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Contamination of Lead and Mercury in Coal Basin of India

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Abstract

The coal is contaminated with toxic metals at the trace levels. They are released into the environment during mining, handling and burning of coal. The Korba basin has one of the largest coal exploitation areas in the country. In this work, contamination and sources of toxic metals *i.e.* Hg and Pb in the air, soil and sediment of the Korba basin, India are described. The concentration of Hg and Pb in the ambient air was ranged from 7.4 - 29 and 7.0 - 585 ng/m^3 with mean value of 18 ± 4 and 129 ± 104 ng/m^3 in the winter season. The mean concentration of Hg in the soil and sediment was 0.22 ± 0.03 and 0.44 ± 0.08 mg/kg, respectively. The higher concentration of Pb in the environmental samples was observed.

Keywords

Lead, Mercury, Aerosol, Soil, Sediment

1. Introduction

Heavy metals *i.e.* Pb and Hg are highly toxic to the developing brain and nervous system [1]-[2]. Coal is a naturally occurring combustible fuel containing the toxic metals at trace levels [3]-[5]. They are emitted from the thermal power plant stacks in both gaseous and particulate forms by retaining some fractions in the ash residues [6]-[8]. They are persistent in the environment, could enter bodies through the oral route and prove a great threat to people, especially those living in the vicinity of these thermal power plants. The contamination of environment with the Pb and Hg in various parts of the World was reported [9]-[45]. In the present work, contamination,

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enrichment and sources of Pb and Hg in the environment of the Korba basin, India are described.

2. Methods and Materials

2.1. Study Area

The Korba basin (22˚21'N, 82˚40'E) has largest coal deposit in the country extending over ≈530 km^2. Several open and underground coal mines are in operation with production of >10,000 MT/Yr coal. They are consumed by the thermal power plants running in the basin for production of electricity (40,000 MW) by pouring effluents into the environment. The population (≈0.5 million) of the basin is exposed severely with particulate and fly ash pollution. The increased prevalence rate of air and water borne diseases in human and domestic animals was observed.

2.2. Sample Collection and Meteorological Analysis

The sampling network for collection of particulate matters (PM), soil and sediment is shown in **Figure 1**. The Lata Envirotech air sampler was used for the collection of the coarse particulate matters (PM_{10}). The PM_{10} was collected over the quartz filer paper (47-mm, Whatmann) at flow rate of 16 lit/min. The sampler was run for duration of 24 hr at the 1st floor of the building (≥3 m above the ground level). Ten samples were collected from 10 different locations of the Korba basin during period: December, 2012-February, 2013.

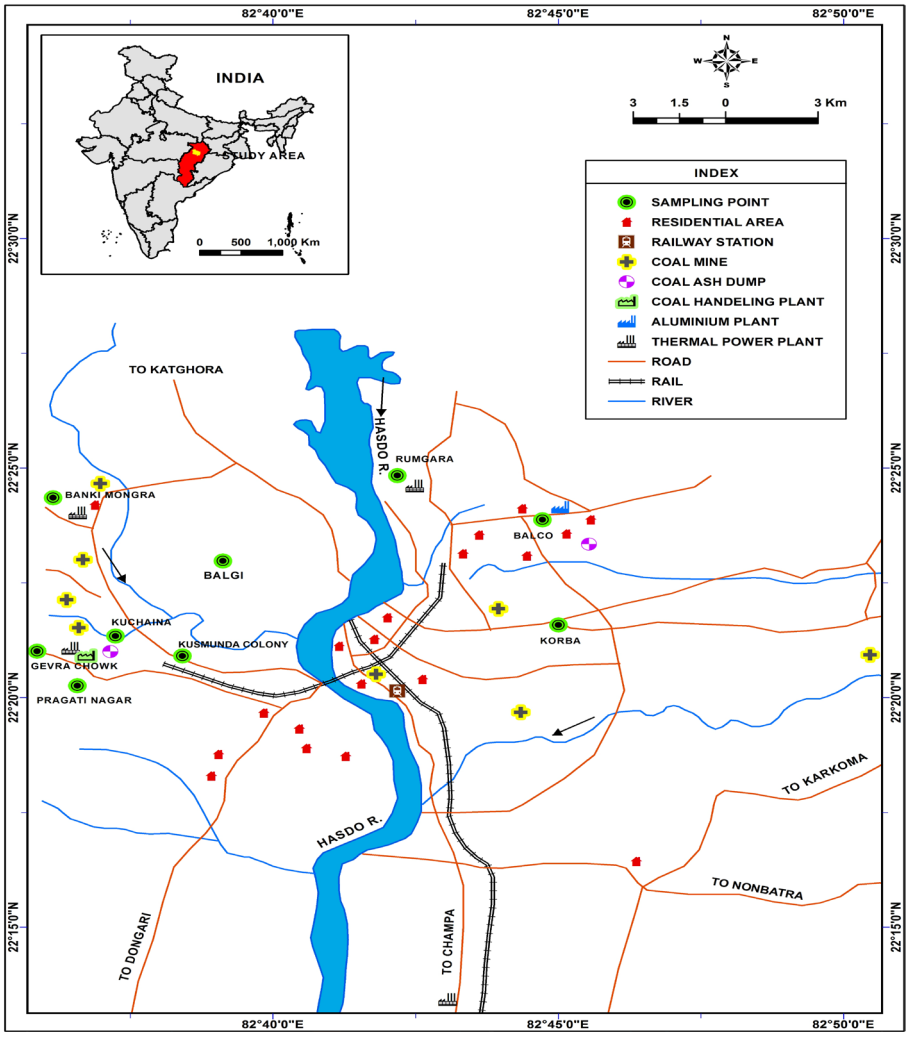


Figure 1. Representation of sampling locations.

The Anderson sampler (1531-107B-G289X) with eight stages: $PM_{10.0-9.0}$, $PM_{9.0-5.8}$, $PM_{5.8-4.7}$, $PM_{4.7-3.3}$, $PM_{3.3-2.1}$, $PM_{2.1-1.1}$, $PM_{1.1-0.7}$ and $PM_{0.7}$ was used for the collection of respirable particulate matters in the segregation forms. The sampler was run for 72 hr at four locations in January, 2013. The mass of dried loaded and blank filters were weighted out.

The surface soil (0 - 10 cm) samples from 30 locations of the basin were collected in January, 2013 [46]. The pond sediment was sampled from 26 locations of the basin in January, 2013 [47]. They were dried, crushed and sieved out particles of ≤0.1 mm sizes. The meteorological parameters *i.e.* ambient temperature (T), humidity (H), wind speed (WS) and wind direction (WD) were measured during the sampling period.

2.3. Analysis

The weighed amount of the sample was digested with acids by the microwave probe by using prescribed procedure. The Pb and Hg contents were analyzed by the Varian GF-AAS and CV-AAS techniques. The elemental or black carbon (BC or EC) and organic carbon (OC) were analyzed by the thermal and titration methods [48]. The pH value of soil and sediment extracts was determined, by shaking the soil or sediment sample in a 1:2 volume ratio with the deionized water.

3. Results and Discussion

The atmosphere of Korba basin is dusty due to huge emission of coal and ash particulates. The meteorology of the studied area during the winter period (2012-13) is summarized in **Table 1**. The value of T, H and WS was ranged from 8˚C - 30˚C, 24% - 93% and 3 - 8 k/hr, respectively during the studied period. The air mass flow was varied from E to S with domination in the SE direction.

3.1. Distribution of PM in Ambient Air

The distribution of the PM in the ambient air is summarized in **Table 2**. Extremely high concentration of PM_{10} in ambient air during the winter period was observed, ranging from 196 - 775 μg/m^3 with mean value of 390 ± 137 μg/m^3. The highest concentration of the PM_{10} was observed at location No. 2 due to input of the thermal power plant (TPP) effluents. The segregation chromatogram of the PM_{10} at four locations is summarized in **Figure 2**. The mean (n = 4) relative concentration of $PM_{10.0-9.0}$, $PM_{9.0-5.8}$, $PM_{5.8-4.7}$, $PM_{4.7-3.3}$, $PM_{3.3-2.1}$, $PM_{2.1-1.1}$, $PM_{1.1-0.7}$ and $PM_{0.7}$ in the air was 17, 14, 9, 9, 15, 19, 12 and 6%, respectively. At least, 52% ± 14% PM lie in the fine and ultrafine modes (≤3.3 μm). The concentration of respirable PM in the air was found to be too much higher than recommended limit of 50 μg/m^3 [49].

Table 1. Meteorology of the studied area.

S. No.	Sampling location	Sampling date	Temperature (T) ˚C		Humidity (H), %		WS km/hr	WD
			Min	Max	Min	Max		
1	Korba city	26-12-2012	8	25	32	61	4	E
2	ITI colony	27-12-2012	11	27.5	54.5	77	4.5	SE
3	CSEB colony	01-01-2013	17.5	27.5	65	92	4.5	E
4	Manikpur	02-01-2013	10.5	24	27	47	8	SE
5	BALCO	05-01-2013	8.5	23.5	35	69	3	SW
6	Kusmunda	06-01-2013	14.5	29.5	40	65	3.5	NW
7	Niharika	08-01-2013	14	26.5	33	55.5	4	SE
8	Darri	09-01-2013	15	27	28	47.5	4	SE
9	Mudapar	13-01-2013	8	26	24	49	4	SE
10	Banki	14-01-2013	30	30	35	57	4	SE

E = East, S = South, W = West, N = North.

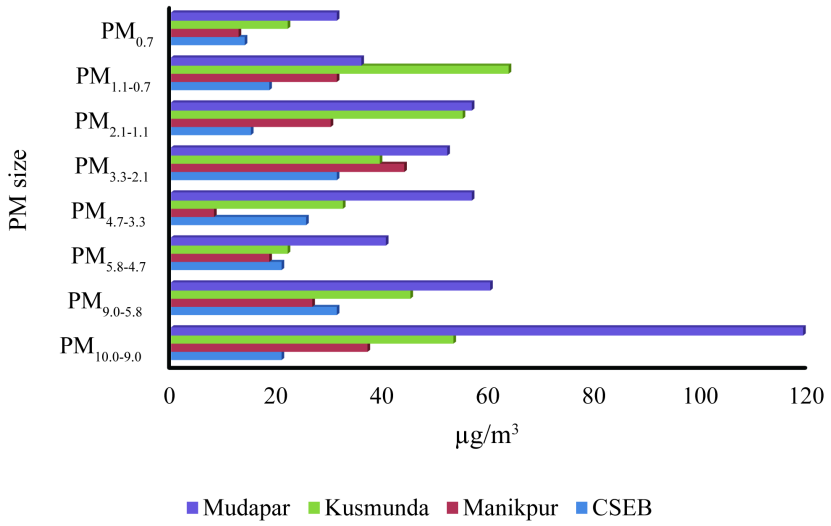


Figure 2. Segregation of PM_{10} in ambient air of Korba.

Table 2. Concentration of EC, Pb and Hg in ambient air and PM.

S. No.	PM_{10}, µg/m^3	EC concentration		Pb concentration		Hg concentration	
		Ambient air, µg/m^3	PM, %	Ambient air, ng/m^3	PM, mg/kg	Ambient air, ng/m^3	PM, mg/kg
1	315	26	8.2	101	320	18.8	59.7
2	775	68	8.8	585	755	18.0	23.3
3	196	16	8.2	109	556	7.4	37.7
4	226	18	7.9	83	368	17.2	76.2
5	209	16	7.5	59	280	15.0	71.8
6	319	19	6.1	7.0	22	17.0	53.3
7	283	22	7.7	71	252	24.3	86.1
8	666	46	6.9	21	31	17.4	26.1
9	666	53	8.0	193	290	29.0	43.5
10	251	18	7.2	60	240	11.7	46.7

3.2. Distribution of Hg in Air, Soil and Sediment

Mercury is a highly mobile metal, being liquid at room temperature, and behaves like organic compounds. The concentration of the Hg (n = 10) in the air (associated to PM_{10}) was ranged from 7.4 - 29 ng/m^3 with mean value of 18 ± 4 ng/m^3, **Table 2**. Its concentration in the PM_{10} (n = 10) was ranged from 23 - 86 mg/kg with mean value of 52 ± 13 mg/kg, **Table 2**. The higher concentration of Hg was observed in the studied area as compared to other regions of the World (*i.e.* Canada, China, Korea, Mexico, Taiwan, Thailand and Vietnam), may be due to huge coal burnings [11]-[15].

All the soil and sediment were composed of micrometer-scale grains with nano-scale structure. They were colored, ranging from whitish (W) to black (B) due to deposition of the fly ash and black carbon, **Table 3** and **Table 4**. The mean pH value of the soil and sediment extracts were found to be slightly acidic, ≈6.6 due to presence of high content of chloride and sulfate ions. The concentration of Hg in the soils (n = 30) was ranged from 0.11 - 0.39 mg/kg with the mean value of 0.22 ± 0.03 mg/kg. The concentration of Hg in the soil of studied area was found to be comparable to the contents reported in other regions of the World (*i.e.* China, Greece, Iran, Poland, USA) [16]-[20].

At least 2-folds higher concentration of Hg in the sediment was observed and may be due to its highly mobile nature. The concentration of Hg in the sediments (n = 26) was ranged from 0.12 - 0.82 mg/kg with the mean value of 0.44 ± 0.08 mg/kg. Extremely high concentration of Hg in the sediment of Hong Kong and Mumbai, maximum up to in the 0.855 - 2.66 mg/kg was reported [21]-[22]. The Hg loading in the sediments of Amazonian basin, Brazil, China, and Poland was ranged from 55 - 386 µg/kg [23]-[28].

Table 3. Distribution of Pb and Hg in soil.

S. No.	Location	pH	Color	EC, %	Pb, mg/kg	Hg, mg/kg
1	Niharica	7.0	W	6.8	163	0.21
2	Kuan Bhatta	7.0	W	4.7	119	0.18
3	Railway Station	7.0	B	3.5	95	0.11
4	Sitamani	6.9	BW	6.8	126	0.23
5	Rajgamar	6.9	BW	7.9	189	0.39
6	Rumgara	6.9	W	5.6	126	0.24
7	Darri dam	6.4	BW	4.4	116	0.19
8	Chaildren Garden	6.9	BW	4.5	116	0.20
9	Dipka Area	6.5	W	4.5	117	0.14
10	Pragati Nagar	6.9	BW	5.4	137	0.23
11	Gevera Chowk	6.7	W	4.5	114	0.22
12	Kusmunda-I	6.8	B	4.4	127	0.21
13	Kusmunda-II	6.7	W	5.7	126	0.25
14	Kusmunada-III	6.7	B	6.3	154	0.25
15	Korba	5.4	BW	7.3	190	0.37
16	Banki mongra	6.5	BW	5.6	110	0.26
17	Balgi	7.0	W	5.5	88	0.25
18	Kuchaina	6.8	W	4.8	72	0.13
19	Balco	5.7	BW	6.8	168	0.22
20	Bhadrapara	7.0	B	5.7	106	0.11
21	Risdi Chowk	6.7	BW	5.5	102	0.13
22	Manikpur	6.6	BW	4.7	96	0.15
23	Dadar	6.9	BW	5.7	138	0.24
24	SECL-I	6.4	W	5.7	140	0.21
25	Mudapar	6.4	W	5.5	119	0.24
26	Rampur	5.8	BW	5.5	125	0.22
27	SECL-II	6.2	BW	6.4	160	0.31
28	Belakachar	6.1	BW	5.9	149	0.30
29	Urga	7.1	B	5.5	129	0.26
30	Patadi	7.5	B	7.9	194	0.38

B = Black, W = White, BW = Blackish white.

Table 4. Distribution of Pb and Hg in sediment.

S. No.	Location	pH	Color	EC, %	Pb, mg/kg	Hg, mg/kg
1	Shakti Nagar	5.6	B	8.5	33	0.16
2	Gevra, Dipka	6.7	B	9.6	37	0.17
3	PN, Dipka	6.8	B	8.8	49	0.23
4	Banki, Dipka	7.4	B	4.8	47	0.25
5	Delwadih	6.1	B	8.8	81	0.31
6	Shingali	6.2	B	8.7	78	0.28
7	Kusmunda	6.9	B	8.8	92	0.36
8	Rajgamar-3	6.7	B	8.6	74	0.26
9	Mudapar	7.3	B	10.2	35	0.21
10	PN, Darri	5.5	BW	11.1	106	0.61
11	Darri west	6.1	BW	10.5	127	0.77
12	Jamnipali	6.4	W	12.7	82	0.63
13	Gopalpur	7.3	W	13.8	120	0.82
14	HTPP, Darri	6.1	W	11.4	112	0.74
15	Manuikpur-1	6.6	W	12.9	107	0.63
16	Manikpur-2	5.7	W	3.7	31	0.30
17	Dader-1	8.1	W	5.3	54	0.54
18	Dader-2	6.3	W	9.1	87	0.65
19	Kudarikhar	5.8	BW	6.9	37	0.33
20	Naktikhar	6.8	BW	10.1	75	0.53
21	Danras-1	5.4	BW	9.8	53	0.46
22	Danras-2	7.4	BI	3.6	26	0.12
23	SN-Balco	8.1	BW	9.9	48	0.32
24	Pathadi	6.2	BW	11.5	125	0.71
25	Dhendheni	7.5	B	9.2	108	0.61
26	Sukhri	7.6	BW	8.5	35	0.31

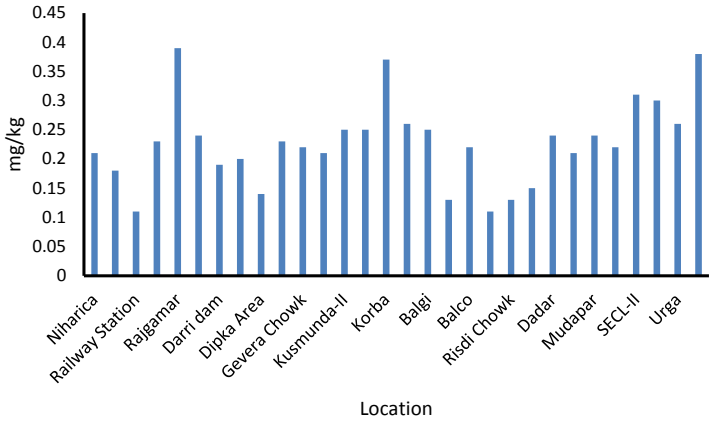
B = Black, W = White, BW = Blackish white.

3.3. Distribution of Pb in Air, Soil and Sediment

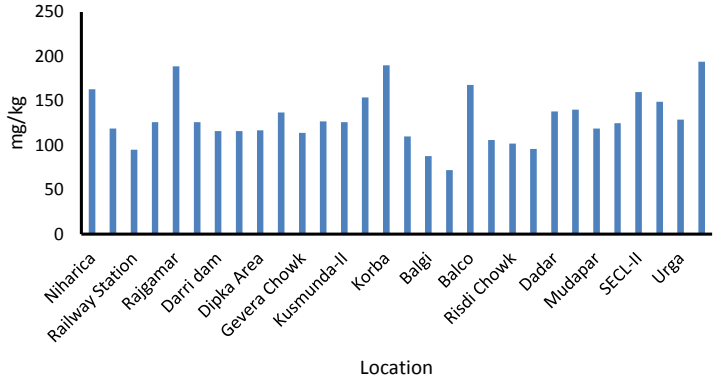
Lead is least mobile and lethargic metal, generally deposited in surface soil. The concentration of Pb (n = 10) in the ambient air and PM_{10} was ranged from 7 - 585 ng/m^3 and 22 - 755 mg/kg with mean value of 129 ± 104 ng/m^3 and 311 ± 136 mg/kg, respectively. Unlikely to Hg, lead concentration in the soil was found to be remarkably higher than the sediment, may be due to its hydrophobic nature. Lead concentration in the soil and sediment of the studied area was ranged from 72 - 194 and 26 - 127 mg/kg with mean value of 130 ± 10 and 75 ± 13 mg/kg, respectively. The concentration of Pb reported in the ambient air of various parts of the World *i.e.* China, India, Nigeria and USA was ranged from 3.9 - 1123 ng/m^3 [29]-[33]. The Pb levels in soil and sediment of other regions of the World reported were ranged maximum up to 926 mg/kg [34] [45].

3.4. Spatial and Vertical Distribution of Metals

Similar spatial distribution patterns of Hg and Pb in the soil and sediment of the studied area was observed. The higher concentration of the metals was observed in the locations near point sources *i.e.* mining and thermal power plant, **Figure 3** and **Figure 4**. The concentration of the Hg was found to increase as the depth profile was increased from 0 - 30 cm, may be due to its hydrophilic nature and less binding with the soil organic compounds, **Figure 5**. However, the reverse trend was observed with Pb, may be due to its hydrophobic nature and higher binding with the soil components, **Figure 5**.

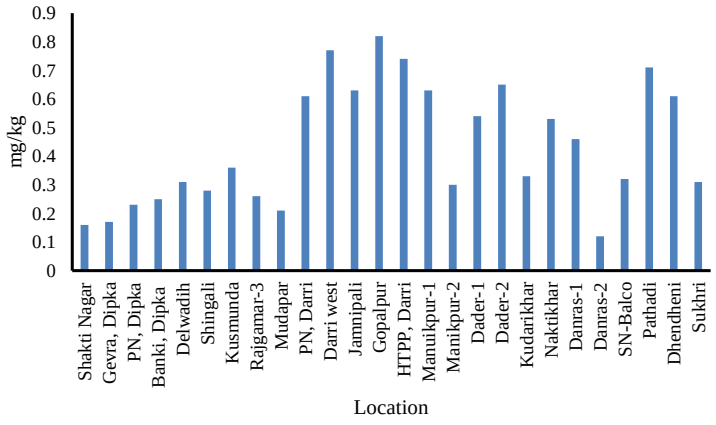


(a)

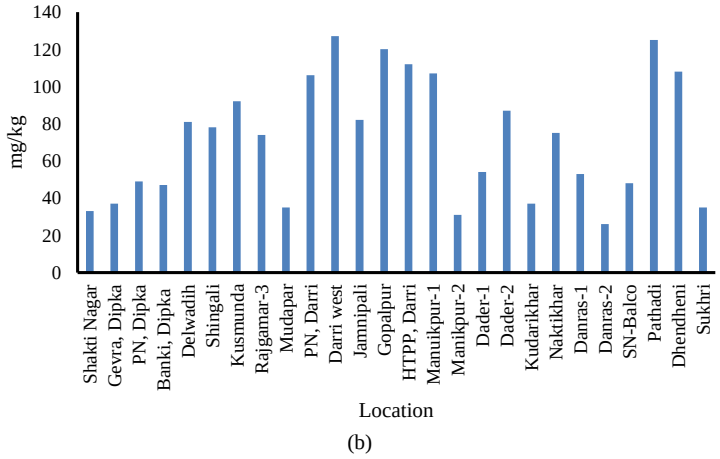


(b)

Figure 3. Spatial distribution of Hg (a) and Pb (b) in soil.

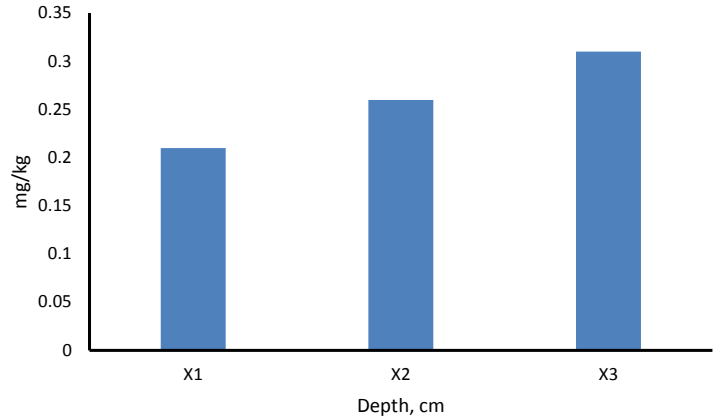


(a)

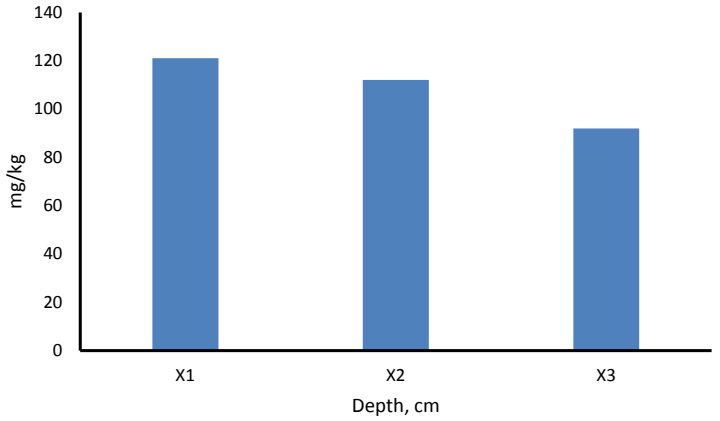


(b)

Figure 4. Spatial distribution of Hg (a) and Pb (b) in sediment.



(a)



(b)

Figure 5. Depth profile studies of Hg (a) and Pb (b) in soil, X1 = 0 - 10 cm, X2 = 10 - 20 cm, X3 = 20 - 30 cm.

3.5. Enrichment of Metals

The background concentration of Hg and Pb in the soil reported is 0.05 and 17 mg/kg, respectively [50]. The Hg and Pb in the PM_{10} was found to be extremely (1049 ± 261) and significantly (18 ± 8) enriched, respectively. However, they were found to be moderately enriched in the soil and sediment of the studied area, **Figure 6**.

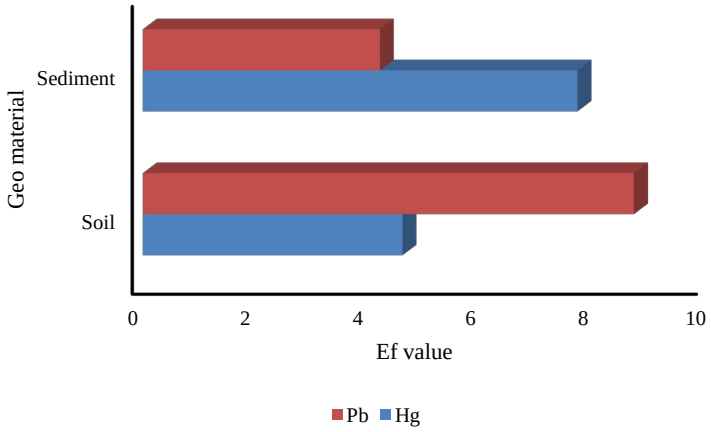


Figure 6. Enrichment of Pb and Hg in soil and sediment.

3.6. Sources of Metals

The PM and EC in the air are mainly generated during the burning processes. A good correlation (r = 0.98) of the EC with the PM was achieved, showing origin from the burning processes. Similarly, the EC with Pb and Hg contents in the air, soil and sediment was found to be fairly correlated (r = 0.63 - 0.81), indicating origin mainly from the coal burning processes.

4. Conclusion

The enrichment of Hg and Pb in the environment depends strongly on the particle size of the sorbent, and their remarkable higher concentrations are observed in the ambient PM_{10}. Mercury was enriched > 100-folds higher in the ambient PM_{10} with respect to the soil and sediment media. The increased vertical mobility of Hg via the soil was marked unlikely to Pb. The coal burning and mining are expected to be the major sources for contaminations of the metals in the environment.

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