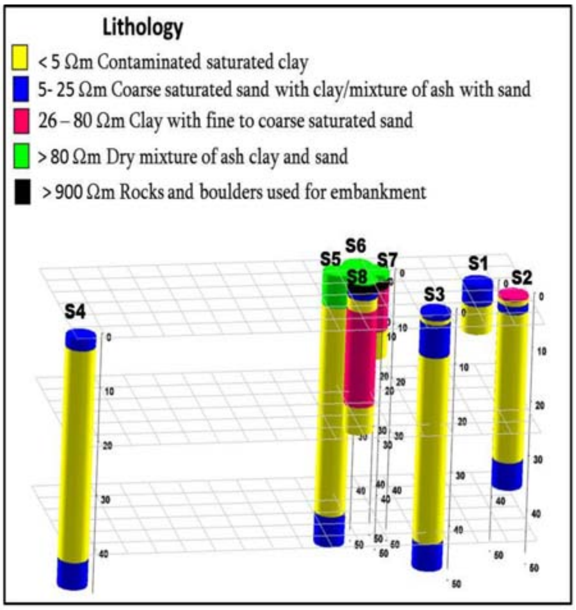
The general lithology of the area, obtained during the tube well installation in the vicinity of the study area is shown in Figure 4. The subsurface lithology showed primarily the presence of alternate layers of clay and sand. Almost similar lithology was observed in the VES. The differences in resistivity values of the layers were due to the variation in saturation and/or due to the presence of loose ash deposition. The findings of the dc resistivity thus conformed well to the borehole data. The comparison of the resistivity value from the interpreted models and borehole logs indicate that low resistivity values correspond to clay layers, intermediate resistivity values correspond to sandy layers, high resistivity corresponds to dry ash mixed layers and very high resistivity values to rocks and boulders.

Figure 4: Litholog of a Tubewell at Kolaghat Block, Tamluk Subdivision



The major aim of the present work was to identify the extent of contamination and subsequent vulnerability to groundwater around the ash ponds. The leachate from the ash ponds, posing maximum risk to the groundwater, is basically a mixture of water soluble metallic species from ash in water. Generally clay acts as a natural barrier to the leachates from any kind of waste dumps. Sand, on the contrary, due to its high porosity not only acts as a potential aquifer but also, allows an easy passage to the leachates from the waste dumps. In this study, presence of the sandy layers above the clay layers thus allow easy percolation of the leachate from the ash dumps to deeper levels. Extreme precipitation events during monsoon allow higher infiltration of the contaminants from the ash dumps. The thick clay layer, identified as saturated contaminated clay (resistivity <5 Ωm) , shown in Figure 5, present below the sand layer almost in all the locations thus, acts as the first barrier to the leachate flow. However, in case of high hydraulic head, continuous ash dumping in the ash ponds over years (in the present case for three decades), can cause the saturation of the retention potential of the clay. This might allow further percolation of the leachate to the deeper aquifers that serve as the source of drinking water in this locality. Besides, breaking of organic

Figure 5: Geoelectric Section of the Study Area Derived From Interpreted Resistivity and Borehole Log



matrix, changes in pH as well as redox potential due to weathering process, the local hydrogeological parameters, like porosity, permeability etc., can considerably enhance the mobility of once retained metal species.

In the earlier study by Mandal *et al.* (2007), VES soundings on the ash ponds showed the presence of a highly conducting zone starting at a depth of 2 - 9 m and with about 29 - 50 m in thickness. The geochemical studies of water samples, collected from a 50 m deep tube well in the vicinity, by Mandal *et al.* (2007), further strengthened the presence of the aforesaid contaminated layer. They confirmed the presence of high TDS count (550 - 760 ppm), abundance of Ca^{2+}, Na^{+}, presence of anions (HCO_3^-, SO_4^{2-} and Cl^-) and high concentration of trace elements (like Li, As, Zn, Ag, Pb, Cr, Mn, Se, Cd, Cu) indicating the contamination within the clay layer. A close observation of the borehole log, Figure 4, also indicates the presence of a highly conductive contaminant layer in the study area. Instead of alternate layers of clay and sand (as seen in the log), all the VES showed lower resistivity values than expected. This is possible only when there is a significant amount of ionic species and/or water is present in the clay and sand layers. The most common pathway of contaminant intrusion is through direct contact of the clay and sand layers with contaminated water. Thus the present study when compared with the earlier study, conducted over the entire stretch of the area strongly indicates the contamination of the deeper aquifer (approximately at about 50 m depth). In case of continuous loading of contaminated water from the ash ponds, lateral migration of the same in sandy layers become obvious. Once saturated, the water/ leachate can percolated further down vertically thus contaminating even deeper layers.

Thus the present study was able to give an insight to the spatial distribution of the contaminants from the ash ponds to the vicinity, which was not considered in the earlier work by Mandal *et al.* (2007). Hence, it becomes apparent that the population depending on the tube well waters for drinking purpose are highly vulnerable to the contamination. This underscores the necessity of a thorough monitoring of the water quality in the area undertaken during the present study.

CONCLUSION

The present study helped in understanding the local sub-surface in the region close to the thermal power plant operating since its initial commissioning in 1984. A thick conductive zone (resistivity < 5 Ωm) was present throughout the region. The depth of this layer was within a range of 2 – 10 m from the soil surface and the thickness ranged between ~ 27 – 39 m. Based on available borehole data and earlier observations, this zone was identified as saturated clay with high concentration of various ionic species. The presence of sandy layers at the top facilitated the percolation of the leachate into the deeper clay layers. Although clay is considered as a repository of trace/heavy metals, however, continuous loading of these species at higher concentration resulted in further percolation. Ultimately, reaching the deeper aquifer at around ~50 m, the leachate contaminated the groundwater. Thus, it can be inferred that the population is at a risk of being exposed to the contaminants from the ash pond through groundwater. As groundwater is the major source of drinking water in this region, the finding of this study, an extension with the previous study, emphasized the importance of meticulous monitoring of the groundwater quality and the temporal variation in the nature of the contaminant. Therefore, the necessity of thorough understanding and intensive study of the ambient hydrogeological conditions is suggested.

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