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Sewage Pollution in Central India

Khageshwar Singh Patel[1], Nohar Singh Dahariya[1], Suryakant Chakradhari[1], Pravin Kumar Sahu[1], Keshaw Prakash Rajhans[1], Shobhana Ramteke[1], Lesia Lata[2], Huber Milosh[2]

[1]School of Studies in Chemistry/Environmental Science, Pt. Ravishankar Shukla University, Raipur, India
[2]Department of Soil Science/Geology, Maria Curie-Skłodowska University, Lublin, Poland
Email: patelks_55@hotmail.com

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Abstract

Raipur is a fast growing city in central India due to being commercial centre for the steel, cement and forest products of the country. Large quantity (≈300 million lit/day) of untreated sewage waste water is discharged into seven reservoirs located in the city. Sewage carries excessive nutrients, heavy metals, organics, bacteria, yeast and fungi by leaking contents into the drinking water which cause acute health problems, ranging from common diarrhoea to deadly diseases such as hepatitis, cholera, typhoid fever, etc. Therefore, in this work, the microbial and chemical contamination of sewage waste of Raipur city, Chhattisgarh, India is described.

Keywords

Nutrients, Heavy Metals, Microbes, Toxicities

1. Introduction

Sewage is transported by water wastes resulting mainly from human activities such as washing, cooking, sanitation, commerce, industry, agriculture and surface runoff, etc. [1]. The contaminated sewage water discharged into water reservoirs is one of the main culprits for spread of water borne diseases, air pollution and climate change [2]. Sewage wastes are contaminated with heavy metals, surfactants, toxic organic compounds, bacteria, fungi, parasites, and viruses that can cause intestinal, lung, and other infections [3]-[29]. About 60 percent of urban deaths in India are due to the lack of safe drinking water facilities. Further deaths due to water borne diseases are second only to malnutrition. In present study, the microbial and physicochemical characteristics of the sewage waste of a vast growing city, Raipur (capital, Chhattisgarh state, India) are described.

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2. Material and Methods

2.1. Study Area

Raipur city is experiencing rapid growth with corresponding increase of economic and commercial activities in an unsustainable order. The city is being the commercial center for steel, cement and forest products. More than two million people living over ≈1000 km^2 area discharges ≈300 million L/day waste flowing into seven open reservoirs constructed in the city, **Figure 1**. The area of sewage sinks was ranged from 2 - 4 km^2. Every year, several people are died due to outbreak of waterborne diseases *i.e.* jaundice, fatal diarrhea, dysentery, hepatitis, cholera, typhoid fever, etc. in every summer by mixing of the municipal waste with the drinking water.

2.2. Sample Collection

The composite water sample (100 × 5 mL from five points of each location) was collected into sterile glass bottles (500 mL) in April 2015 as prescribed in the literature [30]. The pH, electrical conductivity (EC), dissolved oxygen (DO) and reduction potential (RP) values of the water were measured at spot by Hanna made sensors. The total hardness and alkalinity values were determined by the titration methods. One kilogram of the top composite sewage sludge from five points of each location (0 - 10 cm) was taken from seven reservoirs in April 2015 by a stainless steel spoon and stored in a glass jar [31]. Samples were transported to the laboratory and immediately stored in a freezer.

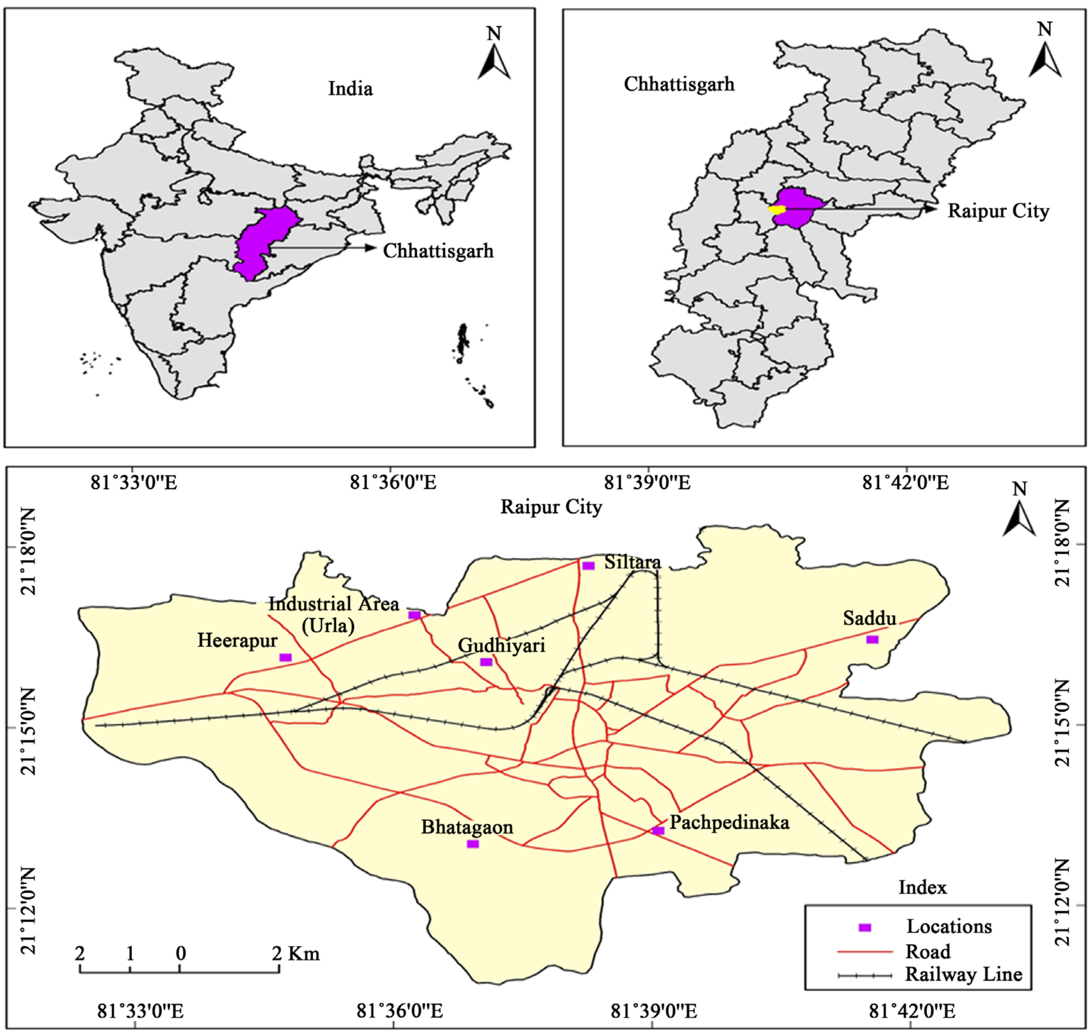


Figure 1. Representation of sampling locations in Raipur city, India.

2.3. Analysis

2.3.1. Analysis of Microbe

The microbes *i.e.* TBC (total bacterial count, all aerobic species of bacteria), pseudomonas, *E. coli* or yeast + fungi were detected by the bactaslyde (presterilized slide, coated with specially developed media of lactose and indicator) method established by Rakiro Pvt. Ltd. [32]. The slide no. BS-101, BS-102 and BS-103 were used for detection of *E. coli* + TBC, pseudomonas + TBC and yeast-fungi + TBC, respectively. The packed slide was opened, plunged into the test liquid vertically for 20 - 25 sec. The slide was shaken 3 - 4 times gently to remove the excess water by putting back into the tube with tight closing. The bactaslyde was incubated for 24 hrs at 37˚C for development of colonies. After incubation, the density of the colonies grown on the slide was compared with the standard chart provided. The TBC, pseudomonas, *E. coli*, and yeast or fungi were marked by dark red colored colonies, respectively, **Figure 2**. The Salmonella bacteria in the water were detected by the pouch pack (*i.e.* containing organics and sulfite material) method [32]. The content (10 g) of two pouches was added into a 150-mL sterilized bottle filled with 100 mL of contaminated water, and incubated for 24 hrs at 37˚C. The light blue color of the solution was turned into dark black in presence of Salmonella species, **Figure 3**.

2.3.2. Analysis of Inorganic Species

The sample was filtered through glass fibre filter (0.45 µm) for analysis of ions and metals. The F^- content was analyzed by using Metrohm-720 ion meter using the fluoride selective electrode.

The Dionex chromatography DX120 equipped with anion separation columns (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^-, NO_3^-, SO_4^{2-}, Mg^{2+} and Ca^{2+}).

A 0.25 g of the sample was digested with acids (3 mL HCl and 1 mL HNO_3) in a closed system with P/T MARS CEM (Varian Company) microwave oven for use of metal analysis. The Varian ICP-OES-700-ES series was used for monitoring of metals (*i.e.* Cr, Fe, Mn, Ni, Cu, Zn and Pb) in the extract. The GF-AAS SpectrAA 220 Zeeman was used for the analysis of As, Cd and Hg. The NCS DC 73382 CRM sediment sample was used for the quality control.

2.3.3. Water Quality Index

For this study, ten parameters *i.e.* pH, EC, DO, hardness, alkalinity, Mg, Ca, Cl^-, NO_3^- and SO_4^{2-} were chosen for computation of water quality index (*WQI*) by using the standard values recommended by WHO and BIS [22] [23]. The weighed arithmetic method was employed for calculation of the WQI of sewage water bodies with the help of following expression.

$$WQI = \sum q_n W_n / \sum W_n$$

where:

$$q_n = 100 (V_o - V_{io}) / (V_s - V_{io})$$

q_n = Quality rating of the *n*th water quality parameter;

V_n = Estimated value of the *n*th parameter of a given water;

S_n = Standard permissible value of the *n*th parameter;

V_{io} = Ideal value of the *n*th parameter of pure water (*i.e.*, 0 for all other parameters except pH) and Dissolved oxygen (7.0 and 14.6 mg/L, respectively);

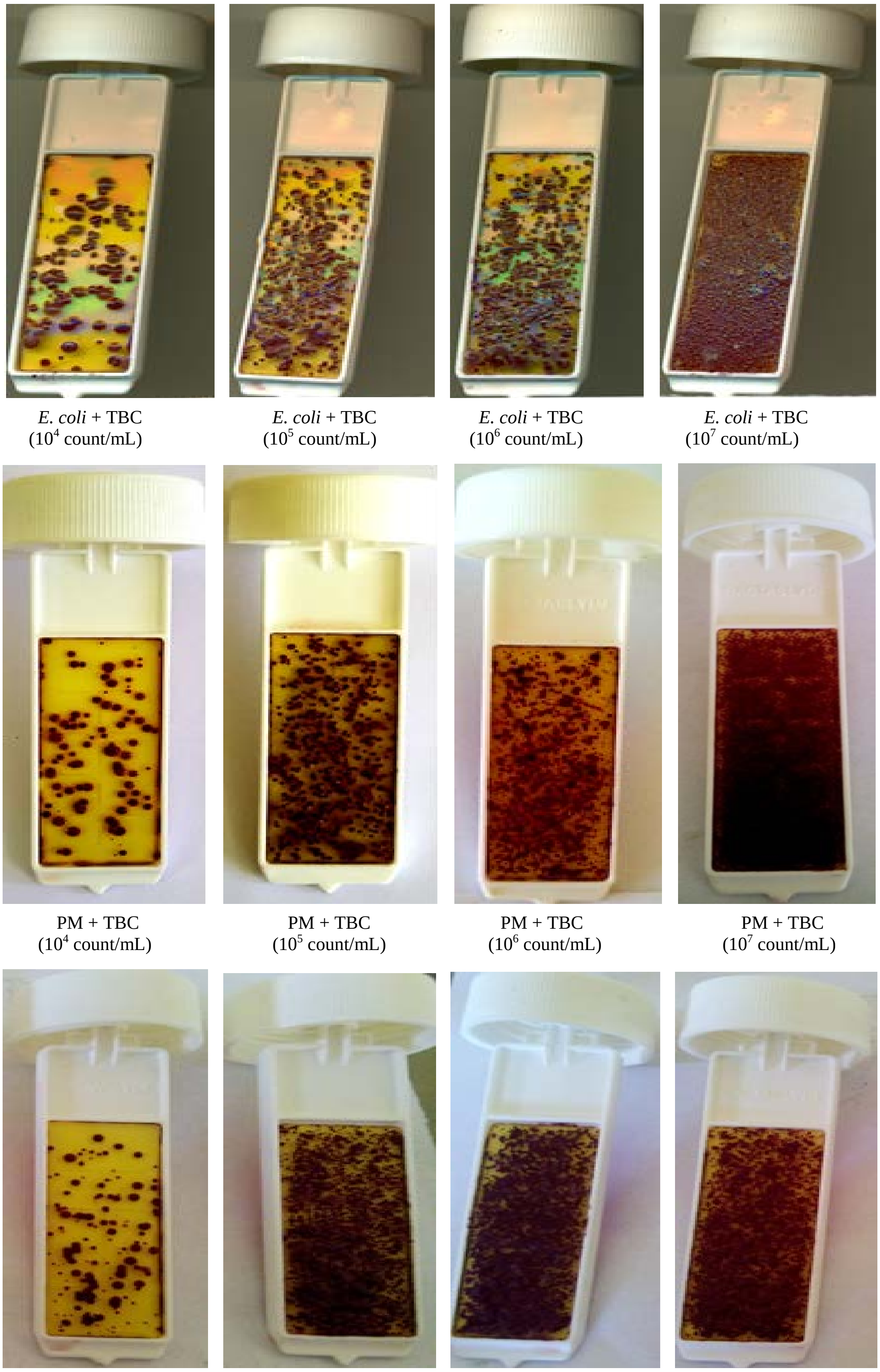
W_n = Unit weight for the *n*th parameter;

K = Proportionality constant.

3. Results and Discussion

3.1. Physical, Chemical and Microbial Characteristic of Sewage Water

The physical, chemical and microbial characteristics of the water are presented in **Tables 1-4**. The water was colored with offensive smell. The value of pH, EC, DO, RP, total hardness (TH) and alkalinity was ranged from 6.9 - 7.8, 698 - 1520 µS/cm, 5.2 - 7.7 mg/L, 86 - 337 mV, 270 - 670 mg/L and 320 - 940 mg/L with mean value of 7.4 ± 0.2, 1075 ± 252 µS/cm, 6.8 ± 0.6 mg/L, 157 ± 63 mV, 447 ± 107 mg/L and 503 ± 156 mg/L, respectively.



E. coli + TBC (10^4 count/mL) | *E. coli* + TBC (10^5 count/mL) | *E. coli* + TBC (10^6 count/mL) | *E. coli* + TBC (10^7 count/mL)

PM + TBC (10^4 count/mL) | PM + TBC (10^5 count/mL) | PM + TBC (10^6 count/mL) | PM + TBC (10^7 count/mL)

Y + F + TBC (10^4 count/mL) | Y + F + TBC (10^5 count/mL) | Y + F + TBC (10^6 count/mL) | Y + F + TBC (10^7 count/mL)

Figure 2. Bactaslyde for microbes (1 colony of microbe = 10^2 count microbe), TBC = Total bacterial count, PM = Pseudomonas, Y = Yeast, F = Fungi.

(a) (b)

Figure 3. (a) The black color of the solution due to sulphide by reduction of the sulphite with the Salmonella bacteria; (b) The reagent blank.

Table 1. Physical characteristics of sewage water.

S. No.	Location	Area, km^2	Color	pH	EC µS/cm	DO mg/mL	RP mV	TH mg/mL	Alk mg/mL
1	Gudhiyari	4	BBr	7.8	720	7.7	168	270	320
2	Bhatagaon	3	BBr	7.6	816	7.1	161	350	580
3	Saddu Mowa	4	BBr	7.2	1058	6.1	127	390	490
4	Urla	4	BBr	6.9	1520	5.2	86	350	360
5	Siltara	3	BBr	7.4	1364	7.0	107	530	940
6	Heerapur	2	BG	7.2	1350	7.2	337	670	410
7	Pachpedinaka	2	BG	7.6	698	7.4	111	570	420

TH = Total hardness, Alk = Alkalinity, BBr = Blackish brown, BG = Blackish green.

Table 2. Chemical characteristics of sewage water, mg/L.

S. No.	F^-	Cl^-	NO_3^-	SO_4^{2-}	PO_4^{3-}	NH_4^+	Na^+	K^+	Mg^{2+}	Ca^{2+}
1	1.1	31	492	42	9.5	134	73	41	13	48
2	1.3	28	512	36	10.4	124	136	33	12	50
3	1.4	36	610	48	7.4	120	112	30	16	68
4	1.5	31	589	37	8.3	115	134	51	13	48
5	1.6	46	485	71	6.2	110	137	27	16	80
6	1.3	41	680	49	9.1	171	125	48	23	96
7	0.9	48	560	105	7.8	128	83	26	18	84

Table 3. Contamination levels of sewage water with As and other heavy metals, mg/L.

Metal	Se1	Se2	Se3	Se4	Se5	Se6	Se7
As	0.032	0.026	0.046	0.051	0.037	0.046	0.042
Cr	0.18	0.23	0.19	0.31	0.16	0.0.34	0.23
Mn	2.1	2.7	2.5	1.8	1.6	1.7	1.5
Fe	4.1	4.6	3.8	3.2	4.7	4.8	2.9
Ni	0.13	0.17	0.22	0.18	0.31	0.28	0.16
Cu	0..37	0.45	0.52	0.61	0.48	0.38	0.54
Zn	5.1	4.9	4.2	6.3	6.8	5.7	4.8
Cd	0.010	0.012	0.014	0.009	0.008	0.013	0.011
Pb	0.13	0.1	0.11	0.14	0.12	0.1	0.15
Hg	0.004	0.004	0.006	0.007	0.009	0.004	0.005

Se = Sewage.

Table 4. Microbial contamination levels of sewage water.

S. No.	Location	*E. coli* + TBC	Pseudomonas + TBC	Yeast + Fungi + TBC	Salmonella
1	Gudhiyari	10^7	10^5	10^4	Positive
2	Bhatagaon	10^6	10^6	10^6	Positive
3	Saddu Mowa	10^7	10^7	10^6	Positive
4	Urla	10^7	10^7	10^7	Positive
5	Siltara	10^7	10^6	10^7	Positive
6	Heerapur	10^6	10^6	10^4	Positive
7	Pachpedinaka	10^6	10^6	10^5	Positive

TBC = Total Bacterial Count (comprises of all the aerobic species of bacteria present in the sample), *E. coli* = *Escherichia coli*.

The EC and TH value was observed to be higher than the recommended values reported for the water [22] [23]. The RP value was found to be 4-times less than the recommended value of 650 mV [23].

The concentration of the F^-, Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}, NH_4^+, Na^+, K^+, Mg^{2+}, Ca^{2+}, As, Cr, Fe, Mn, Ni, Cu, Zn, Cd, Pb and Hg was ranged from 0.9 - 1.6, 28 - 48, 485 - 680, 36 - 105, 6.2 - 10.4, 110 - 171, 73 - 137, 26 - 51, 12 - 23, 48 - 96, 0.026 - 0.051, 0.16 - 0.31, 1.5 - 2.7, 2.9 - 4.8, 0.13 - 0.31, 0.38 - 0.61, 4.2 - 6.8, 0.008 - 0.014, 0.10 - 0.15 and 0.004 - 0.009 mg/L with mean value of 1.3 ± 0.2, 37 ± 6, 561 ± 53, 55 ± 18, 8.4 ± 1.1, 129 ± 15, 114 ± 20, 37 ± 8, 16 ± 4, 68 ± 15, 0.040 ± 0.007, 0.22 ± 0.04, 2.0 ± 0.3, 4.0 ± 0.6, 0.21 ± 0.05, 0.50 ± 0.06, 5.4 ± 0.7, 0.011 ± 0.002, 0.12 ± 0.1 and 0.006 ± 0.001 mg/L, respectively. The heavy metal contamination of the water of the studied area was found to be comparable to the Delhi sewage waste water [14]. The observed concentration value of F^-, NO_3^-, Cr, Mn, Fe, Ni, Cu, Zn, Pb, As, Cd and Hg was found to be higher than the reported tolerance limit of 1.0, 45, 0.05, 0.1, 0.3, 0.02, 0.05, 5.0, 0.10, 0.01, 001 and 0.001 mg/L, respectively by agencies *i.e.* BIS (Bureau of Indian Standards) and WHO (World Health Organization) [22] [23].

The chromatograms of indicative bacteria (*i.e.* total coliform, *E. coli*, pseudomonas and salmonella), yeast and fungi are shown in **Figure 2** and **Figure 3**. Their extreme concentrations were observed in all sewage water reservoirs, ranging from 10^4 to 10^7 per mL **Table 4**. The positive test for Salmonella bacteria was marked for all sewage reservoirs. The microbial contamination levels in the sewage water was found to be higher than the microbe contents reported in the water of other region of the country [15]-[21]. The mean WQI value for seven sewage water reservoirs was found to be 191, indicating unsuitability for drinking purpose of the animals, **Table 5**. The EC, hardness, alkalinity, organic matters, nitrate and microbe levels are main deteriorating components of the sewage waste.

3.2. Chemical Characteristics of Solid Sewage

The content of 15 elements in the solid dried sewage samples is presented in **Table 6**. The concentration of elements *i.e.* As, P, S, Cl, K, Ca, Cr, Mn, Fe, Ni, Cu, Zn, Cd, Pb and Hg was ranged from 28 - 41, 414 - 622, 855 - 1241, 298 - 415, 7704 - 9023, 30,493 - 33,160, 191 - 307, 1096 - 1317, 46,215 - 50,157, 52 - 98, 185 - 389, 429 - 725, 0.23 - 0.51, 89 - 124 and 0.15 - 0.27 mg/kg with mean value of 34 ± 54, 503 ± 52, 1049 ± 112, 336 ± 34, 8120 ± 361, 31,875 ± 697, 240 ± 32, 1209 ± 64, 48,332 ± 999, 71 ± 12, 258 ± 58, 549 ± 83, 0.34 ± 0.07, 106 ± 10 and 0.21 ± 0.03 mg/kg, respectively. The sum of total content of 15 elements (As, P, S, Cl, K, Ca, Cr, Mn, Fe, Ni, Cu, Zn, Cd, Pb and Hg), $\Sigma_{15element}$ in the seven reservoirs was ranged from 98 - 106 g/kg of the dried sewage mass with highest value in the Urla reservoir due to industrial waste input. The concentration of the heavy metals in the reservoirs of the studied area was found to be comparable to other regions of the World [24]-[29].

Among them, the highest content of Fe followed by Ca was observed in the sewage waste. The enrichment factor (E_f) value of As, P, S, Cl, K, Ca, Cr, Mn, Fe, Ni, Cu, Zn, Cd, Pb and Hg was computed by using their background level in the earth crust with respect to Al [33]. The mean E_f value of As, P, S, Cl, K, Ca, Cr, Mn, Fe, Ni, Cu, Zn, Cd, Pb and Hg was found to be 54 ± 6, 4.8 ± 0.6, 132 ± 12, 7.1 ± 0.6, 2.8 ± 0.1, 9.7 ± 0.3, 21 ± 3, 12.2 ± 0.6, 9.6 ± 0.4, 12 ± 2, 73 ± 16, 64 ± 10, 30 ± 6, 48 ± 4 and 33 ± 5, respectively. Four elements *i.e.* S, As, Cu and Zn was highly enriched (E_f => 50) in the sewage waste. Six metals *i.e.* Cr, Mn, Ni, Cd, Pb and Hg were

Table 5. Water quality index of sewage water.

Parameter	Observed mean value	Standard mean value	Unit weight (W_n)	Quality rating (q_n)	W_nq_n
pH	7.4	6.5 - 8.5	0.219	22	4.8
EC	1075	300	0.371	343	127
Alkalinity	447	120	0.0155	394	6.1
Hardness	503	300	0.0062	143	0.9
Ca	68	75	0.025	87	2.2
Mg	16	30	0.061	52	3.2
Cl^-	37	250	0.0074	15	0.1
NO_3^-	561	45	0.0412	1239	51
SO_4^{2-}	55	150	0.01236	34	0.4
DO	6.8	4.0	0.3723	53	20
			$\Sigma W_n = 1.131$	$\Sigma q_n = 2382$	$\Sigma W_nq_n = 216$

Table 6. Concentration of element in solid sewage, mg/kg.

Element	Se1	Se2	Se3	Se4	Se5	Se6	Se7
Al	9790	10,515	10,890	11,201	10,556	9876	10,471
P	414	456	499	517	508	622	503
S	855	912	1014	1187	1241	1087	1049
Cl	298	308	317	367	312	336	415
K	7704	7776	8150	8217	9023	7850	8120
Ca	30,493	31,215	32,189	33,160	31,670	32,416	31,857
As	37	32	28	38	41	29	34
Cr	191	208	216	261	256	307	240
Mn	1096	1130	1240	1278	1190	1317	1209
Fe	46,215	47,690	48,075	49,148	48,706	50,157	48,332
Ni	52	61	74	67	72	98	71
Cu	185	206	217	236	317	389	258
Zn	429	468	476	580	614	725	549
Cd	0.31	0.23	0.29	0.29	0.36	0.40	0.51
Pb	107	98	89	116	124	99	106
Hg	0.24	0.19	0.15	0.19	0.23	0.17	0.27

Se = Sewage.

significantly enriched ($E_f > 10 - < 50$). Other elements *i.e.* P, Cl, K, Ca and Fe were moderately enriched ($E_f =\leq 10$) in the sewage waste.

3.3. Correlation Coefficient and Sources

The species (*i.e.* F^-, Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}, NH_4^+, Na^+, K^+, Mg^{2+}, Ca^{2+}, As, Cr, Fe, Mn, Ni, Cu, Zn, Cd and Pb) among themselves had either poor or negative correlation in the waste water, indicating origins from the multiple diverse sources. The correlation coefficient matrix for the chemical species (*i.e.* As, P, S, Cl, K, Ca, Cr, Mn, Fe, Ni, Cu, Zn, Cd, Pb and Hg) in the solid waste are presented in **Table 7**. The ferro alloy elements (*i.e.* P, S, Cr, Mn, Ni, Cu and Zn) and Ca among themselves had good correlations, showing origin from sources *i.e.*

Table 7. Correlation matrix of elements in solid sewage waste.

	P	S	Cl	K	Ca	As	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Pb	Hg
P	1														
S	0.59	1													
Cl	0.32	0.33	1												
K	0.16	0.82	0.06	1											
Ca	0.71	0.71	0.51	0.26	1										
As	−0.35	0.40	0.01	0.57	−0.15	1									
Cr	−0.35	0.72	0.36	0.28	0.70	−0.07	1								
Mn	0.91	0.64	0.44	0.17	0.91	−0.34	0.85	1							
Fe	0.95	0.74	0.39	0.31	0.82	−0.19	0.95	0.91	1						
Ni	0.97	0.48	0.22	0.12	0.59	−0.48	0.87	0.85	0.88	1					
Cu	0.90	0.60	0.16	0.33	0.41	−0.10	0.92	0.67	0.83	0.89	1				
Zn	0.93	0.71	0.30	0.33	0.60	−0.02	0.99	0.78	0.92	0.87	0.96	1			
Cd	0.41	0.29	0.72	0.19	0.13	0.03	0.44	0.30	0.33	0.43	0.51	0.47	1		
Pb	−0.06	0.62	0.13	0.67	0.06	0.95	0.23	−0.08	0.11	−0.20	0.19	0.28	0.18	1	
Hg	−0.40	−0.04	0.40	0.17	−0.46	0.62	−0.22	−0.49	−0.37	−0.43	−0.13	−0.15	0.58	0.55	1

domestic, industrial and vehicular effluents. Other species had either poor or negative correlations, indicating origin by multiple diverse sources *i.e.* wasted food materials, leaded pipes, automobile tire rust, vehicular emissions, industrial discharges, runoff water, etc. The major sources of microbes in the sewages are assumed from the human and animal excreta.

4. Conclusion

Several chemicals and microbes *i.e.* heavy metals, nitrate, nutrients, total coliform, Escherichia, pseudomonas, salmonella, yeast and fungi were found to be present in the sewage waste at extremely high levels. The increased prevalence rate of the acute water borne diseases in the summer season is expected due to high multiplication rates of microbes and mixing of the waste with the drinking water supplies *i.e.* pond, lake, well and shallow tube well. The drinking water contamination could be controlled by improving the sanitary infrastructure with provision of good hygiene system to the population.

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