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Exposure of Fluoride in Coal Basin

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Abstract

Coal is a dirty fuel contaminated with F^- and other elements. Several million tons of coal are burnt in Korba basin, central India to generate electricity with pouring fluorine and other elements into the environment. The water is contaminated with F^- and other chemicals beyond the permissible limits. The contaminated water is consumed by the human and animals by excreting the balanced toxicants through the stool and urine. Several folds higher concentration of F^- in urine (44 mg/L) and stool (266 mg/kg) samples of the cattle are observed. The prevalence of fluorosis diseases in cattle of the Korba basin is reported.

Keywords

Coal, Fluoride, Contamination, Toxicity

1. Introduction

Coal is a dirty fuel contaminated with toxic elements at the traces [1] [2]. The fluoride content in the coals is ranged from 20 - 500 mg/kg [3]. The environments in coal burning areas were severely contaminated with F^- and other toxicants [4]-[9]. The human and other animals living in the coal burning areas were affected by chronic endemic fluorosis diseases due to the excessive intake of F^- from air, water and food [10]-[12]. Several states of the country are suffered with fluorosis diseases due to intake of contaminated groundwater [13]-[20]. In the present work, the contamination of ground and surface water of the largest coal basin of India with F^- and other elements is described. The exposure assessment of the F^- toxicity in the domestic animals is described.

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2. Materials and Methods

2.1. Study Area

Korba basin, CG, India (22˚21'0"N and 82˚40'48"E) has rich deposit of coal over ≈ 1.0 × 10^4 km^2 area. It is a power capital of Chhattisgarh state, India. The basin is composed of four blocks: Kartala, Katghora, Korba and Pali with population of ≈ 1 million distributed over 710 cities, towns and villages. A huge amount of coal > 10000 MT/Yr has been consumed by various units of thermal power plants for generation of ≈ 40000 KW electricity. At least 12 open and underground coal mines are in operation with annual production of ≈3 BT coal by discharging > 100 BT/Yr liquid effluents in the environment. In addition, the Asia biggest Aluminum Plant (BALCO) is running in the Korba basin.

2.2. Sample Collection

The main river flowing through Korba basin is the Hasdeo River. The Bango dam has been constructed across this river through which water flows into canals. Several pit lakes are found to exist in the Korba basin due to mining out of the coal. The ground and surface water samples were collected from 30 and 6 locations of the basin in month of January, 2013 [21] (**Figure 1**). A 1-L cleaned narrow mouth polyethylene bottle was used for the collection. The container was rinsed three times with the sample water and filled with the water up to the mouth.

The physical parameters *i.e*. temperature (T), pH, dissolved oxygen (DO), reduction potential (RP) and electrical conductivity (EC) of the water were measured at the spot by using HANNA sensors.

The first morning stool (1 kg) of the domestic animals (n = 20) was collected manually. The stool sample was stored in the polyethylene bottle and dried in oven at 60˚C till the dryness. They were crushed and sieved out the particles of mesh sizes ≤0.1 mm. A 5.0 g stool sample was extracted out with 25 mL hot deionized water (50˚C) for 6 hr to measure the F^- and pH values.

The first morning urine sample (100 mL) was collected in a plastic bottle containing 0.2 g EDTA. Total 20 (4 × 5) urine samples of domestic animals (*i.e*. cattle, buffalo, sheep and goat) were collected in January, 2013. The samples was shipped to the laboratory in insulated container at about 4˚C and stored at −20˚C until use.

2.3. Analysis

The Metrohm ion meter-781 was used for the measurement of F^- by using TISAB-III buffer in 1:1 ratio. The

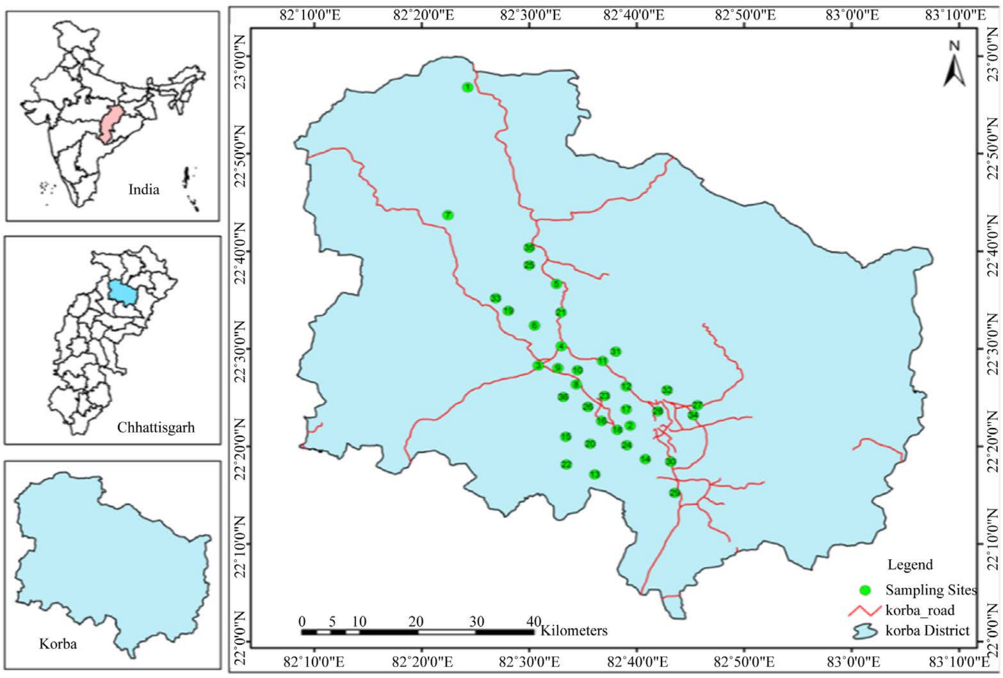


Figure 1. Representation of sampling locations in Korba basin.

buffer was prepared by dissolving 300 g sodium citrate, 22 g 1,2-cyclohexanediamine-N,N,N,N-tetraaceticacid and 60 g NaCl in a volume of 1-L with the de-ionized water with subsequent adjustment of pH value to 5.0 - 5.5). The Dionex ion chromatography-1100 was used for monitoring of ions *i.e*. Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Mg^{2+} and Ca^{2+}. The Thermos ICP-OES and ICP-MS (Polish Geological Institute, NRI, Central Chemical Laboratory, Warsaw) were employed for analysis of the elements.

3. Results and Discussion

3.1. Geology and Hydrology

The rock of the studied area was formed in the Archaean to Cenozoic ages. They consist of granite gneiss and granitoids covering with medium to coarse grained arkosic sandstone, a few pebble beds, conglomerate and shale of coal. The ground water occurs under phreatic, semi-confined and con-fined conditions control of the inter granular pore spaces in the shallow weathered zones and joints, fractures and caverns in deeper horizons. The water level depth is varied from 3.4 - 11.6 mbgl (meter below ground level) during the post-monsoon period in the aquifers.

3.2. Physico-Chemical Characteristics of Groundwater

The physico-chemical parameters of the groundwater are presented in **Tables 1-3**. The age and depth of 30 tube wells was ranged from 4.0 - 130 Yr and 4 - 18 m with mean value of 7 ± 1 Yr and 11 ± 1 m, respectively. A slight variation in temperature of the groundwater was recorded, ranging from 29.5 - 31.2˚C with mean value of 30.6 ± 0.1˚C. The pH value of the water was varied from 5.9 - 8.2 with mean value of 7.1 ± 0.2. The groundwater was found to be acidic in few locations (*i.e*. Surabahar, Sutara, Turali, Lalmatiya, Jenara, Dhelawdih, Banki Mongara, Dipka, Kusmunda, Bhilai, Hardibazar and Rumgara) due to the existence of higher content of the acids. The EC,TDS, DO and RP value of the groundwater was varied from 296 - 964 µS/cm, 414 - 990 mg/L, 5.6 - 6.7 mg/L and 199 - 241 mV with mean value of 497 ± 56 µS/cm, 628 ± 61 mg/L, 6.0 ± 0.1 mg/L and 218 ± 5 mV, respectively. The value of DO, EC and TDS was found moderately higher to the recommended value of 4.0 mg/L, 300 µS/cm and 500 mg/L, respectively [22] [23]. However, the RP value was observed to be at least 3-times less than the recommended value of 600 mV.

The concentration of F^-, Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Mg^{2+}, Ca^{2+}, Al, SiO_2, Fe, Mn and Zn was ranged from 2.1 - 12, 11 - 92, 10 - 90, 10 - 72, 10 - 70, 0.6 - 8.7, 3.0 - 44, 8.0 - 78, 7.2 - 45, 9.0 - 70, 0.4 - 8.2, 0.2 - 1.5 and 1.0 - 2.4 mg/L with mean value of 5.5 ± 0.9, 34 ± 7, 28 ± 7, 21 ± 5, 24 ± 6, 3.7 ± 0.8, 11 ± 3, 31 ± 6, 16 ± 3, 31 ± 6, 2.2 ± 0.6, 0.5 ± 0.1 and 1.5 ± 0.1 mg/L, respectively. Similarly, concentration of other metals: Li, Be, Rb, Co, Ni, Cu, Sn, Sb, Mo, Cd, La, Ce, Pb and U was observed in microgram levels, ranging from 4.7 - 36, 1.1 - 6.7, 1.4 - 38, 1.1 - 7.7, 2.4 - 27, 2.3 - 22, 1.2 - 11, 0.9 - 9.8, 0.1 - 5.0, 0.11 - 0.33, 0.1 - 2.1, 0.1 - 0.8, 1.1 - 29 and 1.0 -12 µg/L with mean value of 16 ± 3, 2.1 ± 0.5, 16 ± 5, 3.3 ± 0.8, 9.2 ± 2.4, 8.0 ± 2.1, 3.0 ± 1.0, 3.2 ± 0.8, 1.0 ± 0.4, 0.19 ± 0.02, 0.4 ± 0.2, 0.4 ± 0.1, 7.0 ± 2.4 and 2.5 ± 1.0 µg/L, respectively. Among them, the highest content of Cl^- was observed, may be due to leaching from the coal. The occurrence trend of 27 elements in the water was found in following decreasing order: $Cl^- > Ca \approx SiO_2 < NO_3^- < Na^+ > SO_4^{2-} > Al > Mg > K^+ > F^- >$ Fe > Zn > Mn >> Li ≈ Rb > Ni > Cu > Pb > Sb ≈ Co > Sn > U > Be < Mo > La ≈ Ce > Cd. The concentration of F^- in the groundwater of the studied area was found to be comparable to F^- contents reported in the water of other locations of the country [5]-[18].

Factor analysis was used for 17 variables of the water. Four factors were extracted which explain 83.27% of the total variance. A 58.49% of the total variance was explained by Factor-1, showing strong positive loadings on EC, TDS, F^-, Cl^-, SO_4^{2-}, Na^+, Mg^{2+}, Fe, Mn, Zn, Be, Rb, Co, Ni, Cu, Cd, Pb, La, Ce and Ca^{2+}. They were related to the mineralization of the groundwater which involved also weathering of gypsum and fluoride bearing minerals such as CaF_2. They were correlated well in the water as shown in **Table 4**, **Table 5**. A 10.93% of the total variance was accounted by factor-2, pyrite with strong positive loadings on NO_3^- and K^+, related to coal burning and mining activities. A 7.78% of the total variance was explained by factor-3, describing a strong loading on SiO_2. A 6.06% of total variance was explained by factor-4 related to the age factor of tube wells.

3.3. Physico-Chemical Characteristics of Surface Water

The physico-chemical characteristic of the surface water is shown in **Tables 6-8**. The value of T, pH, DO, RP,

Table 1. Physical characteristics of groundwater in Korba basin, January 2013.

S. No.	Location	pH	EC, µS/cm	TDS, mg/L	DO, mg/L	RP, mV
1	Pauli	7.4	296	745	5.9	199
2	Surabahar	6.6	527	627	5.8	228
3	Sutara	5.9	398	563	5.8	241
4	Katghora	7.8	388	509	5.9	202
5	Konkona	7.3	514	589	5.7	221
6	Turali	6.6	964	813	6.2	230
7	Lalmatiya	6.4	312	588	6.1	237
8	Jenara	6.8	464	574	5.6	199
9	Lakhanpur	7.1	633	611	5.8	215
10	Dhelawdih	6.7	515	628	6.1	212
11	Churri	7.2	629	738	6.7	201
12	Gopalpur	7.7	519	922	5.9	241
13	Darri	7.2	523	650	5.8	202
14	Banki Mongara	6.8	634	722	5.8	221
15	Dipka	6.9	511	441	5.9	230
16	Ghordeva	7.2	534	487	5.7	199
17	Balgi	7.0	713	933	6.2	228
18	Kuchana	7.3	391	633	6.1	241
19	Kusmunda	6.7	704	926	5.6	202
20	Bhilai	6.8	362	455	5.8	221
21	Dadar	7.0	322	464	6.1	230
22	Hardibazar	6.9	367	434	6.7	237
23	NTPC	7.4	380	471	5.7	199
24	Barpali	7.6	342	414	6.1	215
25	Manikpur	7.2	650	821	6.2	212
26	Korba	7.3	756	990	6.1	201
27	Balco	7.1	410	497	5.6	221
28	Rumgara	6.9	390	449	5.8	230
29	Urga	8.2	418	680	6.1	237
30	Bilaikhund	7.8	347	462	6.3	199

Table 2. Concentration of major elements in groundwater during January 2013, mg/L.

S. No.	F^-	Cl^-	NO_3^-	SO_4^{2-}	Na^+	K^+	Mg^{2+}	Ca^{2+}	Al	SiO_2	Fe	Mn	Zn
1	2.8	32	28	14	11	6	16	52	17	64	3.7	0.51	1.4
2	4.5	18	11	12	17	2	12	36	15	11	1.2	0.31	2.4
3	3.7	39	17	12	12	5	6	18	14	23	2.0	0.55	2.2
4	5.8	53	14	15	14	2	7	22	15	19	1.1	0.33	1.3
5	10	39	35	14	22	2	9	30	9.1	23	1.0	0.17	2.0
6	4.6	92	23	72	17	5	6	17	10	18	4.1	0.69	1.6
7	3.5	32	21	24	23	6	16	51	7.2	9	1.1	0.38	1.7
8	3.8	39	21	44	17	2	8	22	18	12	2.8	0.68	1.2
9	3.8	39	30	22	28	2	9	24	16	26	1.1	0.93	2.0
10	4.5	50	31	10	16	3	11	36	11	35	0.4	0.22	1.3
11	6.0	67	31	26	18	3	11	36	11	35	0.4	0.22	1.3
12	4.8	39	25	30	24	1.6	22	66	19	70	4.2	0.48	1.2
13	3.6	11	10	13	18	1.3	5	22	17	12	1.4	0.29	2.0
14	8.4	39	15	16	60	2.7	18	36	16	25	2.3	0.52	1.8
15	11	18	13	10	16	1.5	5	32	17	21	1.2	0.31	1.1
16	4.6	28	31	15	10	5.9	8	22	10	25	1.1	0.16	1.7
17	5.8	67	90	40	38	3.3	14	48	45	20	4.7	0.65	1.3
18	3.7	11	19	13	15	4.8	6	18	7.5	10	1.2	0.36	1.4
19	7.9	43	19	20	53	1.3	26	78	21	68	3.2	0.64	1.0
20	6.2	14	27	14	18	8.5	3	10	18	29	1.3	0.88	1.7
21	2.9	14	28	14	17	3.9	4	18	12	39	0.5	0.21	1.1
22	2.9	14	28	14	17	3.9	4	8	12	39	0.5	0.21	1.1
23	2.1	21	13	16	10	1.7	8	10	30	42	1.4	0.35	1.3
24	3.5	14	15	12	14	3.3	4	14	26	29	1.7	0.35	1.1
25	12	38	83	50	65	3.9	44	60	18	55	8.2	1.53	1.8
26	7.3	70	78	40	58	3.9	16	50	11	58	5.9	0.86	1.2
27	7.7	28	31	15	10	5.9	8	22	10	25	1.3	0.16	1.7
28	3.5	14	18	16	11	6.7	6	24	7.6	40	1.7	0.27	1.0
29	9.2	18	17	10	70	0.6	12	36	27	23	1.8	0.32	1.8
30	3.9	18	19	15	10	8.7	5	16	24	31	2.1	0.35	1.0

Table 3. Concentration of trace elements in groundwater during January 2013, μg/mL.

S. No.	Li	Be	Rb	Co	Ni	Cu	Sn	Sb	Mo	Cd	La	Ce	Pb	U
1	18	2.4	3.8	1.9	7.4	6.5	1.6	2.3	0.66	0.25	0.24	0.51	4.7	2.8
2	20	2.4	37	2.9	13.3	4.8	3.4	4.7	1.76	0.13	0.22	0.23	2.7	1.6
3	18	2.5	3.2	2.2	10.6	3.0	2.7	3.4	2.08	0.22	0.15	0.20	1.2	1.4
4	17	1.5	4.9	1.7	5.1	8.6	1.7	2.8	2.05	0.14	0.52	0.71	5.6	1.4
5	12	1.5	25.5	5.0	3.9	8.8	2.0	6.0	0.28	0.17	0.27	0.08	9.0	1.3
6	11	1.5	8.3	4.2	10.0	4.1	2.6	4.6	2.10	0.13	0.24	0.31	1.9	1.6
7	9	1.5	21.1	3.0	9.8	4.7	2.2	3.3	1.11	0.20	0.56	0.67	7.3	1.6
8	19	1.8	2.2	1.4	2.9	2.9	1.5	1.0	0.65	0.19	0.20	0.13	4.3	3.8
9	36	2.2	33	7.6	11.4	6.0	2.9	9.8	1.20	0.20	0.41	0.70	3.6	1.4
10	11	5.2	38	7.7	26.6	18	11	1.7	0.06	0.33	2.11	0.80	9.6	1.6
11	11	5.2	28	7.7	23.8	18	10	1.9	0.08	0.33	1.11	0.60	9.1	1.6
12	16	1.7	3.4	1.6	6.1	5.1	1.3	2.1	0.56	0.21	0.19	0.44	4.3	2.1
13	18	1.7	34	2.4	11	3.8	2.8	4.2	1.49	0.11	0.17	0.2	2.5	1.2
14	16	1.8	2.9	1.8	8.8	2.4	2.2	3.1	1.76	0.19	0.12	0.17	1.1	1.1
15	15	1.1	4.4	1.4	4.2	6.8	1.4	2.5	1.74	0.12	0.41	0.61	5.1	1.1
16	11	1.1	23	4.2	3.2	6.9	1.6	5.4	0.24	0.14	0.21	0.07	8.3	1.0
17	10	1.1	7.5	3.5	8.3	3.2	2.1	4.1	1.78	0.11	0.19	0.27	1.7	1.2
18	8.6	1.1	19	2.5	8.1	3.7	1.8	3.0	0.94	0.17	0.44	0.58	6.7	1.2
19	17	1.3	2	1.2	2.4	2.3	1.2	0.9	0.55	0.16	0.16	0.11	3.9	2.9
20	33	1.6	30	6.3	9.4	4.7	2.4	8.8	1.02	0.17	0.32	0.61	3.3	1.1
21	10	3.7	35	6.4	22	14	9.1	1.5	0.05	0.28	1.66	0.69	27	1.2
22	10	3.7	35	6.4	23	14	9.1	1.5	0.05	0.28	1.66	0.69	29	1.2
23	29	1.9	1.4	1.2	2.4	2.3	1.6	1.1	0.87	0.19	0.14	0.22	2.6	10
24	13	1.5	28	1.9	7.7	18	1.7	1.2	0.24	0.25	0.19	0.31	20	1.1
25	21	1.3	1.5	1.6	5.5	9.0	1.8	1.1	0.55	0.17	0.11	0.17	4.9	4.1
26	25	6.7	13	1.3	2.7	5.7	1.7	1.2	4.95	0.11	0.12	0.23	5.2	9.0
27	6.1	1.1	23	4.2	3.2	6.9	1.6	5.4	0.24	0.19	0.21	0.27	8.3	1.0
28	4.7	1.1	1.5	2.9	10	22	2.4	3.2	1.23	0.16	0.14	0.25	6.8	12
29	20	1.2	7.3	1.1	7.3	21	1.2	1.2	0.22	0.31	0.31	0.58	8.4	1.2
30	9.2	1.1	1.4	1.1	5.4	3.8	1.5	1.9	0.55	0.16	0.13	0.19	1.5	1.2

Table 4. Correlation matrix of elements in groundwater.

	F^-	Cl^-	NO_3^-	SO_4^{2-}	Na^+	K^+	Mg^{2+}	Ca^{2+}	Al	SiO_2	Fe	Mn	Zn
F^-	1												
Cl^-	0.18	1											
NO_3^-	0.36	0.47	1										
SO_4^{2-}	0.13	0.72	0.52	1									
Na^+	0.64	0.24	0.46	0.28	1								
K^+	−0.26	−0.12	0.09	0.01	−0.36	1							
Mg^{2+}	0.51	0.27	0.52	0.39	0.68	−0.20	1						
Ca^{2+}	0.42	0.34	0.40	0.25	0.59	−0.28	0.83	1					
Al	0.04	0.01	0.26	0.07	0.26	−0.25	0.13	0.13	1				
SiO_2	0.10	0.12	0.30	0.10	0.29	−0.01	0.54	0.56	0.09	1			
Fe	0.37	0.44	0.69	0.70	0.57	0.01	0.74	0.58	0.29	0.48	1		
Mn	0.32	0.32	0.56	0.61	0.54	0.05	0.63	0.35	0.21	0.29	0.78	1	
Zn	0.16	−0.02	−0.06	−0.06	0.12	−0.10	0.09	−0.06	−0.16	−0.44	−0.05	0.14	1

Table 5. Correlation matrix of trace elements in groundwater.

	Li	Be	Rb	Co	Ni	Cu	Sn	Sb	Mo	Cd	La	Ce	Pb	U
Li	1													
Be	0.11	1												
Rb	0.00	0.38	1											
Co	−0.04	0.42	0.75	1										
Ni	−0.22	0.57	0.63	0.74	1									
Cu	−0.31	0.28	0.29	0.35	0.51	1								
Sn	−0.24	0.68	0.61	0.76	0.95	0.51	1							
Sb	0.32	−0.25	0.39	0.48	−0.05	−0.25	−0.15	1						
Mo	0.30	0.27	−0.25	−0.33	−0.29	−0.39	−0.32	0.07	1					
Cd	−0.12	0.41	0.30	0.44	0.65	0.64	0.66	−0.31	−0.60	1				
La	−0.26	0.58	0.58	0.69	0.86	0.50	0.93	−0.19	−0.37	0.67	1			
Ce	0.04	0.30	0.39	0.49	0.59	0.39	0.53	0.05	−0.17	0.52	0.69	1		
Pb	−0.34	0.31	0.51	0.41	0.52	0.59	0.59	−0.27	−0.44	0.55	0.67	0.40	1	
U	0.16	0.18	−0.38	−0.29	−0.24	0.12	−0.16	−0.28	0.34	−0.18	−0.23	−0.28	−0.15	1

Table 6. Physical parameter of surface water during January 2013.

S. No.	Location	pH	EC, µS/cm	TDS, mg/L	DO, mg/L	RP, mV
1	Churri	6.7	220	430	7.8	182
2	Rumgara	7.2	331	409	6.7	202
3	Kusmunda	7.5	493	413	5.8	210
4	Balco	7.3	172	391	5.9	208
5	Manikpur	7.4	210	494	8.1	176
6	Krishi Nagar	6.8	304	437	7.8	182

Table 7. Chemical parameter of surface water during January 2013.

S. No.	F^-	Cl^-	NO_3^-	SO_4^{2-}	Na^+	K^+	Mg^{2+}	Ca^{2+}	Al	SiO_2	Fe	Mn	Zn
1	2.3	21	38	20	11	8.3	8.1	20	1.0	7.7	0.9	0.4	0.28
2	1.8	11	17	10	46	15	5.2	16	1.2	7.7	0.4	0.4	0.39
3	2.4	14	13	16	47	13	6.0	16	1.3	3.1	0.6	0.3	0.45
4	2.2	18	17	30	16	7.1	5.1	18	1.4	9.2	1.3	0.7	0.29
5	3.1	27	25	40	20	6.0	6.2	20	1.6	7.7	1.4	1.1	0.31
6	2.6	14	30	20	18	9.2	9.1	28	1.3	6.1	1.5	1.2	0.42

Table 8. Concentration of trace elements in surface water during January 2013.

S. No.	Li	Rb	Cr	Co	Ni	Cu	Sb	Pb	U
1	16	13	5.1	2.7	5.2	6.6	3.8	7.4	0.92
2	22	25	4.2	3.2	5.8	9.6	3.4	6.3	0.74
3	23	18	4.6	3.9	4.8	7.5	3.4	5.7	0.89
4	15	19	4.4	4.2	6.4	7.9	4.4	6.2	0.97
5	14	14	4.8	2.5	4.0	6.4	2.4	4.5	0.68
6	18	16	8.1	5.9	7.9	14	1.4	2.8	0.32

EC and TDS of water (n = 6) in the post monsoon period was ranged from 20.8˚C - 22.2˚C, 6.7 - 7.5, 5.8 - 8.1 mg/L, 176 - 210 mV, 172 - 493 µS/cm and 391 - 494 mg/L with mean value of 21.6˚C ± 0.4˚C, 7.3 ± 0.3, 7.0 ± 0.8 mg/L, 193 ± 12 mV, 429 ± 29 µS/cm and 429 ± 29 mg/L, respectively. The concentration of F^-, Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Mg^{2+}, Ca^{2+}, Al, SiO_2, Fe, Mn and Zn was ranged from 1.8 - 3.1, 11 - 27, 13 - 38, 10 - 40, 11 - 47, 6.0 - 15, 5.0 - 9.0, 16 - 28, 3.1 - 9.2, 0.06 - 0.26, 0.4 - 1.5, 0.3 - 1.2 and 0.3 - 0.5 mg/L with mean value of 2.4 ± 0.3, 18 ± 4.7, 23 ± 8, 23 ± 9, 26 ± 13, 10 ± 3, 6.5 ± 1.3, 20 ± 4, 1.3 ± 0.2, 6.9 ± 1.7, 1.0 ± 0.4, 0.7 ± 0.3 and 0.4 ± 0.1 mg/L, respectively. Similarly, concentration of other metals: Li, Rb, Cr, Co, Ni, Cu, Sb, Pb and U was observed at microgram levels, ranging from 14 - 23, 13 - 25, 4.2 - 8.1, 2.5 - 5.9, 4.0 - 7.9, 6.4 - 14, 1.4 - 4.4, 2.8 - 7.4 and 0.3 - 1.0 µg/L with mean value of 18 ± 3, 18 ± 4, 5.2 ± 1.2, 3.7 ± 0.9, 5.7 ± 1.1, 8.7 ± 2.3, 3.1 ± 0.9, 5.5 ± 1.3 and 0.8 ± 0.2 µg/L, respectively. They were found to occur in following decreasing order: NO_3^- > Ca > Na^+ > Cl^- > SO_4^{2-} > K^+ > Mg > F^- > Al > Fe > Mn > Zn > Li > Rb > Cu > Pb > Ni > Cr > Co > Sb > U. The concentration of F^- in the surface water of the studied basin was found to be higher than other locations of the country [19] [20].

The factor analysis was applied and four factors were extracted. Factor-1 was accounted for 48.70% of the total variance, related to anions, Ca^{2+} and Mg^{2+}. It could be correlated to complex processes such as weathering of fluoride bearing minerals (AlF_3, CaF_2, MgF_2), gypsum, carbonate minerals and anthropogenic activities *i.e.* coal burning and leaching, aluminum plant effluents, etc. Factor-2 was accounted for 22.15% of the total variance, related to EC, TDS and Na^+ which determined the mineralization of pond water. Factor-3 was accounted for 16.23% of the total variance having strong loadings of Fe and Mn, related to the speciation of Fe and Mn in the water. Factor-4 was accounted for 9.23% of the total variance, negatively loaded with the pH values. This factor was in the inverse relationship with the other factors.

3.4. Water Quality

The concentration of F^-, Al, Mn and Fe was found to be several folds higher than recommended value of 1.0, 0.03, 0.10 and 0.30 mg/L, respectively. The higher values of EC, TDS, RP, F^-, Cl^-, NO_3^-, Mg^{2+}, Ca^{2+}, SiO_2, Al, Fe, Ni, Zn, Sb, Pb and U in the groundwater than the surface water was observed, may be due to leaching from the coal (**Figure 2**, **Figure 3**). The main sources of the contaminants in the water of the studied area expected are

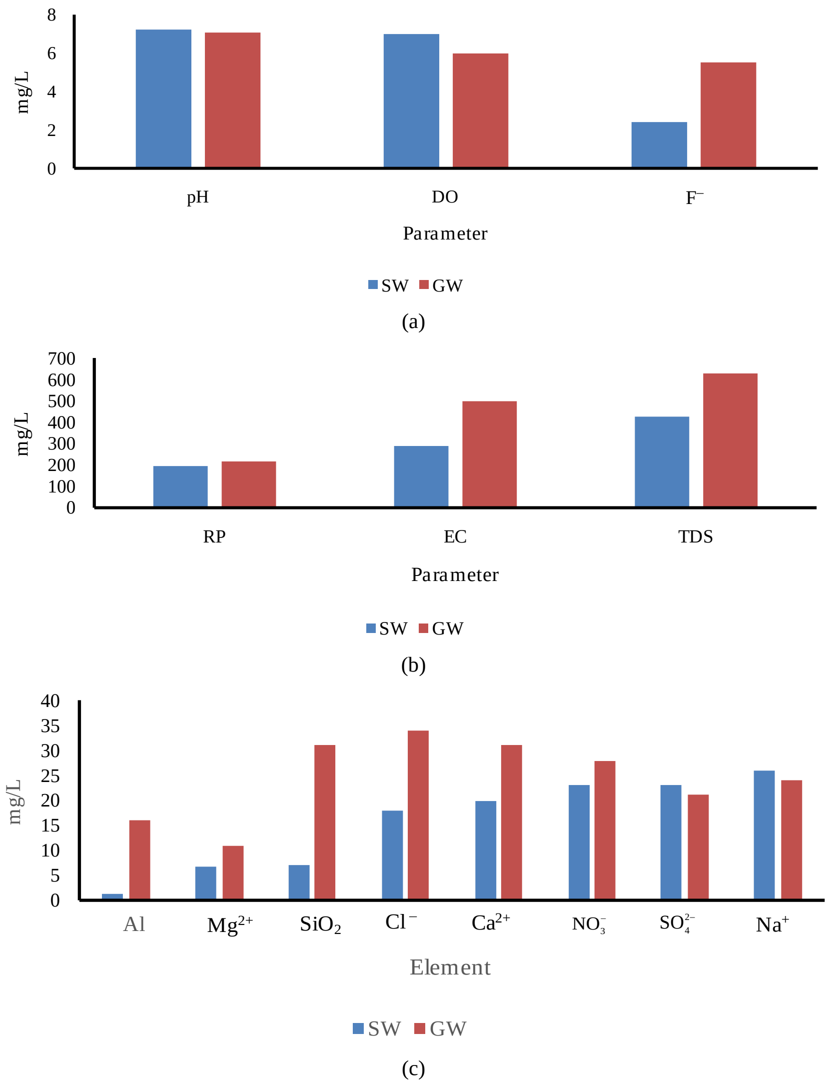


Figure 2. Distribution of pH and elements in ground and surface water in the post monsoon period, January, 2013.

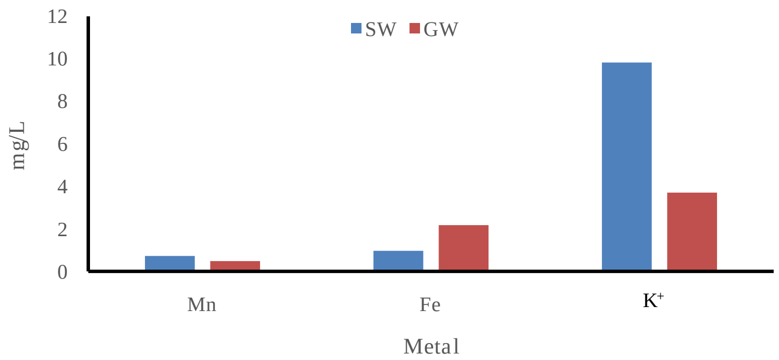
coal mine leachates and the Aluminum and Thermal power plant effluents discharged into the environment.

3.5. Exposure Assessment

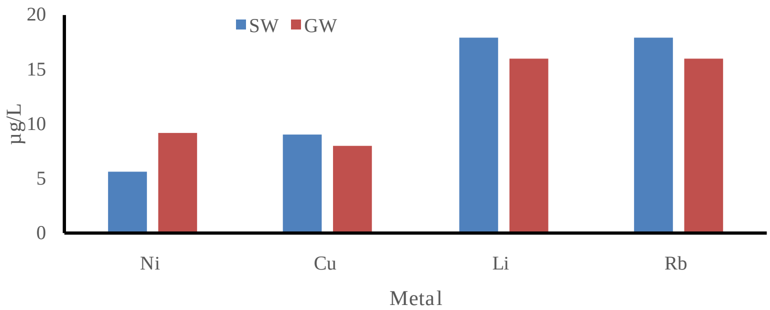
The toxic elements *i.e.* F^-, Al, Mn, Fe, Cu, Cd, Pb and U are exposed to human and animals through the contaminated water. Among them, the concentration of F^- is dominated in ground and surface water. The stool and urine samples were reported as good indicator for the exposure assessment. In this study, the F^- content was analyzed in stool and urine samples of domestic animals *i.e.* cattle, buffalo, sheep and goat (**Table 9**). The F^- concentration in the urine and stool samples (5 × 4 × 2 = 40) was ranged from 32 - 63 mg/L and 186 - 356 mg/kg with mean value of 44 mg/L and 266 mg/kg (dried mass), respectively. The highest F^- concentration was observed in the goat clinical samples, which might be due to higher intake of the contaminated biomass and water (**Figure 4**). Several cases of fluorosis diseases in the domestic animals of the basin was observed and shown in **Figure 5**.

4. Conclusion

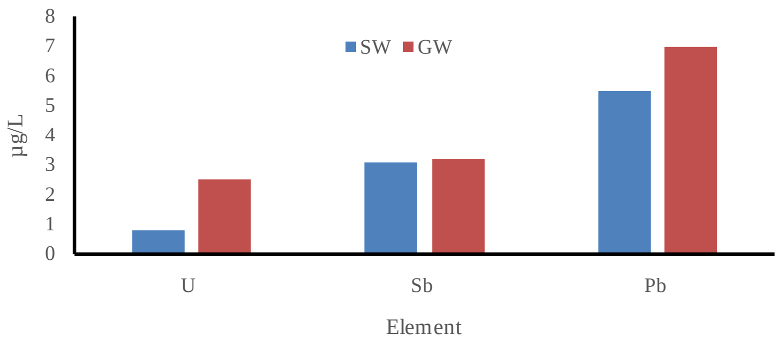
The water of the Korba basin is contaminated with elements (*i.e.* F^-, Al, Fe and Mn) by multiple sources (*i.e.* coal



(a)



(b)



(c)

Figure 3. Distribution trace elementsin ground and surface water in the post monsoon period, January, 2013.

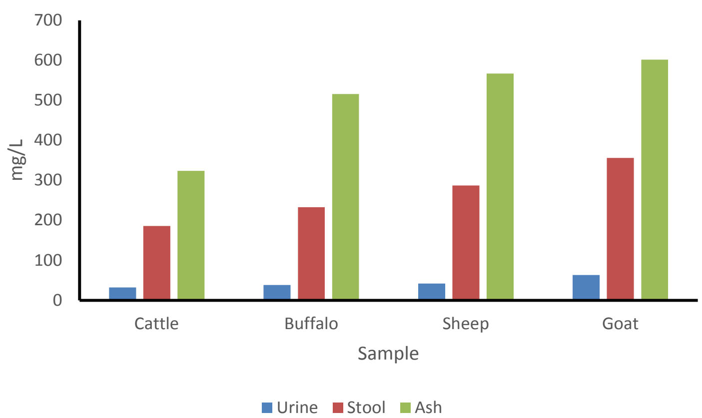


Figure 4. Comparison of F^- concentration in clinical samples.

(a)

(b)

Figure 5. Dental (a) and hair (b) fluorosis in buffalo.

Table 9. Concentration of F^- in clinical samples during January 2013.

S. No.	Sample	Cattle	Buffalo	Sheep	Goat
1	Urine	32	38	42	63
2	Stool	186	233	287	356
3	Ash	324	516	567	602

burning, Aluminum plant effluent, mine leachate, etc.). Fluoride is enriched and several folds higher in the animal urines than recommended limit of 4 mg/L with higher prevalence of fluorosis diseases. The domestic animals are severely affected with fluorosis diseases due to higher consumption of the contaminated food and water.

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