

Contamination of Pond Water and Sediment in Coal Burning Area

Reetu Sharma¹, Khageshwar Singh Patel^{1*}, Lesia Lata², Huber Milosh³

¹School of Studies in Chemistry, Pt. Ravishankar Shukla University, Raipur, India

²Department of Soil Science and Protection, Maria Curie-Skłodowska University, Lublin, Poland

³Geology and Lithosphere Protection Department, Maria Skłodowska-Curie University, Lublin, Poland

Email: *patelks_55@hotmail.com

How to cite this paper: Sharma, R., Patel, K.S., Lata, L. and Milosh, H. (2017) Contamination of Pond Water and Sediment in Coal Burning Area. *Journal of Environmental Protection*, 8, 358-379.

<https://doi.org/10.4236/jep.2017.83027>

Received: September 23, 2016

Accepted: March 28, 2017

Published: March 31, 2017

Copyright © 2017 by authors and Scientific Research Publishing Inc.

This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

The pond water is used by a variety of animals *i.e.* mammals, birds, duck, and fish. Sediments play a significant role in determining the overall environmental quality for the living organism. Therefore, in this work, chemical characterization of pond water and sediment in the largest coal burning basin of India *i.e.* Korba basin is described. Elements *i.e.* C, O, S, F, Cl, Na, Mg, Al, Si, P, K, Ca, Ti, Fe, As, Cr, Cu, Zn, Cd, Pb, and Hg were quantified. Toxic metals *i.e.* As, Cd, Hg, and Pb were highly enriched in the sediments, ranging from 36 - 154, 0.14 - 1.19, 0.12 - 0.82 and 26 - 127 mg/kg with mean value ($p = 0.05$) of 95 ± 12 , 0.62 ± 0.11 , 0.35 ± 0.08 and 75 ± 13 mg/kg, respectively. The concentration variations, pollution indices and sources of elements in water and sediment are discussed.

Keywords

Sediment, Pond Water, Contamination, Ions, Metals, Pollution Indices

1. Introduction

Pond, a stagnant water body is widely used for drinking, bathing, washing for industrial and agricultural purposes. The bottom of the water reservoir is made up of sediment (*i.e.* sand, silt, and clay). The ponds gain water through rainfall, run-off or tail water from irrigation. However, in an urban area, the pond is polluted due to several anthropogenic activities *i.e.* industrial and sewage effluents, runoff water, vehicular emissions, etc. Coal, a naturally occurring combustible material is widely used for energy generation in an urban area by emitting various gasses, the inorganics and organics into the ecosystem [1] [2] [3] [4]. The complex environmental issues *i.e.* acid mine drainage, deposition of toxic compounds, air pollution, halting of acid rain, health hazards, storage of solid waste, etc., were

arisen due to huge coal burnings [5]-[13]. The toxic chemicals *i.e.* fluoride, heavy metals and polycyclic aromatic hydrocarbons, etc., deteriorate the water reservoirs in various region of the World [14] [15] [16] [17] [18]. Hence, in this work, the contamination of pond reservoirs (*i.e.* water and sediment) with fluoride, sulfur, nutrients and heavy metals in the Korba basin, India is described.

2. Materials and Methods

2.1. Study Area

The largest coal deposits in the country are present in the Korba basin (22.35°N and 82.68°E). Several open and underground coal mines are in operation with annual production of ≈ 3 BT coal. A huge amount of coal $>10,000$ MT annually is consumed by the various unit of thermal power plants running in the Korba area by emitting several million tons of fly ash into the environment. The Asia's biggest Aluminum plant is also in the operation in this area. The environment of Korba city has been polluted due to the huge exploitation of coals. The large population (≈ 0.5 million) residing in the basin is exposed from various environmental contaminants related to coal burning and leaching.

2.2. Sample Collection and Preparation

The water and sediment samples were collected from 26 ponds, lie over ≈ 500 km² area of the Husdo river basin in May 2012 as shown in **Figure 1**. The cleaned one-liter narrow-mouth polyethylene bottle was used for the water collection. The container was rinsed twice, and completely filled with the sample water. The physical parameters *i.e.* pH, dissolved oxygen (DO) and electrical conductivity (EC) were measured at the spot by using HANNA made sensors. The sample was transferred to the laboratory and divided into two portions. The 1st portion was treated with few drops of ultra-pure nitric acid (E. Merck) for the metal analysis. The 2nd portion was used for monitoring of anions. All samples were refrigerated at 4°C.

One kilogram of the top sediments (0 - 10 cm) was sampled by a stainless steel spoon, and stored in glass jar [19]. The sediment samples were dried, milled and sieved out particles of ≤ 0.1 mm for the X-ray spectroscopic analysis of the major elements. A 0.25 g of the sample was digested with acids (3 mL HCl and 1 mL HNO₃) in the closed system with P/T MARS CEM (Varian Company) microwave oven. The acid extract was used for monitoring of the metals with the spectroscopic techniques.

A weighed amount of sediment sample (0.25 g) was placed in a 50 mL Pt-crucible by adding 2.0 g NaOH [20]. The crucible was kept in a muffle furnace and slowly raising the temperature up to 600°C. The sample was fused up to 30 min, and the residue was dissolved in hot water. The pH of the extract was adjusted to 9.0 to precipitate the interfering ions *i.e.* Fe, Al, Mn. Then, it was filtered and diluted to 100 mL in a polyethylene volumetric flask for the F⁻ analysis. The sediment sample was mixed with pure water into 1:2 (m/v) in a 100-mL conical flask. The suspension was allowed to stand for overnight, and the pH

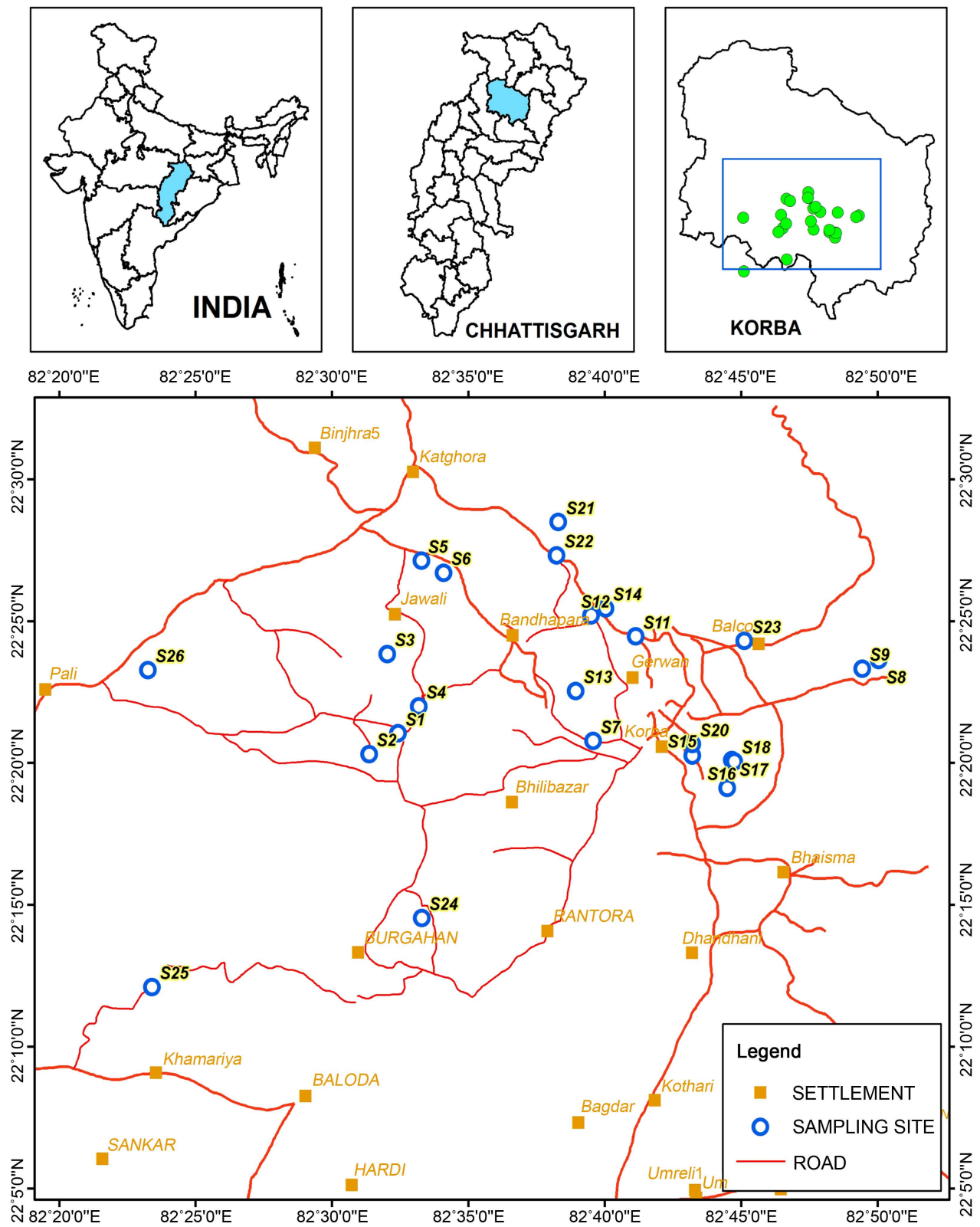


Figure 1. Representation of sampling locations in Korba basin.

value of the settled aqueous solution was measured by a Hanna pH meter (type-HI991300).

2.3. Analysis

The physical parameters (*i.e.* pH, EC and DO) of the water samples were measured with the Hanna made sensors.

The Dionex chromatography DX120 equipped with anion separation column (AS9-HC, 250 × 4 mm), cation separation column (CS12A, 250 × 4 mm) and conductivity detector was used for analysis of the ions (*i.e.* Na⁺, K⁺, Cl⁻, NO₃⁻, SO₄²⁻, Mg²⁺ and Ca²⁺).

The F⁻ content was analyzed by using Metrohm-720 ion meter using the fluoride selective electrode. The calibration curve was prepared by using 1.0, 3.0, 5.0, 7.0 and 10.0 mg/L F⁻ containing the buffer solution in 1:1 ratio (v/v). The buffer was prepared by dissolving sodium citrate (300 g), 1,2-cyclohexanedia-mine-N-tetraaceticacid (22 g) and NaCl (60 g) in a volume of one liter with the de-ionized water by subsequent adjustment of pH value to 5.2 ± 0.2. Ten milliliters of water sample was mixed with the buffer in a 1:1 ratio (v/v), and F⁻ content were analyzed by using standard calibration curve.

The CHNSO-IRMS Analyzer by SV Instruments Analytical Pvt. Ltd. was used for analysis of black or elemental carbon (BC). The sediment sample (15 mg) was oxidized with O₂ at 1020°C with constant helium flow by detecting the resulting CO₂ gas with a thermal conductivity detector. The H₃PO₄ (10 drops) treated sediment sample was oxidized in a similar way for determination of BC and OC content. The OC content was analyzed by titration method using K₂Cr₂O₇ as oxidant [21]. The CC content in the sediment was evaluated by subtracting sum of the BC and OC content to the TC (total carbon) by using the following equation.

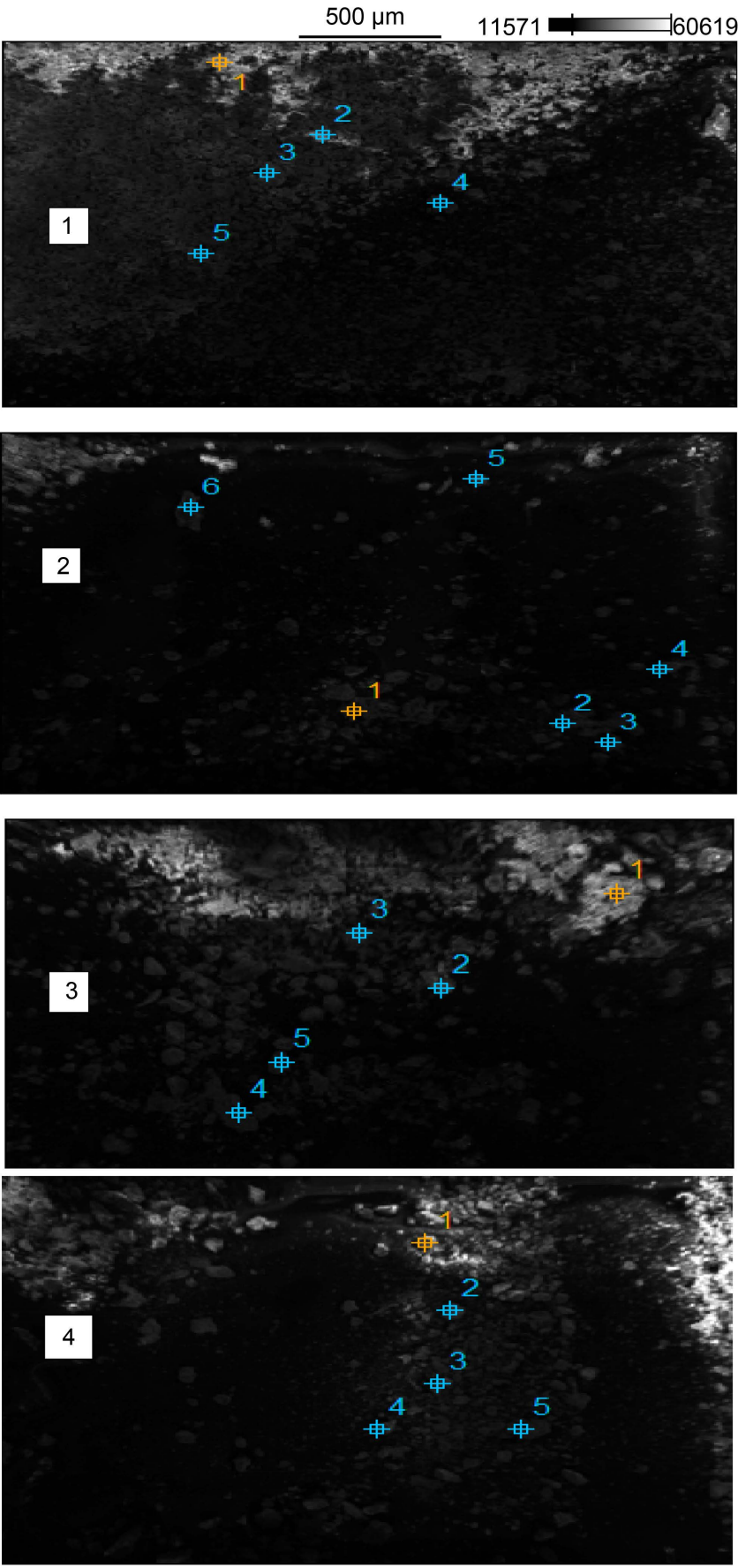
$$CC = TC - (BC + OC).$$

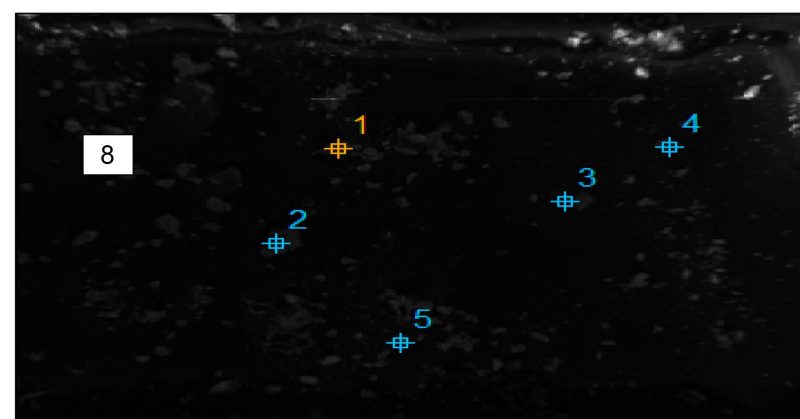
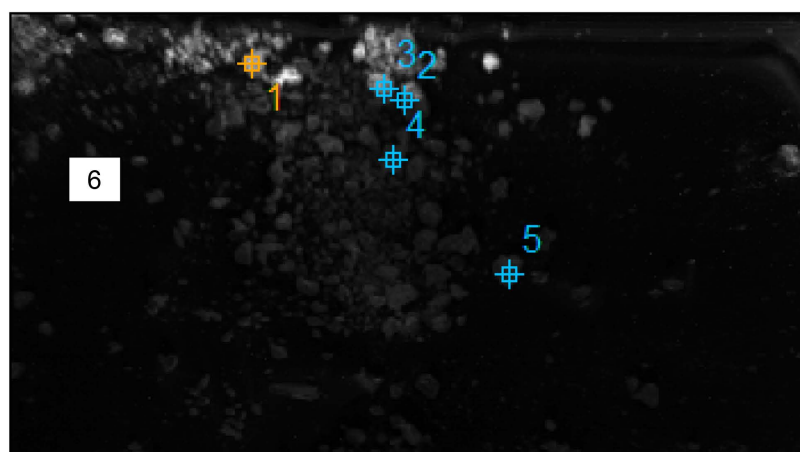
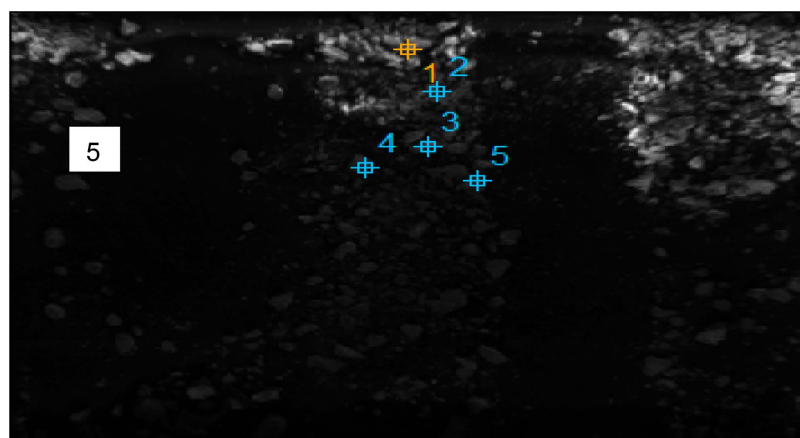
The Hitachi High-Tech Scanning electron microscope (SEM)-SU6600 equipped with the energy dispersive X-ray spectrometer (EDS) and cathode luminescence (CL) detector was used for characterization of elements (*i.e.* C, O, S, Cl, Na, Mg, Al, Si, P, K, Ca, Ti, Fe, Mn, and Ni). The sample was irradiated with X-ray in a polyethylene disc in both secondary electron imaging (SEI) and backscattered electron imaging (BSEI) modes to record surface photographs and elemental peaks as shown in Figure 2 and Figure 3. Three measurements at different locations of a sample were carried out, and their mean values are presented.

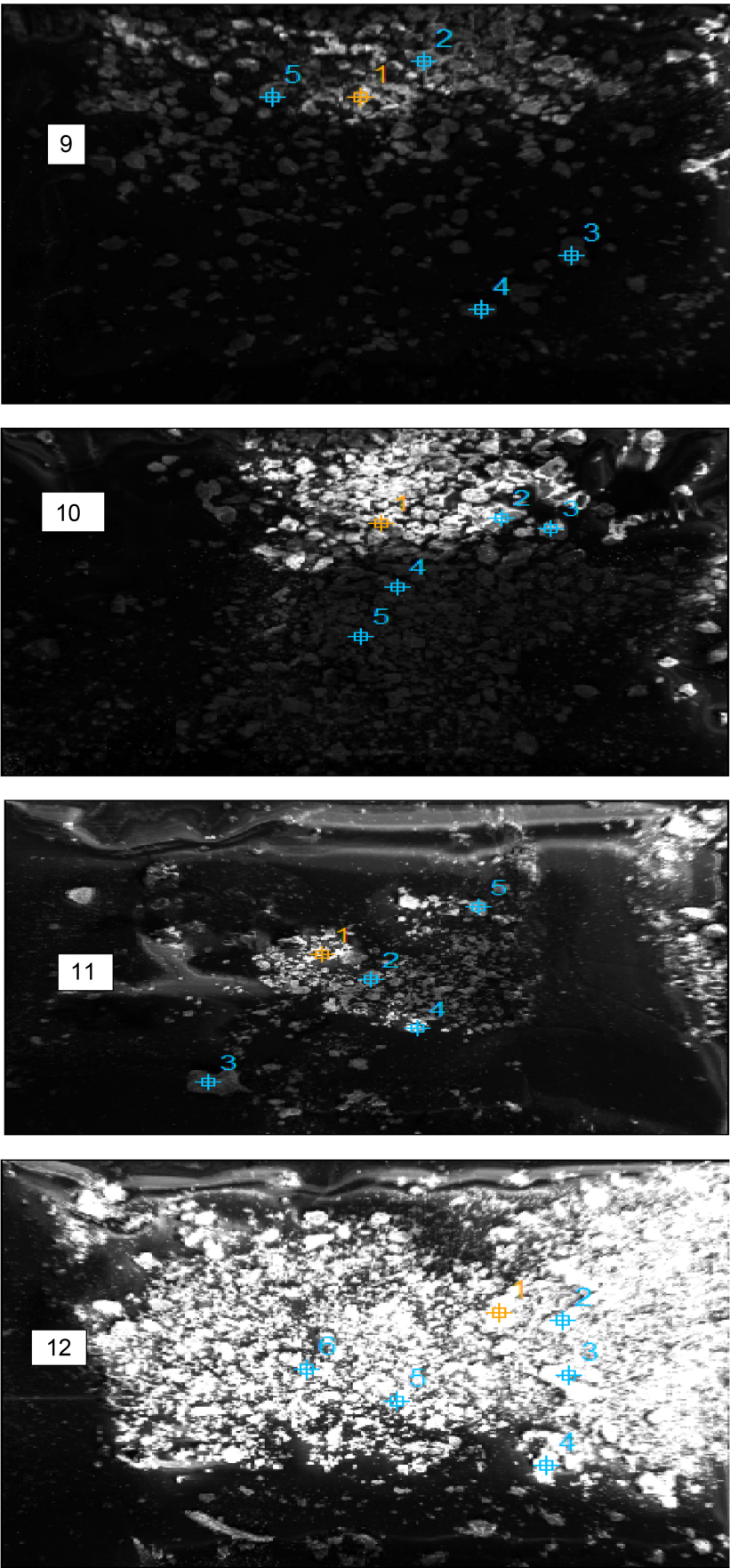
The Varian ICP-OES-700-ES was used for monitoring of metals (*i.e.* Cr, Cu, Zn, and Pb) in the sediment extract. The GF-AAS SpectrAA 220 Zeeman and CV-AAS SpectrAA 55B were used for the analysis of As, Cd, and Hg. The results are expressed on a dry-weight basis. The NCS DC 73,382°C RM sediment sample was used for the quality control. The accuracy of analysis of the metals in the reference sample was found within ≤2%. The precision (RSD) of elemental analysis (n = 3) in the sediment with the SEM-EDS, ICP-AES, AAS, ion selective and IC technique was found to be ≤12, 7, 6, 5 and 5%, respectively.

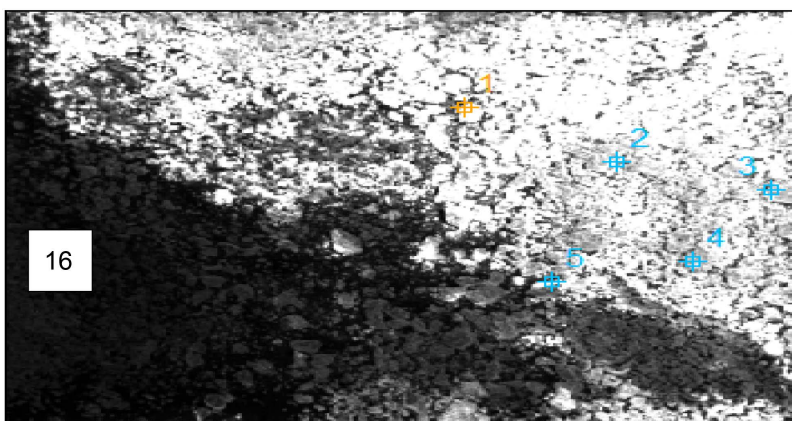
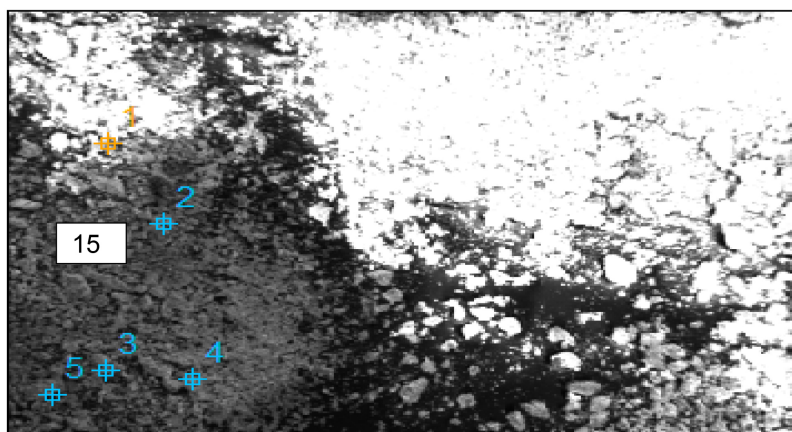
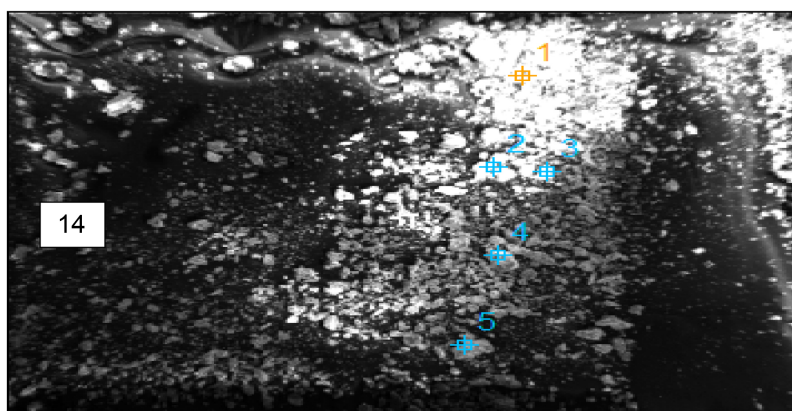
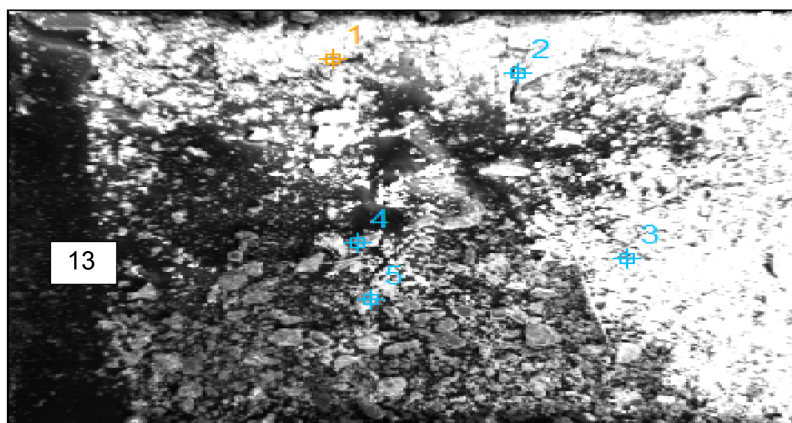
2.4. Enrichment of Contaminants

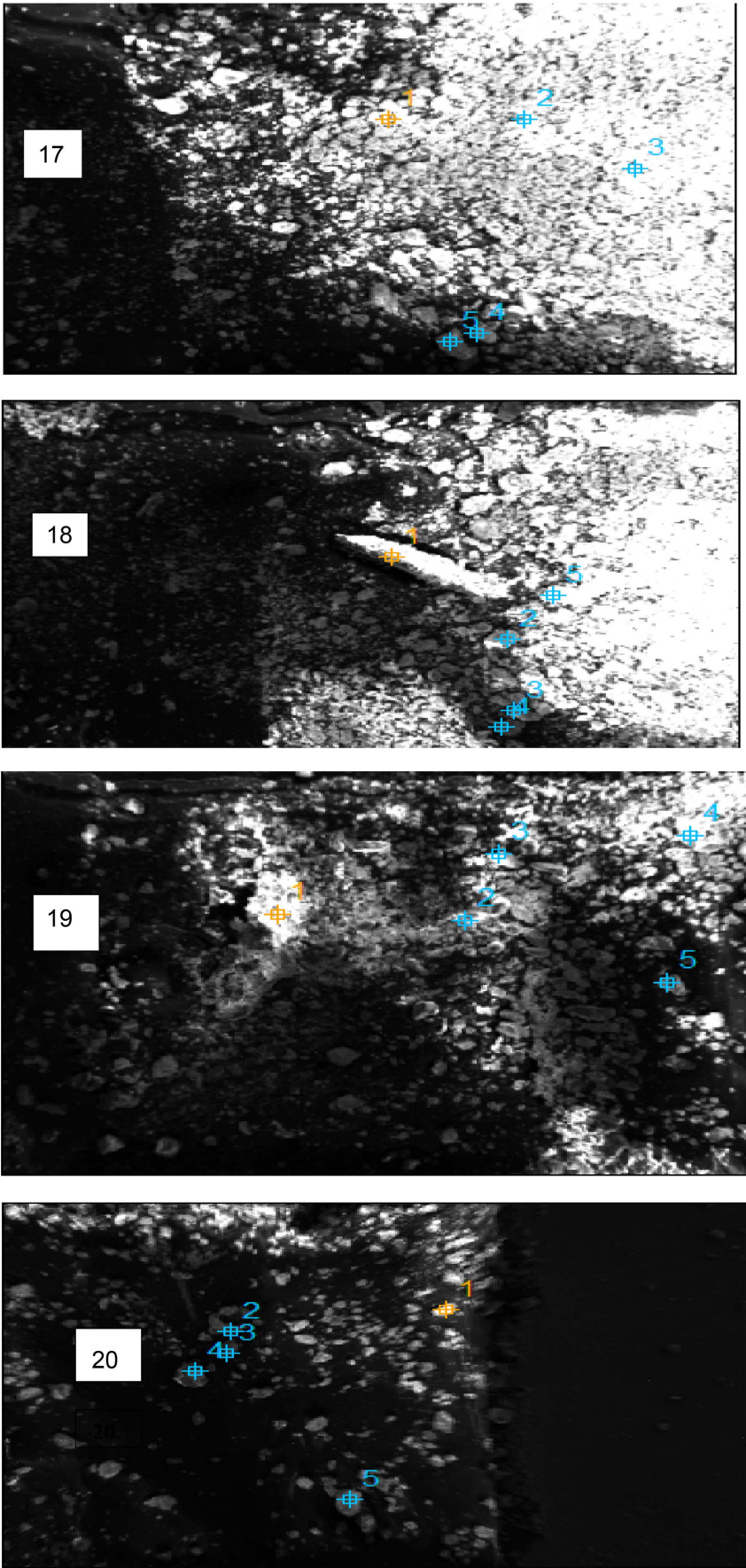
The pollution indices *i.e.* enrichment factor (E_f), contamination factor (C_f) and

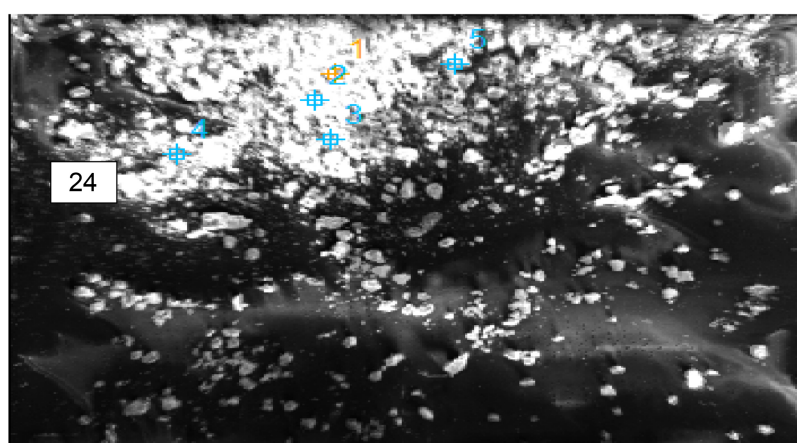
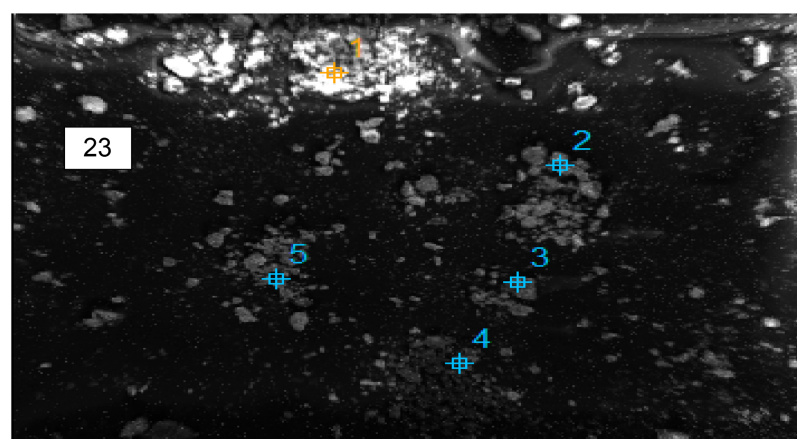
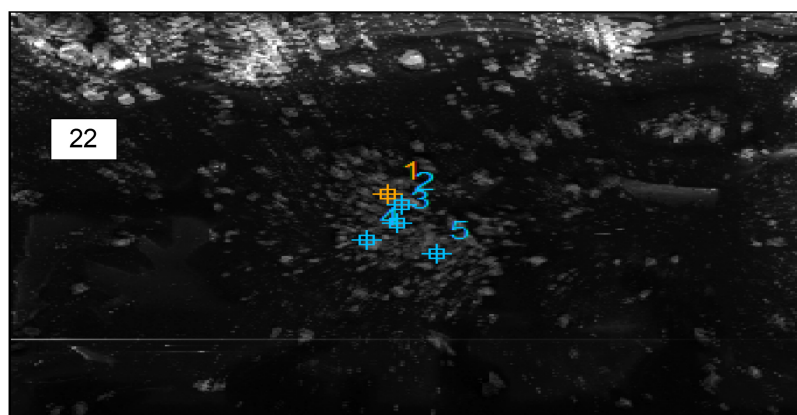
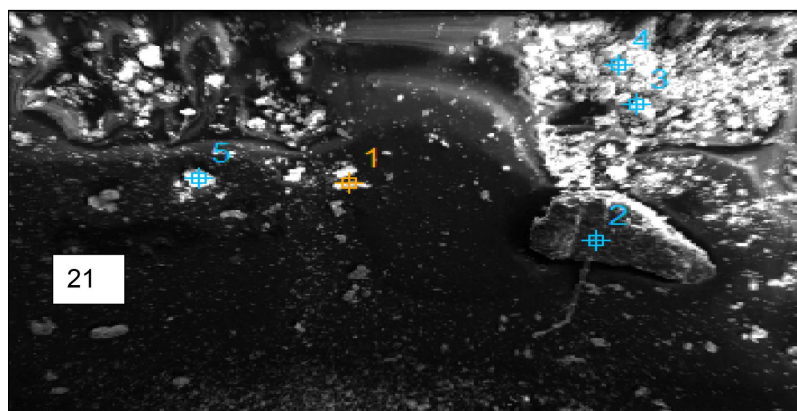












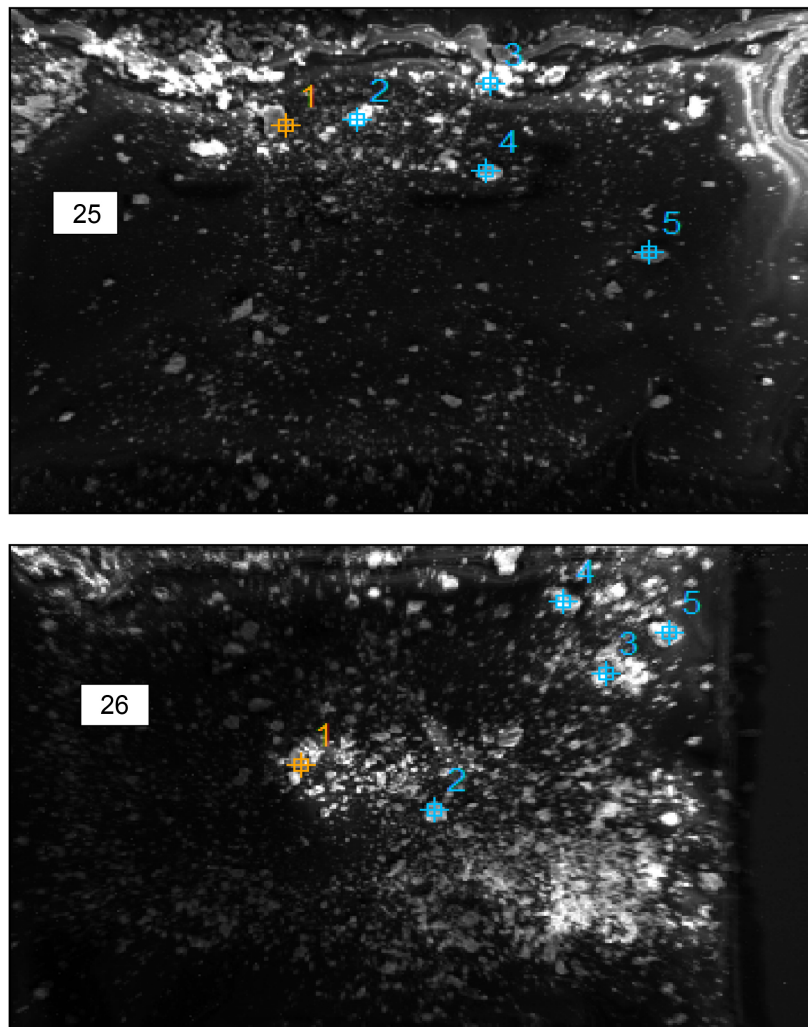


Figure 2. SEM photographs of surface sediments samples no. 1 - 26.

pollution load index (*PLI*) were used to determine element concentration in the sediment samples with respect to the baseline concentration. The concentration ratio of an element, *X* to *Al* in the sediment was normalized to the ratio of element, *X* and *Al* present in the earth's crust. The following equations were used for computation of the pollution indices [22] [23].

$$E_f = \left\{ \left[\frac{X_s}{Al_s} \right] \right\} / \left\{ \left[\frac{X_e}{Al_e} \right] \right\}$$

$$C_f = \left\{ \left[\frac{X_s}{X_e} \right] \right\}$$

$$PLI = \left(C_{f1} \times C_{f2} \times C_{f3} \times C_{f4} \cdots C_{fn} \right)^{1/n}$$

where, X_s and Al_s are concentrations of metal and *Al* in the sediment, and Al_e and X_e are background concentration of metal and *Al* in the earth crust.

3. Results and Discussion

3.1. Water Contamination

The geographical characteristics of twenty six ponds are summarized in **Table 1**.

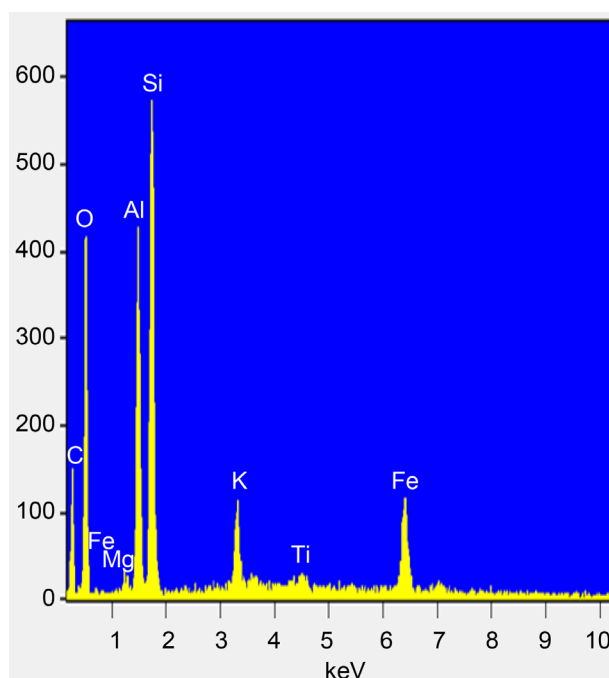


Figure 3. EDX signals of elements in sample no. S4.

Table 1. Physio-chemical characteristic of pond water.

S. No.	Location	Area, m ²	pH	DO, mg/L	EC, μ S/cm
S1	Shakti Nagar	13,000	5.9	8.0	395
S2	Gevra, Dipka	2700	7.0	7.9	378
S3	PN, Dipka	7200	7.1	7.1	402
S4	Banki, Dipka	1000	7.8	7.4	610
S5	Delwadiah	2700	6.4	6.3	530
S6	Shingali	1800	6.5	6.6	512
S7	Kusmunda	9000	7.2	6.4	460
S8	Rajgamar-3	3600	7.0	6.5	320
S9	Mudapar	5400	7.7	6.7	341
S10	PN, Darri	2700	5.8	6.7	362
S11	Darri west	7200	6.4	6.9	367
S12	Jamnipali	13,000	6.7	5.8	428
S13	Gopalpur	7200	7.7	6.3	515
S14	HTPP, Darri	1000	6.4	5.9	540
S15	Manuikpur-1	36,000	6.9	6.8	532
S16	Manikpur-2	7200	6.0	7.9	345
S17	Dader-1	7200	8.5	7.8	278
S18	Dader-2	27,000	6.6	7.1	320
S19	Kudarikhar	3600	6.1	8.4	418
S20	Naktikhar	2700	7.1	8.3	436
S21	Danras-1	18,000	5.7	7.7	456
S22	Danras-2	5000	7.8	8.2	378
S23	SN-Balco	5000	8.5	8.1	310
S24	Pathadi	7200	6.5	7.2	605
S25	Dhendheni	3600	7.9	7.5	376
S26	Sukhri	1800	8.0	8.2	380

PN = Pragati Nagar, HTPP = Hydro Thermal Power Plant, SN = Shanti Nagar.

The catchment areas of the ponds were ranged from 1000 - 36,000 m². Among them, five ponds exhibited with larger catchment area, ranging from 18,000 to 36,000 m². The pH, DO and EC value of the water (n = 26) was ranged from 5.7 - 8.5, 5.8 - 8.4 mg/L and 278 - 610 µS/cm with mean value of 7.0 ± 0.3 , 7.2 ± 0.3 mg/L and 423 ± 35 µS/cm, respectively. The ratio of sum of total concentration of anions to cations, $\Sigma_{\text{anion}}/\Sigma_{\text{cation}}$ was found to be 0.8 ± 0.6 . The concentration of elements *i.e.* F⁻, Cl⁻, NO₃⁻, SO₄²⁻, Na⁺, K⁺, Mg²⁺, Ca²⁺, Al, and Fe was ranged from 1.7 - 4.9, 12 - 46, 19 - 52, 17 - 70, 6.0 - 30, 4.0 - 19, 5.0 - 16, 16 - 45, 1.1 - 2.4 and 0.4 - 2.3 mg/L with mean value (p = 0.05) of 2.8 ± 0.4 , 27 ± 4 , 34 ± 4 , 39 ± 6 , 16 ± 2 , 8.6 ± 1.4 , 10.4 ± 1.2 , 30 ± 3 , 1.7 ± 0.1 and 1.2 ± 0.2 mg/L, respectively, **Table 2**. The heavy metals *i.e.* As, Cr, Cu, Zn, Cd, Pb and Hg in the surface water was found at microgram levels, ranging from 8 - 30, 10 - 21, 11 - 42, 76 - 300, 2 - 15, 12 - 43 and 0.6 - 3.8 µg/L with mean value (p = 0.05) of 17.2 ± 2.1 , 14.0 ± 1.2 , 17.2 ± 2.8 , 161 ± 3 , 6.7 ± 1.3 , 23.4 ± 3.5 and 1.7 ± 0.4 µg/L, respectively, **Table 3**. Among 17 elements detected in the water, the highest concentration of SO₄²⁻ was observed due to burning and mining of the coal. They were found to

Table 2. Concentration of ion and metal in water, mg/L.

S. No.	F ⁻	Cl ⁻	SO ₄ ²⁻	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺	Al	Fe
S1	2.8	29	35	14	8	9	30	1.9	1.9
S2	2.5	21	29	16	7	10	32	2	1.2
S3	2.1	32	22	21	12	11	29	2.3	1.1
S4	3.6	46	50	30	19	13	36	3.2	1.4
S5	4.1	39	43	22	10	14	43	3.7	2.3
S6	2.6	28	70	19	8	10	28	1.6	2.7
S7	1.8	17	66	14	7	12	31	2.8	1.1
S8	1.9	18	18	13	6	9	26	2.4	1.5
S9	1.7	12	41	13	7	7	19	1.6	1.0
S10	3.2	15	23	14	7	13	37	2.7	2.0
S11	4.9	16	48	10	6	7	22	1.3	1.8
S12	3.8	32	17	24	12	12	35	2.5	1.6
S13	4.8	36	34	20	10	16	45	3.9	1.3
S14	3.4	42	47	23	14	12	32	2.5	2.9
S15	4.2	36	45	19	11	15	42	3.7	1.8
S16	1.9	19	35	11	7	8	22	1.6	1.8
S17	1.7	16	17	11	7	8	22	2.3	0.9
S18	2.8	26	40	12	6	11	30	1.8	1.6
S19	4.1	26	51	14	6	7	23	1.1	1.3
S20	2.4	36	37	18	6	9	24	1.4	1.1
S21	4.2	28	35	16	8	14	43	1.5	1.4
S22	2.1	37	33	19	9	5	16	1.9	0.7
S23	1.9	22	28	9	5	7	18	1.4	0.6
S24	4.7	37	57	22	16	15	44	3.6	2.7
S25	2.2	31	31	12	6	10	27	1.2	1.6
S26	2.4	17	59	6	4	6	20	1.7	1.1

Table 3. Concentration of heavy metal in water, µg/L.

S. No.	As	Cr	Cu	Zn	Cd	Pb	Hg
S1	15	11	12	120	2.1	12	1.2
S2	20	13	13	115	3.2	13	1.1
S3	21	16	18	129	4.2	15	1.2
S4	8.3	15	17	117	5.1	14	1.0
S5	18	11	15	184	6.5	26	1.1
S6	17	12	16	167	4.7	25	1.5
S7	18	17	31	214	6.6	26	1.2
S8	9.0	10	17	176	6.4	23	0.9
S9	18	11	14	76	7.0	14	2.7
S10	23	21	42	300	9.2	33	3.6
S11	18	20	31	296	10	43	1.6
S12	30	11	21	117	14	24	3.8
S13	27	14	21	271	15	30	3.4
S14	17	11	12	212	10	31	1.6
S15	22	12	17	205	8.2	34	1.3
S16	9.1	14	12	78	5.2	14	0.9
S17	16	12	14	134	7.3	22	1.7
S18	19	14	16	167	8.3	27	0.8
S19	9.2	13	11	110	6.4	16	1.3
S20	17	15	13	198	7.2	25	1.1
S21	18	14	11	90	8.1	21	0.6
S22	13	12	12	87	2.5	12	1.7
S23	12	13	15	99	2.6	17	3.3
S24	25	21	21	232	10	41	2.1
S25	17	17	13	213	7.1	36	1.5
S26	11	14	11	86	4.2	15	0.9

occur in following increasing order in the ecosystem: $\text{Hg} < \text{Cd} < \text{Cr} < \text{Cu} < \text{As} < \text{Pb} < \text{Zn} < \text{Fe} < \text{Al} < \text{F}^- < \text{K}^+ < \text{Mg}^{2+} < \text{Na}^+ < \text{Cl}^- < \text{Ca}^{2+} < \text{NO}_3^- < \text{SO}_4^{2-}$. The concentration of F^- , As, Cr, Cu, Zn, Cd, Pb, and Hg in the surface water of the study area was found to be comparable to the values reported in other regions of the country and World [24]-[33]. The value of physical parameters *i.e.* pH, DO and EC of the surface water was found within recommended limits reported for drinking water [34] [35]. The tolerance limit reported for elements *i.e.* F^- , Al, Fe, Cd, Pb and Hg in drinking water is 1.5, 0.05, 0.300, 0.005, 0.01 and 0.001 mg/L [34] [35]. The higher concentration of elements *i.e.* F^- , Al, Fe, Pb and Hg than permissible limits was observed in all locations, mainly due to their discharge of the industrial effluent of the Aluminum and Thermal power plants. The surface water is widely used for drinking purpose by domestic animals *i.e.* cattle, buffalo, sheep, and goats. The reflection of fluoride toxicities in the domestic animals (*i.e.* cattle, buffalo, sheep, and goat) was marked as dental and bone fluorosis as

shown in **Figure 4**.

3.2. Sediment Contamination

Sediment is composed of organic and inorganic particles of various sizes. The sediment includes boulders, cobbles, pebbles, sand, silt, and clay. The particle sizes of all sediments were found in inhomogeneous orders (**Figure 2**). The colour was varied from white (W) to black (B) due to deposition of the BC and fly ash particulates. Among them, 9 samples *i.e.* (10, 12 - 18 and 24) were contaminated with elevated levels of ash particles.

The pH value of sediments was found to be slightly acidic, ranging from 5.4 - 8.1 with mean value ($p = 0.05$) of 6.60 ± 0.03 due to high S content (**Table 4**).

The concentration of five elements *i.e.* C, P, O, S, and Cl in the sediments are summarized in **Table 4**. The concentration of TC, BC, P, O, S, and Cl was ranged from 8.9 - 31.5, 3.6 - 14.0, 0.20 - 0.92, 35.7 - 56.1, 0.08 - 1.10 and 0.11% - 0.58% with mean value ($p = 0.05$) of 20.9 ± 2.0 , 9.2 ± 1.0 , 0.46 ± 0.07 , 45.9 ± 2.1 , 0.57 ± 0.09 and $0.32\% \pm 0.05\%$, respectively.

The concentration of crustal elements *i.e.* Si, Al, and Fe was ranged from 6.0 - 14.9, 4.3 - 11.0 and 0.8% - 4.9% with mean value ($p = 0.05$) of 11.0 ± 0.9 , 7.4 ± 0.7 and $2.1\% \pm 0.4\%$, respectively, **Table 5**. The concentration of metals *i.e.* Na, K, Mg, Ca, and Ti were occurred at moderate levels, ranging from 0.30 - 1.2, 0.37 - 1.96, 0.12 - 0.59, 0.31 - 0.88 and 0.16% - 0.88% with mean value ($p = 0.05$) of 0.72 ± 0.10 , 0.72 ± 0.15 , 0.30 ± 0.04 , 0.28 ± 0.06 and $0.34\% \pm 0.04\%$, respectively, **Table 5**.

The heavy metals *i.e.* As, Cr, Cu, Zn, Cd, Pb and Hg were found to be present at the trace levels, ranging from 36 - 154, 29 - 79, 18 - 92, 42 - 294, 0.14 - 1.19, 26 - 127 and 0.12 - 0.82 mg/kg with mean value ($p = 0.05$) of 95 ± 12 , 47 ± 5 , 49 ± 8 , 133 ± 28 , 0.62 ± 0.11 , 75 ± 13 and 0.35 ± 0.08 mg/kg, respectively, **Table 6**.

Among 22 detected elements, oxygen was found to exist at the highest level with the lowest value for Hg. They were occurred in following increasing trend in sediment: $Hg < Cd < Cr \approx Cu < Pb < As < Zn < Ti \approx Mg \approx Cl < P < S \approx Ca < Na < K \approx F < Fe < Al < BC < Si < TC < O$. The content of three elements *i.e.* P, S, and Cl was observed to be much higher than the baseline value of 0.065,



Figure 4. Dental fluorosis in the buffalo.

Table 4. Physico-chemical characteristics of sediment.

S. No.	Color	pH	%						
			BC	TC	O	Cl	P	S	F
S1	B	5.6	8.5	15.3	54.9	0.31	0.45	0.52	1.02
S2	B	6.7	9.6	20.6	48.5	0.28	0.28	0.38	1.09
S3	B	6.8	8.8	21.6	40.5	0.38	0.28	0.34	1.19
S4	B	7.4	4.8	16.2	48.6	0.56	0.68	0.82	1.28
S5	B	6.1	8.8	23.7	39.5	0.41	0.55	0.67	0.92
S6	B	6.2	8.7	20.2	41.8	0.32	0.92	1.10	0.88
S7	B	6.9	8.8	23.7	43.6	0.23	0.34	1.01	1.10
S8	B	6.7	8.6	20.5	44.3	0.23	0.23	0.24	1.34
S9	B	7.3	10.2	23.7	45.2	0.11	0.41	0.70	0.87
S10	BW	5.5	11.1	19.1	45.9	0.22	0.2	0.34	0.92
S11	BW	6.1	10.5	27.8	47.2	0.18	0.44	0.56	0.74
S12	W	6.4	12.7	31.5	35.9	0.44	0.68	0.14	0.86
S13	W	7.3	13.8	22.8	38.2	0.42	0.54	0.45	1.11
S14	W	6.1	11.4	28.5	35.7	0.58	0.68	0.78	1.02
S15	W	6.6	12.9	26.8	41.1	0.46	0.54	0.69	0.84
S16	W	5.7	3.7	16.5	51	0.22	0.37	0.48	0.87
S17	W	8.1	5.3	12.0	50.5	0.19	0.23	0.36	1.21
S18	W	6.3	9.1	18.7	44.1	0.31	0.45	0.60	0.96
S19	BW	5.8	6.9	16.0	55.3	0.32	0.44	0.57	0.72
S20	BW	6.8	10.1	16.6	49.8	0.45	0.56	0.69	0.78
S21	BW	5.4	9.8	19.5	47.3	0.37	0.49	0.62	0.81
S22	BI	7.4	3.6	8.9	56.1	0.48	0.7	0.61	1.06
S23	BW	8.1	9.9	21.9	49.3	0.21	0.38	0.50	0.68
S24	BW	6.2	11.5	24.3	43.7	0.43	0.6	0.76	0.71
S25	B	7.5	9.2	24.1	45.9	0.27	0.36	0.42	0.64
S26	BW	7.6	8.5	23.6	49.1	0.13	0.21	0.08	0.92

0.006% and 0.037%, respectively [36]. The content of BC, F⁻, Cl⁻, As, Pb, and Hg content in the sediment of the study area was found to be higher than the values reported in the sediments of other regions of the country and World due to huge coal burning [37]-[49].

The background concentration of Al, Fe, Na, K, Mg, Ca, P, S, F, Cl, Cr, Zn, Cu, Pb, As, Cd, and Hg reported in the earth crust was 81,530, 39,200, 24,300, 23,200, 14,900, 25,600, 650, 62, 557, 370, 92, 67, 28, 17, 4.8, 0.09, and 0.05 mg/kg, respectively [50]. The mean E_f -value for Cu, Zn, Pb, Cd, P, Cl, Hg, F, As and S was computed and found to be 2.1, 2.5, 5.0, 7.8, 8.3, 10.2, 10.5, 21, 23 and 105, respectively. Three elements *i.e.* F⁻, As, and S were highly enriched, ($E_f > 20$) in the sediment. Five elements *i.e.* P, Cl, Cd, Pb, and Hg were enriched significantly, ($5 \geq E_f < 20$). Whereas, other two metals: Cu and Zn were enriched moderately, ($2 \geq E_f < 5$).

Table 5. Concentration of major element in sediment, %.

S. No.	Na	K	Al	Si	Mg	Ca	Ti	Fe
S1	0.7	0.78	8.3	13.8	0.25	0.62	0.27	1.92
S2	0.6	0.72	8.6	13.9	0.26	0.62	0.39	2.43
S3	0.8	1.24	10.0	14.7	0.4	0.60	0.41	2.12
S4	1.2	1.96	10.1	14.2	0.46	0.70	0.16	0.76
S5	0.9	0.97	7.2	10.2	0.59	0.86	0.45	2.79
S6	0.8	0.88	6.8	9.2	0.39	0.58	0.44	1.74
S7	0.6	0.72	9.3	11.1	0.26	0.6	0.23	1.73
S8	0.5	0.62	11.0	14.6	0.19	0.56	0.19	1.09
S9	0.5	0.71	6.6	12.4	0.18	0.36	0.40	2.08
S10	0.5	0.71	6.9	13.6	0.31	0.71	0.35	3.75
S11	0.4	0.65	5.5	10.4	0.29	0.43	0.26	1.83
S12	1.1	1.23	6.4	11.3	0.42	0.72	0.29	3.26
S13	1.0	1.09	9.1	14.9	0.31	0.88	0.52	4.86
S14	1.2	1.37	8.5	9.1	0.28	0.66	0.35	3.99
S15	1.0	1.05	7.6	9.2	0.47	0.72	0.57	3.87
S16	0.5	0.64	7.6	9.4	0.12	0.39	0.28	1.71
S17	0.5	0.70	10.4	11.2	0.26	0.45	0.31	1.77
S18	0.6	0.70	7.9	10.1	0.28	0.66	0.41	2.86
S19	0.6	0.61	4.3	8.6	0.19	0.43	0.26	1.85
S20	0.8	0.61	5.2	6.3	0.28	0.44	0.37	2.09
S21	0.7	0.84	5.8	10.7	0.23	0.59	0.33	2.75
S22	0.8	0.98	8.8	13.5	0.21	0.31	0.28	1.31
S23	0.4	0.46	4.8	11.6	0.35	0.34	0.23	1.49
S24	1.0	1.85	5.8	11.2	0.52	0.86	0.45	4.65
S25	0.6	0.65	4.6	11.4	0.21	0.52	0.39	2.86
S26	0.3	0.37	7.1	12.5	0.16	0.39	0.31	1.86

The C_f value for Cu, Zn, Pb, Cd, P, Cl, Hg, F, As, and S were found to be 1.7, 2.1, 4.2, 6.5, 7, 9, 9, 17, 19, and 90, respectively. The sediment was highly ($C_f \geq 6$) contaminated with seven elements *i.e.* Cd, P, Cl, Hg, F, As, and S [51]. The sediment was contaminated moderately to significantly with three metals *i.e.* Cu, Zn and Pb. The PLI value for elements *i.e.* F, Cl, P, S, As, Pb, Cd, and Hg were found to be 16.6, 8.1, 6.6, 79, 18, 3.8, 5.7 and 7.6, respectively. These data confirmed the extreme contamination of the sediment with elements *i.e.* F, Cl, P, S, As, Pb, Cd, and Hg.

A good correlation ($r = 0.91 - 0.99$) between water and sediment content of species *i.e.* Cl^- , As, Na, K, Ca, Cr, Zn, Cd, and Pb were observed, indicating origin from the similar sources. Poor to fair correlation ($r = 0.34 - 0.72$) between water and sediment content of species *i.e.* SO_4^{2-} , Mg, Al, Fe, Cu and Hg were marked, indicating contamination by multiple sources. However, a negative correlation ($r = -0.28$) of the F^- contents of the water and sediment was seen, showing origin entirely from

Table 6. Concentration of heavy metals in sediment, mg/kg.

S. No.	Cr	Cu	Zn	Pb	Hg	Cd	As
S1	36	33	89	33	0.16	0.14	63
S2	52	36	85	37	0.17	0.24	96
S3	62	63	106	49	0.23	0.27	98
S4	56	60	105	47	0.25	0.52	36
S5	42	53	167	81	0.31	0.63	100
S6	50	42	153	78	0.28	0.36	82
S7	64	66	190	92	0.36	0.50	92
S8	33	46	152	74	0.26	0.45	65
S9	29	25	53	35	0.21	0.65	114
S10	74	87	294	106	0.61	0.82	138
S11	74	81	288	127	0.77	0.95	127
S12	37	39	113	82	0.63	1.19	154
S13	54	68	268	120	0.82	1.18	149
S14	42	36	185	112	0.74	0.84	111
S15	38	52	199	107	0.63	0.77	127
S16	47	31	42	31	0.30	0.39	51
S17	35	21	85	54	0.54	0.66	79
S18	51	63	154	87	0.65	0.72	99
S19	41	22	78	37	0.33	0.42	43
S20	54	56	186	75	0.53	0.64	93
S21	45	32	78	53	0.46	0.62	98
S22	41	32	67	26	0.12	0.20	59
S23	47	53	85	48	0.32	0.22	65
S24	79	92	218	125	0.71	0.96	127
S25	69	66	198	108	0.61	0.62	84
S26	30	18	57	35	0.31	0.35	60

different sources. A good correlation ($r = 0.97$) of F^- with Al content of the sediment was observed, indicating origin mainly from the Aluminum plant effluents. A fair correlation ($r = 0.42 - 0.84$) of the BC with the elements *i.e.* As, Fe, Cu, Zn, Pb, Pb, and Hg in the sediment was marked, indicating the origin mainly from the coal-burning processes, **Table 7**. A fair correlation ($r = 0.29 - 0.88$) of these elements in the sediment among themselves was recorded, showing origin from multiple sources *i.e.* coal burning, fly ash, runoff water, etc.

4. Conclusion

The concentration of elements *i.e.* F^- , Al, As, Fe, Cd, Pb, and Hg in the surface water was found to be above the permissible limits. Three elements *i.e.* F^- , S, and As were highly enriched in the sediment. The high BC content in sediment may demobilize the metal contents. However, the high fluoride fraction in the ponds was seen to reflect as fluorosis diseases in the animals. A careful evaluation of the health

Table 7. Correlation matrix of BC and heavy metals in sediment.

	BC	Fe	Cr	Cu	Zn	Pb	Hg	Cd	As
BC	1.00								
Fe	0.75	1.00							
Cr	0.19	0.29	1.00						
Cu	0.42	0.41	0.87	1.00					
Zn	0.60	0.57	0.67	0.82	1.00				
Pb	0.67	0.68	0.58	0.74	0.93	1.00			
Hg	0.63	0.74	0.41	0.52	0.73	0.86	1.00		
Cd	0.64	0.71	0.27	0.44	0.64	0.77	0.88	1.00	
As	0.84	0.79	0.31	0.48	0.64	0.71	0.70	0.80	1.00

condition of the human being and animals using this contaminated water is urgently required.

Acknowledgements

We are thankful to Pt. Ravishankar Shukla University, Raipur, India for awarding scholarship to one of the authors: R. S.

References

- [1] Cooper, B.S. and Murchison, D.G. (1969) Organic Geochemistry of Coal. In: Eglington, G. and Murphy, M.T.J., Eds., *Organic Geochemistry*, Springer-Verlag, New York, 699-726. https://doi.org/10.1007/978-3-642-87734-6_36
- [2] Chou, C.L. (2012) Sulfur in Coals: A Review of Geochemistry and Origins. *International Journal of Coal Geology*, **100**, 1-13. <https://doi.org/10.1016/j.coal.2012.05.009>
- [3] Saikia, B.K., Goswamee, R.L., Baruah, B.P. and Baruah, R.K. (2009) Occurrence of Some Hazardous Metals in Indian Coals. *Coke and Chemistry*, **52**, 54-59. <https://doi.org/10.3103/S1068364X09020033>
- [4] Guttikunda, S.K. and Jawahar, P. (2014) Atmospheric Emissions and Pollution from the Coal-Fired Thermal Power Plants in India. *Atmospheric Environment*, **92**, 449-460. <https://doi.org/10.1016/j.atmosenv.2014.04.057>
- [5] Chandrawanshi, C.K., Patel, V.K. and Patel, K.S. (1997) Acid Rain in Korba City of India. *Indian Journal of Environmental Protection*, **17**, 656-661.
- [6] Ando, M., Tadano, M., Yamamoto, S., Tamura, K., Asanuma, A., Watanabe, T., Kondo, T., Sakurai, S., Ji, R., Liang, C., Chen, X., Hong, Z. and Cao, S. (2001) Health Effects of Fluoride Pollution Caused by Coal Burning. *Science of Total Environment*, **271**, 107-116. [https://doi.org/10.1016/S0048-9697\(00\)00836-6](https://doi.org/10.1016/S0048-9697(00)00836-6)
- [7] Patel, K.S., Shukla, A., Tripathi, A.N. and Hoffmann, P. (2001) Heavy Metal Concentrations of Precipitation in East Madhya Pradesh of India. *Water Air and Soil Pollution*, **130**, 463-468. <https://doi.org/10.1023/A:1013857923368>
- [8] Mandal, A. and Sengupta, D. (2006) An Assessment of Soil Contamination Due to Heavy Metals around a Coal-Fired Thermal Power Plant in India. *Environmental Geology*, **51**, 409-420. <https://doi.org/10.1007/s00254-006-0336-8>
- [9] Agrawal, P., Mittal, A., Prakash, R., Kumar, M., Singh, T.B. and Tripathi, S.K. (2010) Assessment of Contamination of Soil Due to Heavy Metals around Coal Fired Thermal Power Plants at Singrauli Region of India. *Bulletin of Environmental*

- Contamination and Toxicology*, **85**, 219-223.
<https://doi.org/10.1007/s00128-010-0043-8>
- [10] Sengupta, S., Chatterjee, T., Ghosh, P.B. and Saha, T. (2010) Heavy Metal Accumulation in Agricultural Soils around a Coal Fired Thermal Power Plant (Farakka) in India. *Journal of Environmental Science and Engineering*, **52**, 299-306.
 - [11] Dragović, S., Čujić, M., Slavković-Beskoski, L., Gajić, B., Bajat, B., Kilibarda, M. and Onjia, A. (2013) Trace Element Distribution in Surface Soils from a Coal Burning Power Production Area; A Case Study from the Largest Power Plant Site in Serbia. *Catena*, **104**, 288-296. <https://doi.org/10.1016/j.catena.2012.12.004>
 - [12] Yonglin, L., Kunli, L., Ling, L. and Muhammad, Z.S. (2013) Fluoride and Sulfur Dioxide Indoor Pollution Situation and Control in Coal-Burning Endemic Area in Zhaotong, Yunnan, China. *Atmospheric Environment*, **77**, 725-737.
<https://doi.org/10.1016/j.atmosenv.2013.05.043>
 - [13] Martin, J.A.R., Nanos, N., Grigoratos, T., Carbonell, G. and Samara, C. (2014) Local Deposition of Mercury in Top Soils around Coal-Fired Power Plants: Is It Always True? *Environmental Science and Pollution Research*, **21**, 10205-10214.
 - [14] Donahue, W.F., Allen, E.W. and Schindler, D.W. (2006) Impacts of Coal-Fired Power Plants on Trace Metals and Polycyclic Aromatic Hydrocarbons (PAHs) in Lake Sediments in Central Alberta, Canada. *Journal of Paleolimnology*, **35**, 111-128.
<https://doi.org/10.1007/s10933-005-7878-8>
 - [15] Abdul-Wahab, S.A. and Jupp, B.P. (2009) Levels of Heavy Metals in Subtidal Sediments in the Vicinity of Thermal Power/Desalination Plants; A Case Study. *Desalination*, **244**, 261-282. <https://doi.org/10.1016/j.desal.2008.06.007>
 - [16] Karamanis, D., Ioannides, K. and Stamoulis, K. (2009) Environmental Assessment of Natural Radionuclides and Heavy Metals in Waters Discharged from a Lignite-Fired Power Plant. *Fuel*, **88**, 2046-2052. <https://doi.org/10.1016/j.fuel.2009.02.032>
 - [17] Sanei, H., Goodarzi, F. and Outridge, P.M. (2010) Spatial Distribution of Mercury and Other Trace Elements in Recent Lake Sediments from Central Alberta, Canada: An Assessment of the Regional Impact of Coal-Fired Power Plants. *International Journal of Coal Geology*, **82**, 105-115. <https://doi.org/10.1016/j.coal.2010.01.010>
 - [18] Pathak, R.P., Sharma, P., Vyas, S., Mahure, N.V., Kumar, R. and Murari, R. (2012) Detection of Fluoride Contamination in the Surface and Sub-Surface Water near Thermal Power Station. *International Journal of Engineering and Science*, **1**, 44-47.
 - [19] IAEA (2003) Collection and Preparation of Bottom Sediment Samples for Analysis of Radionuclides and Trace Elements.
http://www-pub.iaea.org/MTCD/Publications/PDF/te_1360_web.pdf
 - [20] Mcquaker, N.R. and Gurney, M. (1977) Determination of Total Fluoride in Soil and Vegetation Using an Alkali Fusion-Selective Ion Electrode Technique. *Analytical Chemistry*, **49**, 53-56. <https://doi.org/10.1021/ac50009a022>
 - [21] Walkley, A. and Black, I.A. (1934) An Examination of the Degtjareff Method for Determining Soil Organic Matter and a Proposed Modification of the Chromic Acid Titration Method. *Soil Science*, **37**, 29-38.
<https://doi.org/10.1097/00010694-193401000-00003>
 - [22] Tomlinson, D.L., Wilson, J.G., Harris, C.R. and Jeffrey, D.W. (1980) Problem in Assessment of Heavy-Metal Levels in Estuaries and the Formation of a Pollution Index. *Helgoländer Meeresunters*, **33**, 566-575. <https://doi.org/10.1007/BF02414780>
 - [23] Sinex, S.A. and Helz, G.R. (1981) Regional Geochemistry of Trace Elements in Chesapeake Bay Sediments. *Environmental Geology*, **3**, 315-323.
<https://doi.org/10.1007/BF02473521>
 - [24] Kowalski, A., Siepak, M. and Boszke, L. (2007) Mercury Contamination of Surface

- p>and Ground Waters of Poznań, Poland.
- Polish Journal of Environmental Studies*
- ,
- 16**
- , 67-74.
- [25] Garcia-Sanchez, A., Contreras, F., Adams, M. and Santos, F. (2008) Mercury Contamination of Surface Water and Fish in a Gold Mining Region (Cuyuni River Basin, Venezuela). *International Journal of Environmental Pollution*, **33**, 260-274. <https://doi.org/10.1504/IJEP.2008.019398>
 - [26] Kar, D., Sur, P., Mandai, S.K., Saha, T. and Kole, R.K. (2008) Assessment of Heavy Metal Pollution in Surface Water. *International Journal of Environmental Science & Technology*, **5**, 119-124. <https://doi.org/10.1007/BF03326004>
 - [27] Moore, F., Forghani, G. and Qishlaqi, A. (2009) Assessment of Heavy Metal Contamination in Water and Surface Sediments of the Maharlu Saline Lake, SW Iran. *Iranian Journal of Science & Technology, Transaction A*, **33**, 43-55.
 - [28] Rosso, J.J., Puntoriero, M.L., Troncoso, J.J., Volpedo, A.V. and Cirelli, A.F. (2011) Occurrence of Fluoride in Arsenic-Rich Surface Waters; A Case Study in the Pampa Plain, Argentina. *Bulletin of Environmental Contamination and Toxicology*, **8794**, 409-413. <https://doi.org/10.1007/s00128-011-0358-0>
 - [29] Mamatha, S.V. and Haware, D.J. (2013) Document on Fluoride Accumulation in Ground and Surface Water of Mysore, Karnataka, India. *Current World Environment*, **8**, 259-265. <https://doi.org/10.12944/CWE.8.2.11>
 - [30] Machender, G., Dhakate, R. and Reddy, M.N. (2014) Hydrochemistry of Groundwater (GW) and Surface Water (SW) for Assessment of Fluoride in Chinnaeru River Basin, Nalgonda District, (AP) India. *Environmental Earth Science*, **27**, 4017-4034. <https://doi.org/10.1007/s12665-014-3291-9>
 - [31] Puntoriero, M.L., Volpedo, A.V. and Cirelli, A.F. (2014) Arsenic, Fluoride, and Vanadium in Surface Water (Chasicó Lake, Argentina). *Frontiers in Environmental Science*, **2**, 1-5.
 - [32] Islam, M.D.S., Ahmed, M.D.K., Raknuzzaman, M., Mamun, M.D.H.A. and Islam, M.K. (2015) Heavy Metal Pollution in Surface Water and Sediment; A Preliminary Assessment of an Urban River in a Developing Country. *Ecological Indicator*, **48**, 282-291. <https://doi.org/10.1016/j.ecolind.2014.08.016>
 - [33] Zhang, Z., Abuduwaili, J. and Jiang, F. (2015) Heavy Metal Contamination, Sources, and Pollution Assessment of Surface Water in the Tianshan Mountains of China. *Environmental Monitoring and Assessment*, **187**, 33. <https://doi.org/10.1007/s10661-014-4191-x>
 - [34] BIS (2012) Drinking Water—Specification, Bureau of Indian Standards. 2nd Edition, New Delhi. <http://cgwb.gov.in/Documents/WQ-standards.pdf>
 - [35] WHO (2011) Guidelines for Drinking-Water Quality. 4th Edition, World Health Organization, Geneva.
 - [36] Barbalace, K. (2007) Periodic Table of Elements. Environmental Chemistry.com. 2007-04-14. Abundance in Earth's Crust. Web Elements.com.
 - [37] Muri, G., Cermelj, B., Faganeli, J. and Brancelj, A. (2002) Black Carbon in Slovenian Alpine Lacustrine Sediments. *Chemosphere*, **46**, 1225-1234. [https://doi.org/10.1016/S0045-6535\(01\)00295-8](https://doi.org/10.1016/S0045-6535(01)00295-8)
 - [38] Durant, J.L., Ivushkina, T., MacLaughlin, K., Lukacs, H., Gawel, J., Senn, D. and Hemond, H.F. (2004) Elevated Levels of Arsenic in the Sediments of an Urban Pond; Sources, Distribution and Water Quality Impacts. *Water Research*, **38**, 2989-3000. <https://doi.org/10.1016/j.watres.2004.04.010>
 - [39] Simpson, M.J. and Hatcher, P.G. (2004) Overestimates of Black Carbon in Soils and Sediments. *Naturwissenschaften*, **91**, 436-440. <https://doi.org/10.1007/s00114-004-0550-8>

- [40] Ribeiro, L.G.L., Carreira, R.S. and Wagener, A.L.R. (2008) Black Carbon Contents and Distribution in Sediments from the Southeastern Brazilian Coast (Guanabara Bay). *Journal of Brazilian Chemical Society*, **19**, 1277-1283. <https://doi.org/10.1590/S0103-50532008000700008>
- [41] Sun, X., Peng, P., Song, J., Zhang, G. and Hu, J. (2008) Sedimentary Record of Black Carbon in the Pearl River Estuary and Adjacent Northern South China Sea. *Applied Geochemistry*, **23**, 3464-3472. <https://doi.org/10.1016/j.apgeochem.2008.08.006>
- [42] Jezierska-Madziar, M., Pińskwar, P. and Golski, J. (2006) Fluorine Content of Bottom Sediments in the Old Warta Reservoir near Luboń, Poland. *Fluoride*, **39**, 39-42.
- [43] Boszke, L. and Kowalski, A. (2006) Spatial Distribution of Mercury in Bottom Sediments and Soils from Poznań, Poland. *Polish Journal of Environmental Studies*, **15**, 211-218.
- [44] Kamala-Kannan, S., Prabhu, D.B.B., Lee, K.J., Kannan, N., Krishnamoorthy, R., Shanthi, K. and Jayaprakash, M. (2008) Assessment of Heavy Metals (Cd, Cr and Pb) in Water, Sediment and Seaweed (*Ulva lactuca*) in the Pulicat Lake, South East India. *Chemosphere*, **71**, 1233-1240. <https://doi.org/10.1016/j.chemosphere.2007.12.004>
- [45] Pradit, S., Wattayakorn, G., Angsupanich, S., Baeyens, W. and Leermakers, M. (2010) Distribution of Trace Elements in Sediments and Biota of Songkhla Lake, Southern Thailand. *Water Air & Soil Pollution*, **206**, 155-174. <https://doi.org/10.1007/s11270-009-0093-x>
- [46] Fattorini, D., Sarkar, S.K., Regoli, F., Bhattacharya, B.D., Rakshit, D., Satpathy, K.K. and Chatterjee, M. (2013) Levels and Chemical Speciation of Arsenic in Representative Biota and Sediments of a Tropical Mangrove Wetland, India. *Environ Science: Process & Impacts*, **15**, 773-782. <https://doi.org/10.1039/c3em30819g>
- [47] Ghani, S., Zokm, G., Shobier, A., Othman, T. and Shreadah, M. (2013) Metal Pollution in Surface Sediments of Abu-Qir Bay and Eastern Harbor of Alexandria Egypt. *Egyptian Journal of Aquatic Research*, **39**, 1-12. <https://doi.org/10.1016/j.ejar.2013.03.001>
- [48] Malhotra, P., Chopra, G. and Bhatnagar, A. (2014) Studies on Sediment Chemistry of River Yamuna with Special Reference to Industrial Effluents in Yamuna Nagar, India. *Current World Environment*, **9**, 210-215. <https://doi.org/10.12944/CWE.9.1.30>
- [49] Zan, F., Huo, S., Zhang, J., Zhang, L., Xi, B. and Zhang, L. (2014) Arsenic Fractionation and Contamination Assessment in Sediments of Thirteen Lakes from the East Plain and Yungui Plateau Ecoregions, China. *Journal of Environmental Science*, **26**, 1977-1984. <https://doi.org/10.1016/j.jes.2014.07.010>
- [50] Rudnick, R.L. and Gao, S. (2003) Composition of the Continental Crust. In: Rudnick, R.L., Holland, H.D. and Turekian, K.K., Eds., *Treatise on Geochemistry*, Elsevier, Amsterdam, 1-64.
- [51] Muller, G. (1969) Index of Geo-Accumulation in Sediments of the Rhine River. *Geo Journal*, **2**, 108-118.



Submit or recommend next manuscript to SCIRP and we will provide best service for you:

Accepting pre-submission inquiries through Email, Facebook, LinkedIn, Twitter, etc.

A wide selection of journals (inclusive of 9 subjects, more than 200 journals)

Providing 24-hour high-quality service

User-friendly online submission system

Fair and swift peer-review system

Efficient typesetting and proofreading procedure

Display of the result of downloads and visits, as well as the number of cited articles

Maximum dissemination of your research work

Submit your manuscript at: <http://papersubmission.scirp.org/>

Or contact jep@scirp.org