

## Radionuclide and trace element contamination around Kolaghat Thermal Power Station, West Bengal – Environmental implications

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**The Kolaghat Thermal Power Station (KTPS), located at Mecheda in Midnapur District, West Bengal is one of the largest thermal power stations in eastern India. Combustion of coal in the KTPS generates large quantities of ash that are disposed-off in vast areas of land adjoining the power station. Geochemical and radiometric analysis of the pond ash has been undertaken to assess the quantity of toxic elements that are likely to contaminate the soil and the groundwater system. Trace element analysis reveals that toxic elements (Pb, Cu, Ni, Fe, As) are sufficiently enriched in pond ash than their crustal abundances, and preferably in the lighter size fractions. Radionuclides (U, Th) also show enrichment of 3–5 times in coal ash compared to their crustal average and are much higher than in the pond ashes of other thermal power plants in India. Chemical analysis of the water samples collected from tubewells near the ash ponds reveals high concentration of trace elements (Al, Li, Ni, Fe, As, Zn, B, Ag, Sb, Co, Si, Mo, Ba, Rb, Se, Pb V, Cr, Cu, Cd, Mn, Sr), whose distribution is mainly controlled by the ash deposited in the area. Among these elements, Al, Li, As, Zn, Ag, Sb, Si, Mo, Ba, Rb, Se and Pb show higher concentration in the tubewell waters near the ash pond, implying significant input from the ash pile. The enrichment of some elements (Al, Fe, As and Mn) above WHO guidelines for drinking water denotes significant contamination of the groundwater from the toxic elements leached from the ash pile.**

THERMAL power generation contributes to more than 70% of the power generation in the country<sup>1</sup>. Indian coal is of bituminous type, with 55–60% ash<sup>1</sup>. Combustion of coal thus generates huge amount of ash which are disposed-off either in dry or slurry form. The Kolaghat Thermal Power Station (KTPS) uses the wet disposal method. Ash generated from coal combustion has a greater tendency to absorb trace elements that are transferred from coal to waste products during combustion due to its small size and hence, large surface area<sup>2</sup>. Coal is also radioactive due to primordial <sup>238</sup>U, <sup>232</sup>Th and <sup>40</sup>K. Earlier work<sup>3</sup> on coal and ash has shown that Indian coals contained 1.8–6.0 ppm <sup>238</sup>U and 6.0–15.0 ppm of <sup>232</sup>Th. But recent studies<sup>4</sup> have shown that pond ash generated from coal contains as high as 50 ppm <sup>232</sup>Th and 10 ppm of <sup>238</sup>U.

Groundwater is vulnerable to metal contamination due to waste disposal and leachate percolation<sup>5–7</sup>. Coal-fired power stations have recently come under scrutiny as potential sources of mercury and other heavy metal pollutants. When large quantities of ash accumulate for long periods of time in the disposal site, hazardous substances are likely to be released by leaching, percolate through the soil layers and eventually reach the groundwater.

The KTPS, situated in Midnapur District, West Bengal, India is the second largest power station in the state, with an installed capacity of 1260 MWe/day, generating 1210 MWe/day of electricity. Figure 1a gives the location map of the study area along with the power station. This station comprises six units of 210 MWe each. The ash is deposited in four large ash ponds (1A, 1B, 4A, 4B), located 4–5 km south of the power station (Figure 1b). The major source of potable water for the villages surrounding the ash pond is the Kasai river, and the tributaries of the Rupnarayan river (Figure 1a). In the present investigation an attempt has been made to study the trace element geochemistry, radioactivity in coal and ash, enrichment of radionuclides from coal to ash and trace elements in water to assess the potential impact of ash disposal on the quality of groundwater. Coal samples were collected from inside the power station, shortly before being fed into the boiler. The ash samples were collected from the ash ponds 1A and 1B, since the other two ash ponds, i.e. 4A and 4B were already full of water and the newly produced ash from the power station was being dumped in slurry form. After collection, the ash samples were air-dried at 100–110°C for about 24 h.

Water samples were collected in 200 ml polyethylene bottles from tubewells located near the ash ponds 1A, 1B, 4A, 4B (numbered as 1A1, 1A2, 1B, 4A1, 4A2, 4B) and from the surrounding villages of Bahala (B1, B2), Raksha (R1, R2, R3, R4), and Mecheda (M1, M2, M3). The sampling bottles were soaked in 10% HNO<sub>3</sub> for 24 h and rinsed several times with deionized water prior to use. The samples were filtered in the laboratory with a Whatmann 42 filter paper. After filtration, each sample was acidified with 2 ml HNO<sub>3</sub> to prevent any precipitation of metals. Elemental analysis of each water sample was carried out using the Inductively Coupled Plasma–Mass Spectroscopy (ICP–MS) MODEL Perkin-Elmer Sciex ELAN DRC II (Toronto, Canada) at the Central Research Facility available at National Geophysical Research Institute (NGRI), Hyderabad. Radon measurements were performed by LSC technique with the ultra low-level Quantulus 1220<sup>TM</sup> (Wallac Qy). Samples were prepared with 15 ml water samples and 5 ml RADONS (Etrac Lab.) following the procedure at our laboratory. The counting time was 200 min.

Laboratory measurements of <sup>238</sup>U, <sup>232</sup>Th and <sup>40</sup>K in coal and ash samples were undertaken using a low-level gamma-ray spectrometric set-up at NGRI. The detector is a 5" × 6" NaI (Tl) crystal coupled to a 5" diameter photomultiplier tube. In closed systems, the activity concentrations of nuclei in the decay chain reach secular equilibrium<sup>8</sup>, meaning that

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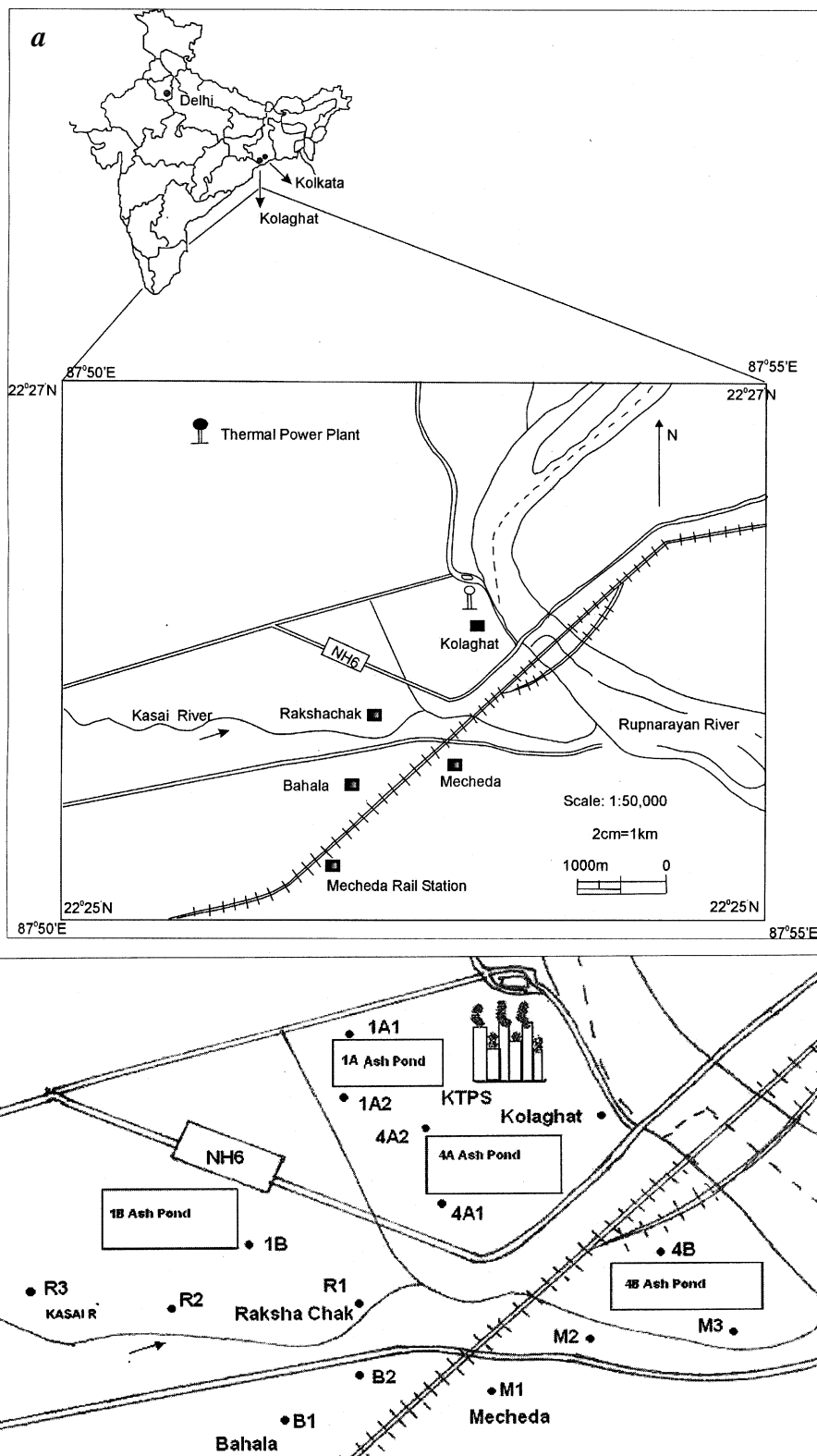


Figure 1. Location map of (a) study area and (b) sites of collection of water samples.

the activity concentrations of all nucleides are the same. As a result, measuring the activity concentration of one member in a closed system provides information on the presence of all the members<sup>9</sup>. After drying, the samples were sealed

and stored in an airtight container to prevent escape of radioactive gases  $^{222}\text{Rn}$  and  $^{220}\text{Rn}$ , and to allow attainment of radioactive equilibrium in the decay chain. After attainment of secular equilibrium between  $^{232}\text{Th}$ ,  $^{238}\text{U}$  and their daughter

products, the samples were subjected to gamma-ray spectrometric analysis. Natural radionuclides of relevance to this work are mainly  $^{232}\text{Th}$ ,  $^{238}\text{U}$  and  $^{40}\text{K}$ . While the concentration  $^{40}\text{K}$  can be measured directly by its own gamma-rays,  $^{232}\text{Th}$  and  $^{238}\text{U}$  are not gamma-ray emitters. Concentration of  $^{238}\text{U}$  and  $^{232}\text{Th}$  was assessed from the intensity of the gamma lines of their daughters:  $^{214}\text{Bi}$  (1.76 MeV) and  $^{208}\text{Tl}$  (2.62 MeV), assuming all daughter products are in equilibrium with their parents. Concentration of  $^{40}\text{K}$  was measured from the 1.46 MeV peak. Assaying was carried out by the method followed at NGRI<sup>10</sup>. The relationship between the number of atoms of a certain species,  $N$ , and its activity,  $A$ , is defined as

$$N = T_{1/2}A/\ln 2, \quad (1)$$

where  $T_{1/2}$  is the half-life of the radionuclide. Since activities are expressed in becquerel (1 Bq corresponds to one decaying atom/s),  $T_{1/2}$  has to be expressed in seconds. Using eq. (1) and Avogadro's number<sup>9,11</sup>, one notes that 1 ppm  $^{238}\text{U}$  and  $^{232}\text{Th}$  corresponds to 12.3 and 4.0 Bq  $\text{kg}^{-1}$  respectively, of  $^{238}\text{U}$  and  $^{232}\text{Th}$ . Similarly, one notes that 1%  $^{40}\text{K}$  corresponds to 310 Bq  $\text{kg}^{-1}$   $^{40}\text{K}$ . In this study activity concentrations are expressed in Bq  $\text{kg}^{-1}$  using the conversion factors for conversion of ppm of  $^{238}\text{U}$  and  $^{232}\text{Th}$  to Bq  $\text{kg}^{-1}$ .

Results of chemical analysis show that the feed coal is dominated by  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$  followed by  $\text{Fe}_2\text{O}_3$ ,  $\text{K}_2\text{O}$ ,  $\text{TiO}_2$ ,  $\text{CaO}$ ,  $\text{MgO}$ , and  $\text{Na}_2\text{O}$  (Table 1). Coal from KTPS is thus aluminosilicious in nature. Chemical analysis of the ash sam-

ples of Kolaghat shows that the ash is dominantly composed of oxides of silica, alumina and iron with minor amounts of  $\text{TiO}_2$ ,  $\text{K}_2\text{O}$ ,  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{MnO}$  and  $\text{Na}_2\text{O}$  (Table 1). Trace element concentration of the ash shows that the ashes of Kolaghat contain sufficient amounts of As, Cu, Pb, Ni, Zn, Co, V, Sc, Be, Cs and Zr relative to the feed coal (Table 1). Combustion of coal causes decomposition of organic and inorganic matter. Trace elements associated with the organic material get released and accumulate in the refractory phases, e.g. mullite and other aluminous phases as clays are the highest repositories of trace elements. Enrichment of trace elements in ash relative to the crustal abundance has been determined by the 'enrichment factor' (EF) which is defined as the ratio of the concentration of an element in coal with respect to its concentration in the crust<sup>12</sup>. In the present study EF was calculated by normalizing the concentration of elements with that of Al, since it is considered to be non-volatile under combustion conditions<sup>13</sup>.

Thus  $\text{EF}_{(\text{Ash})}$  relative to the crust is defined as:

$$\text{EF}_{(\text{Ash})} = (C_X/C_{\text{Al}})_{\text{Ash}} / (C_X/C_{\text{Al}})_{\text{Crust}}, \quad (2)$$

where  $(C_X/C_{\text{Al}})_{\text{Coal}} = (\text{Concentration of 'X'}/\text{Concentration of Al})_{\text{Ash/Crust}}$ ,  $X = \text{Element}$ .

EF of the elements in pond ash relative to their crustal abundance was also determined using eq. (2) and are shown in Table 2. It is seen that among the trace elements, As, V and Pb show maximum enrichment compared to their crustal abundances. These are volatile elements and are generally associated with organic matter in coal. Combustion of coal results in release of these elements, which on cooling condense down the tract and get deposited on the ash particles.

Radioactivity of coal and ash samples from KTPS are given in Table 3. The data show that the activity concentrations of  $^{238}\text{U}$  and  $\text{Th}^{232}$  range from 98.88 to 119.00 Bq  $\text{kg}^{-1}$  and from 126.00 Bq  $\text{kg}^{-1}$  to 146.65 Bq  $\text{kg}^{-1}$  in ashes, with a mean of 98.80 and 126.00 Bq  $\text{kg}^{-1}$  respectively.  $^{238}\text{U}$  and  $^{232}\text{Th}$  in feed coal range from 25.00 to 50.00 Bq  $\text{kg}^{-1}$  and from 39.00 to 55.00 Bq  $\text{kg}^{-1}$ , with a mean of 25.00 and 39.00 Bq  $\text{kg}^{-1}$  respectively. The activity concentrations of  $^{232}\text{Th}$  are much higher than those of  $^{238}\text{U}$  in KTPS coal. Combustion of coal enhances the radioactivity in ash, with  $^{232}\text{Th}$  activity concentrations exceeding those of  $^{238}\text{U}$ .  $^{40}\text{K}$  in ashes ranges from 266.00 to 415.00 Bq  $\text{kg}^{-1}$ , with a mean of 360.00 Bq  $\text{kg}^{-1}$ . The activity concentrations of radionuclides are high compared to those in fly ash from the thermal power stations in other parts of India, e.g. in Uttar Pradesh<sup>14</sup>, where the activity concentrations of  $^{226}\text{Ra}$  (daughter product of  $^{238}\text{U}$ ) is 39.00 Bq  $\text{kg}^{-1}$  and that of  $^{232}\text{Th}$  is 40.00 Bq  $\text{kg}^{-1}$ .

The enrichment factor ( $\text{EF}_R$ ) of radionuclides in ash as computed by eq. (2) is 3.5 for  $^{238}\text{U}$  and 5 for  $^{232}\text{Th}$ . Thus thorium concentrations in ash from Kolaghat are five times higher compared to their crustal abundance. The total gamma dose emitted from the ash pond has also been calculated

**Table 1.** Bulk chemical composition of feed coal and pond ash from KTPS

Compound	Unit	Average coal	Average (pond ash)
$\text{Na}_2\text{O}$	wt%	0.05	0.10
$\text{MgO}$	wt%	0.24	0.56
$\text{Al}_2\text{O}_3$	wt%	9.52	26.00
$\text{SiO}_2$	wt%	23.14	57.81
$\text{P}_2\text{O}_5$	wt%	0.22	0.48
$\text{K}_2\text{O}$	wt%	0.48	1.19
$\text{CaO}$	wt%	0.39	0.83
$\text{TiO}_2$	wt%	0.69	1.82
$\text{MnO}$	wt%	0.02	0.04
$\text{Fe}_2\text{O}_3$	wt%	2.49	4.95
C	wt%	48.10	3.48
S	wt%	0.39	0.03
Be	ppm	2.27	5.70
Sc	ppm	10.70	28.68
V	ppm	61.20	238.18
Co	ppm	7.78	24.16
Ni	ppm	22.50	80.70
Cu	ppm	32.00	63.3
Zn	ppm	46.10	100.48
As	ppm	5.41	18.63
Rb	ppm	28.97	75.89
Sr	ppm	84.28	204.60
Zr	ppm	157.80	444.58
Ba	ppm	252.00	708.62
Pb	ppm	18.5	66.70

**Table 2.** Enrichment factors of elements in pond ash from KTPS with respect to their crustal abundance

Element	Be	As	V	Co	Ni	Cu	Zn	Rb	Sr	Zr	Pb	Ba	Sc
Enrichment factor (ash)	1.25	2.32	2.32	1.41	2.34	2.11	0.92	0.44	0.38	1.53	1.99	0.79	1.7

**Table 3.** Radioactivity in pond ash and coal samples from KTPS

S. No.	Location	<sup>238</sup> U (Bq/kg)	<sup>232</sup> Th (Bq/kg)	<sup>40</sup> K (Bq/kg)
IIT-KAP 1	Ash pond	117.42	145.84	403.00
IIT-KAP 2	Ash pond	119.82	146.65	279.00
IIT-KAP 3	Ash pond	114.95	144.23	282.10
IIT-KAP 4	Ash pond	117.42	143.02	266.60
IIT-KAP 5	Ash pond	98.88	141.80	372.00
IIT-KAP 6	Ash pond	110.00	146.65	272.80
IIT-KAP 7	Ash pond	117.53	136.15	372.00
IIT-KAP 8	Ash pond	108.03	136.35	372.00
IIT-KAP 9	Ash pond	113.71	126.05	359.60
IIT-KAP 10	Ash pond	108.40	138.70	384.40
IIT-KAP 11	Ash pond	107.20	139.70	368.90
IIT-KAP 12	Ash pond	107.53	146.25	415.40
IIT-KAP 13	Ash pond	113.95	141.44	403.00
IIT-KAP 14	Ash pond	105.18	129.72	359.60
No. of samples		14	14	14
Max.		119.82	146.65	415.40
Min.		98.88	126.05	266.60
Average		111.43	140.182	350.742
Standard deviation		5.92	6.34	52.35
IIT-KC 1	Kolaghat (coal)	37.20	47.80	124.00
IIT-KC 2	Kolaghat (coal)	38.30	52.60	155.00
IIT-KC 3	Kolaghat (coal)	35.70	48.40	124.00
IIT-KC 4	Kolaghat (coal)	25.00	39.30	124.00
IIT-KC 5	Kolaghat (coal)	49.90	55.20	124.00
No. of samples		5	5	5
Max.		49.90	55.20	155.00
Min.		25.00	39.30	124.00
Average		25.00	39.30	124.00
Standard deviation		37.22	48.66	130.20

using dose conversion factors of UNSCEAR<sup>15</sup>. The total gamma dose rate in air at 1 m above the ground at each location in the ash pond is calculated using the following equation:

$$D = (0.462C_U + 0.604C_{Th} + 0.0417 C_K)nGy\text{h}^{-1}, \quad (3)$$

where  $C_U$ ,  $C_{Th}$ ,  $C_K$  are the activity concentrations (Bq/kg) of <sup>238</sup>U, <sup>232</sup>Th and <sup>40</sup>K in the ash. The mean dose rate as computed from the above equation was found to be 150.77 nGy<sup>-1</sup>, which is about three times higher than the world average<sup>15</sup> of 51 nGy<sup>-1</sup>. Thus the population within 80 km radius of the ash pond is exposed to a high dose rate.

Details of the concentration of the major and trace elements in the groundwater samples near the ash ponds and at the surrounding villages are given in Table 4. pH of the water samples ranged from 7.02 to 8.70, indicating alkaline nature of the water. The elements found in highest concentration

in the tubewell waters were Ca followed by Na, Mg and K. Na and K are present in higher amounts in the tubewell waters in the villages than those near the ash pond. Ca, on the other hand, is enriched in the tubewell waters of the ash pond, implying a significant input from the ash pile. A comparison (Figure 2) of data is also made between the concentration of the trace elements in the waters of the tubewells near the ash pond and those of the tubewells in the villages. In Figure 2, TAP denotes the average concentration of elements in the ash pond tubewells (1A1, 1A2, 1B, 4A1, 4A2, 4B) and TV is the average concentration of the elements in the tubewells (B1, B2, R1, R2, M1, M2, M3) at the villages Bahala, Raksha and Mecheda.

Among the trace elements, Al, Li, As, Zn, Ag, Sb, Si, Mo, Ba, Rb, Se and Pb show higher concentration in the water samples collected from the tubewells (TAP) than those collected from Bahala, Raksha and Mecheda (TV; Figure 2). Other trace elements V, Cr, Cu, Cd, Mn and Sr show higher concentration levels in TV than in TAP (Figure 2). The concentrations of Ni, Fe and Co are almost the same in the tubewell waters in all locations (Figure 2). The results of the radiometric analysis of some of the water samples are shown in Table 5. The data show that the tube wells (4A1) and (4B) located near the ash ponds 4A and 4B yield high activity of radon than the tube wells (R1 and M1) located at some distance from the ash ponds. SQP(E) is the quenching parameter which gives us an idea of the presence of molecules such as organic or suspension material in the groundwater sample that could affect the measurements. It is done by the Quantulus and high values in the studied samples mean absence of these undesirable molecules. Radon is a daughter product of <sup>238</sup>U. The <sup>238</sup>U concentration in ash samples has been found to exceed the crustal abundance by a factor of three. Since uranium is a soluble radionuclide, it might have been leached out from the ash pile and hence the high concentration of radon in the well waters of the ash pond implies significant input from the ash disposal site.

Table 6 shows the maximum permissible limits for various elements in drinking water. Table 7 shows the respective EFs of the different elements compared to the concentration of the corresponding elements in the WHO guidelines<sup>16</sup>. Mn, Pb show maximum enrichment in all the tubewell waters, while As and Al exceed the limit at a few places. The enrichment of Fe, Ni, Ba is close to 1 in most places indicating that their concentrations are well within the WHO limits. The tubewell waters near the ash ponds show maximum enrichment in the elements compared to the other places. This is especially true for Al, Mn, Pb and As, implying significant input from the ash pile. For other locations although the enrichment values are close to 1 and slightly > 1, they

Table 4. Concentration of different elements (ppm) in tubewell waters near ash ponds and surrounding villages

	4B	4A1	4A2	1A1	1A2	1B	B1	B2	R1	R2	R3	R4	M1	M2	M3
	0.0132	0.2869	0.2831	0.0081	0.5065	0.0095	0.0119	0.0097	0.0084	0.0096	0.0076	0.0298	0.009	0.0143	0.0858
	0.17862	0.49225	0.51154	0.14544	1.28709	0.15514	0.16549	0.19957	0.13918	0.17026	0.10636	0.5253	0.18056	0.18182	0.24013
	97.71148	44.02033	44.95857	83.83683	42.23807	89.02033	117.0604	166.9913	82.57934	106.2231	74.95885	254.6421	111.6519	93.28995	73.96293
	35.452	26.033	26.118	25.628	52.239	25.969	29.542	36.639	31.697	23.622	17.420	76.238	30.176	26.149	19.737
	0.32271	0.22261	0.42199	0.16358	0.19782	0.19625	0.1779	0.17547	0.14372	0.14856	0.19011	0.16575	0.29814	0.14297	0.17319
	5.11252	7.18775	7.45979	3.28974	10.9922	5.37158	3.63696	43.8036	4.19624	4.04271	5.46609	25.5059	5.45664	3.08268	6.44025
	623.315	611.8707	628.9924	734.126	696.3861	751.6333	665.5055	419.2105	759.2785	606.5043	354.6379	447.1253	282.4631	738.3087	435.1903
	0.00639	0.00542	0.00525	0.00303	0.00369	0.00331	0.0046	0.00748	0.00498	0.00328	0.00957	0.00661	0.00419	0.00855	0.00435
	0.01174	0.0107	0.01091	0.01123	0.01298	0.01224	0.01083	0.01322	0.01074	0.01226	0.01624	0.01326	0.03761	0.01216	0.01328
	0.45977	0.11734	0.11699	0.27074	0.11627	0.28804	0.46066	0.15882	0.34971	0.21411	0.11678	0.10974	0.13611	0.20507	0.52544
	0.31707	0.2911	0.37645	0.25542	0.29556	0.32979	0.31015	0.31645	0.30047	0.32165	0.32054	0.33085	0.26412	0.29678	0.31718
	0.00938	0.02354	0.02473	0.01827	0.01511	0.06991	0.01438	0.02667	0.00759	0.01106	0.01044	0.01147	0.08932	0.0085	0.02571
	0.0006	0.00122	0.00053	0.00029	0.0004	0.0006	0.00054	0.00071	0.00033	0.00027	0.00028	0.00039	0.00143	0.00028	0.00058
	0.0112	0.01161	0.01494	0.01981	0.02233	0.02672	0.01924	0.01955	0.01678	0.01444	0.01184	0.01483	0.03246	0.01837	0.01793
	0.21585	0.15052	0.28307	0.15708	0.1379	0.24644	0.14398	0.12927	0.12459	0.11519	0.1441	0.19748	0.38107	0.18975	0.13612
	0.00333	0.095	0.1639	0.00367	0.14472	0.00453	0.00312	0.01106	0.00219	0.00357	0.0055	0.00717	0.00456	0.00051	0.00756
	0.0037	0.12524	0.12513	0.00084	0.16823	0.00257	0.00219	0.00354	0.00074	0.00111	0.00344	0.00332	0.00186	0.0037	0.01198
	0.76146	0.49579	0.7396	0.59911	1.24847	0.11193	0.00879	0.01253	0.00334	0.00208	0.00992	0.00398	0.00446	0.02163	0.01668
	0.0036	0.0011	0.0015	0.0070	0.0032	0.0018	0.0003	0.0006	0.0001	0.0002	0.0004	0.0028	0.0016	0.0003	0.0005
	0.0032	0.5379	0.5652	0.0016	0.5335	0.2938	0.2201	0.1028	0.1868	0.2353	0.0870	0.0812	0.4865	0.2599	0.1292
	0.299	0.131	0.042	0.273	0.0401	0.1294	0.152	0.106	0.033	0.123	0.047	0.016	0.187	0.041	0.035

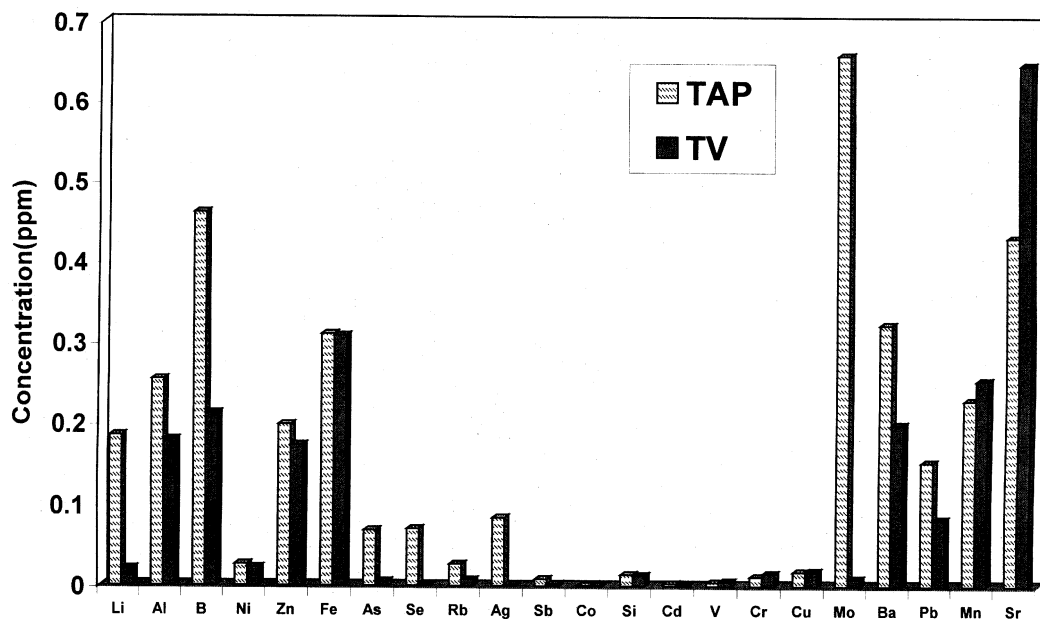


Figure 2. Variation in concentration of trace elements in water collected from tube wells located near the ash pond (TAP) and those in the nearby villages (TV).

Table 5. Radon activity concentration and quenching parameter

Sample	Rn activity (Bq/l)	SQP(E) (quenching parameter)
4A1	12.24 ± 0.35	987.79
R1	6.05 ± 0.18	990.9
M1	1.68 ± 0.06	913.09
4B	13.82 ± 0.40	905.45

Table 6. WHO guidelines for drinking water<sup>17</sup>

Element	Maximum permissible limit (ppm)
Al	0.2
As	0.01
Ba	0.7
Cr	0.05
Cu	2
Fe	0.3
Mn	0.1
Ni	0.02
Pb	0.01
Zn	3

are likely to exceed the WHO<sup>16</sup> guidelines in future with unabated input of ash particles rich in Fe, Ni and Ba.

The high concentration of trace elements in waters of the tube wells (1A1, 1A2, 1B, 4A1, 4A2, 4B), possibly, can be attributed to the leaching of the elements from the ash pile and subsequent mixing of the ash-pond leachate with

groundwater. In the present study, it is seen that the ashes contain high concentrations of Al, Ni, Fe, As, Zn, Mo, Mn, Ba and Pb, which exceed their crustal abundance by a factor of 2–3. Hence there are chances of these elements being leached out from the ash pile by the percolating rainwater and other sources of groundwater. Higher concentrations of these elements in tube-well waters of the ash ponds could be attributed to their input from the wind-blown ash particles. It is postulated that the elevated concentration of these elements in the well waters is due to leaching from the ash pile, contributing to the dissolved element load of groundwater.

The analyses presented above show that combustion of coal in KTPS causes significant amount of environmental pollution, with the generation of ashes that are high in radioactive and other toxic trace elements compared to other thermal power stations in India (Table 8). Earlier workers<sup>17,18</sup> have measured the activity of <sup>226</sup>Ra and <sup>228</sup>Ac (daughter product of <sup>232</sup>Th) in the ash samples. Since coal contains naturally occurring radioactive materials in radioactive equilibrium, measuring the activity concentration of one member in a closed system provides information on the presence of all other members<sup>9</sup>. Hence in the present study the activity concentrations of <sup>238</sup>U and <sup>232</sup>Th were compared with those of their daughter isotopes (<sup>226</sup>Ra and <sup>228</sup>Ac). Uranium, being relatively more soluble than thorium in water, can be leached out by the percolating water. On the other hand, thorium migrates as a mineral fragment. The dose, emitted from the ash pond to the surrounding<sup>15</sup> is about three times higher than the world average of 51 nGy<sup>-1</sup>. The natural radiation dose to population from thermal power plants is slightly higher than that from nuclear power plants of the same capacity, due to

high ash content and higher population density around such plants<sup>1</sup>. The target organs of the radionuclides <sup>238</sup>U and <sup>232</sup>Th are bones and lungs. Increased incidence of leukaemia, bone sarcomas and chromosomal aberrations are due to the radio-toxicity of thorium. Study of 29 thermal power stations has shown<sup>18</sup> the collective effective dose equivalent commitments from doses to bones, lungs and thyroid is 206 man Sv.y<sup>-1</sup> and from doses to the whole body of 73 man Sv. y<sup>-1</sup>. Lalit *et al.*<sup>18</sup> have taken into account, the installed capacity of the power stations, the population density per km<sup>2</sup> of the power stations and the concentration of radionuclides in the ash. The power stations studied<sup>18</sup> have installed capacity in the range 63–870 MWe. On the other hand, the KTPS has an installed capacity of 1260 MWe. The ash released per year is 44%. Moreover, the population density around the power plant is 767 per km<sup>2</sup>. Concentrations of radionuclides (<sup>238</sup>U = 111 Bq/kg and <sup>232</sup>Th = 140 Bq/kg) in the ashes from KTPS are much higher than those of radionuclides in the ashes of other thermal power stations (Table 8). Considering the high population density, ash content and radioactivity in ash, disposal of ash from the power station results in similar high effective doses to the population near the ash ponds and the surrounding villages. Moreover, considering the high absorbed dose rates (150 nGy h<sup>-1</sup>) from the ash pond, disposal of ash may cause radiation hazard to the population in the neighbouring villages of the KTPS. Prolonged exposure to the high dose rates may lead to risk in lung and bone cancer. The bricks made of ash from KTPS showed high activity concentrations of <sup>232</sup>Th (122.24 Bq/kg) and <sup>238</sup>U (87.33 Bq/kg) compared to those of ordinary bricks (<sup>232</sup>Th, 83.5 Bq/kg and <sup>238</sup>U, 43.65 Bq/kg). Hence if we take into account the 4p geometry for dwellings made of fly-ash bricks, the total radiation effect will get enhanced and could lead to serious health hazards.

Nuclear power plants emit radioactive and negligible amounts of gaseous or particulate pollutants. The risk associated with nuclear radiation is probabilistic. On the other hand,

**Table 7.** Enrichment of elements in tube-well waters with respect to those according to WHO guidelines

S. No.	Al	Cr	Mn	Fe	Ni	As	Ba	Pb
4B	1.6	0.2	4.5	1.1	0.5	0.3	–	29.9
4A1	1.1	0.2	1.2	0.9	1.1	9.5	0.7	13.1
4A2	2.1	0.2	1.2	1.2	1.2	16.4	0.8	4.2
1A1	0.8	0.2	2.7	0.8	0.9	0.4	–	27.4
1A2	0.9	0.2	1.2	0.9	1.1	14.5	0.7	4.0
1B	0.9	0.2	2.8	1.1	1.3	0.5	0.4	12.9
B1	0.8	0.2	4.6	1.0	0.9	0.3	0.3	15.2
B2	0.8	0.2	1.6	1.1	1.3	1.1	0.1	10.6
R1	0.7	0.2	3.4	1.0	0.8	0.2	0.2	3.3
R2	0.7	0.2	2.1	1.1	0.7	0.4	0.3	12.3
R3	0.8	0.2	1.1	1.1	0.5	0.7	–	1.6
R4	0.9	0.2	1.2	1.1	0.6	0.6	–	4.7
M1	1.4	0.7	1.4	0.8	1.6	0.5	0.6	18.7
M2	0.7	0.2	2.1	0.9	0.9	0.5	0.3	4.1
M3	0.8	0.2	5.3	1.1	1.2	0.8	0.1	3.5

thermal power plants using fossil fuels produce particulates, oxides of sulphur, nitrogen, carbon and toxic metals like arsenic, mercury, etc. in trace concentrations. The health risk of all these is deterministic<sup>1</sup>. Organ dose commitments are greater in the case of thermal power stations compared to nuclear power plants, mainly because the *a*-emitting bone seekers such as <sup>226</sup>Ra, <sup>228</sup>Th and <sup>228</sup>Ra (through its *a*-emitting daughter products) released from thermal power plants result in higher organ doses, while *b*-emitting noble gases and fission products give more external exposure to the whole body due to their high emission rates. Thus, overall dose commitments due to coal production are comparable with those from heavy-water reactor-type nuclear power plants. The doses computed are mainly due to inhalation during the passage of the cloud containing radioactive emissions and from external radiation due to the activity deposited. There is no universally acceptable method for assessing the health risks from conventional pollutants and nuclear radiations. However, if all the gaseous and particulate emissions are considered, coal-based plants have a higher health risk to the population. Carbon dioxide emission from coal giving rise to global warming is almost absent in nuclear power plants<sup>1</sup>.

Geochemical study of the water samples shows that the tube-well waters near the ash pond and in the surrounding villages are contaminated by toxins released from the ash pile. The enhancement in concentration of toxins (Al, Ni, Fe, As, Zn, Mo, Mn, Ba, Pb) in the tube-well waters near the ash pond denotes significant input from the ash pond. Mn and Pb shows significant enrichment in the waters, exceeding the WHO guideline values for drinking water. Al and As

**Table 8.** Radioactivity in pond ash from different thermal power stations in India

Thermal power station	Average activity			Reference
	Concentration (Bq/kg)			
	<sup>226</sup> Ra	<sup>228</sup> Ac	<sup>40</sup> K	
Allahabad (Uttar Pradesh)	78.4	89.1	362.7	17
Angul (Orissa)	78.5	86.5	278.1	17
Badarpur (Delhi)	75.5	88.1	286.4	17
Bakreshwar (West Bengal)	76.3	87.5	288.1	17
Chandrapur (Madhya Pradesh)	58.2	89.2	301.2	17
Farakka (West Bengal)	84.1	98.8	297.1	17
Raichur (Karnataka)	83.1	102.5	334.1	17
Talchir (Orissa)	79.2	96.3	291.6	17
Bokaro (Bihar)	102.9	154.7	233.0	18
Ramagundam (Andhra Pradesh)	92.5	120.3	255.0	18
Neyvelli (Tamil Nadu)	64	126.9	370.0	18
Amarkantak (Madhya Pradesh)	18.5	22.2	37.0	18
Bandel (West Bengal)	18.5	18.5	37.0	18
Indraprastha (Delhi)	22.2	63.0	255.0	18
Durgapur (West Bengal)	18.5	29.6	66.7	18
Korba (Madhya Pradesh)	22.2	44.3	137.1	18
Nasik (Maharashtra)	44.5	37.0	96.0	18

show enrichment above the WHO guideline value in some places, mainly in the tube wells located near the ash ponds 4A, 4B and 1A (Table 7). Excess amount of arsenic and manganese affects the cardiovascular system, gastrointestinal tract, kidney, liver, skin and blood and prostate. Excess amount of lead could lead to dysfunctioning of the kidney, gastrointestinal tract and respiratory systems due to inhalation of fine ash particles rich in lead.

The present study shows many potential environmental hazards related to coal combustion. Hence proper measures should be taken to check the release of toxins from the ash pond and subsequent mixing with the groundwater. A remedy is to have underground lining in the ash ponds to prevent direct contact of the ash pile with the top soil and the local drainage bodies. Use of bricks from fly ash meant for dwellings should be curtailed in the absence of detailed studies on the indoor radiation dose and its effect on the inhabitants for prolonged exposure. The radiation dose from thermal power plants can be reduced by reducing the ash content of coal and establishing thermal power plants away from populated area.

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ACKNOWLEDGEMENTS. We thank the authorities at KTPS for permission to carry out field work and providing us with water and ash samples; Drs R. Srinivasan and G. K. Reddy for radiometric assaying on rock samples using gamma-ray spectrometry at NGRI and Dr V. Balaram for the elemental analysis of water samples by Inductively Coupled Plasma Spectrometry at NGRI.

Received 6 July 2004; revised accepted 22 November 2004

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## Identification of elicitor-induced PR5 gene homologue in *Piper colubrinum* Link by suppression subtractive hybridization

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*Piper colubrinum* Link., the exotic wild *Piper* shows high degree of resistance to fungal pathogens and is a potential source of resistance genes. A PCR-based suppression subtractive hybridization (SSH) was used to identify *P. colubrinum* genes that are differentially expressed in response to the signalling molecule, salicylic acid (SA). A subtracted library of SA-induced genes was synthesized and one of the clones showed sequence homology to osmotin, a member of class-V group of pathogenesis-related (PR) gene family. The 315 bp gene fragment was used to probe total RNA prepared from untreated and SA-treated leaf tissues. Osmotin fragment cloned from the subtracted library was also used to probe RNA from ethylene-treated leaf tissues. Northern blot analysis revealed that osmotin is dominantly expressed in SA/ethylene-treated tissue. This indicates that SSH can be used to identify and clone PR genes in *P. colubrinum*.

*PIPER colubrinum* Link. is an exotic wild species of *Piper*, which shows high degree of resistance to many devastating

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