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Pit Lake Water Quality of Central India

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Abstract

Several pit lakes exist in the Raipur area due to lime stone mining. The water of pit lakes is used for bathing, washing and irrigation purposes. They are found to be contaminated with toxicants *i.e.* fluoride, surfactants and microbes far above the recommended limits. In this work, the water quality of 29 pit lakes locates in two districts: Raipur and Baloda Bazar, Chhattisgarh, India are assessed for drinking and irrigation purposes.

Keywords

Pit Lake, Water Quality, Fluoride, Surfactant, Microbe

1. Introduction

Several pit lakes were occurred in various parts of world due to mining activities. They are found to be contaminated due to anthropogenic activities *i.e*. bathing, washing, mixing of waste and runoff water which impart the water to be unsuitable for drinking and aqua-culture [1]-[14]. A largest lime stone rock is deposited in the Raipur-Baloda Bazar area, Chhattisgarh, India. Several cement plants are running in this area by consuming the raw materials with creation of > 100 pit lakes in the Chhattisgarh state over a large area, $\approx 1.10^4$ km^2. Their waters are used for drinking, bathing, laundry and irrigation purposes. Hence, in this work, the water quality of 29 pit lakes of Raipur-Baloda Bazar areas, Chhattisgarh is assessed for rating of the drinking purposes.

2. Material and Methods

2.1. Study Area

Many cement plants *i.e*. Ambuja Cements Ltd, Century Cement, Emami Cement Ltd, Grasim Cement, Lafarge India Ltd, Ultra Tech Cement Works, etc. are in operation nearby Raipur city due to availability of raw materials.

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Thereby, several pit lakes in villages namely *i.e*. Rawan, Pausari, Bharseli, Kukurdih, Suhela, Chandi, Karmandih, Maldi, Mopar, Amlidih, Turmha, Matia, Gaitara, etc. of Raipur and Baloda Bazar districts, Chhattisgarh are produced. Their waters are used for various house hold and other purposes.

2.2. Sample Collection

The sampling net-work is shown in **Figure 1**. The composite water samples were collected during the period, January 2013 as prescribed in the literature [15]. The water sample was collected from 5 locations (200 × 5 mL) of a pond in a cleaned polyethylene bottle. The parameters *i.e*. pH, temperature (T), electrical conductivity (EC), dissolved oxygen (DO) and reduction potential (RP) of the water were measured at the spot. The samples were dispatched to the laboratory and refrigerated at −4˚C.

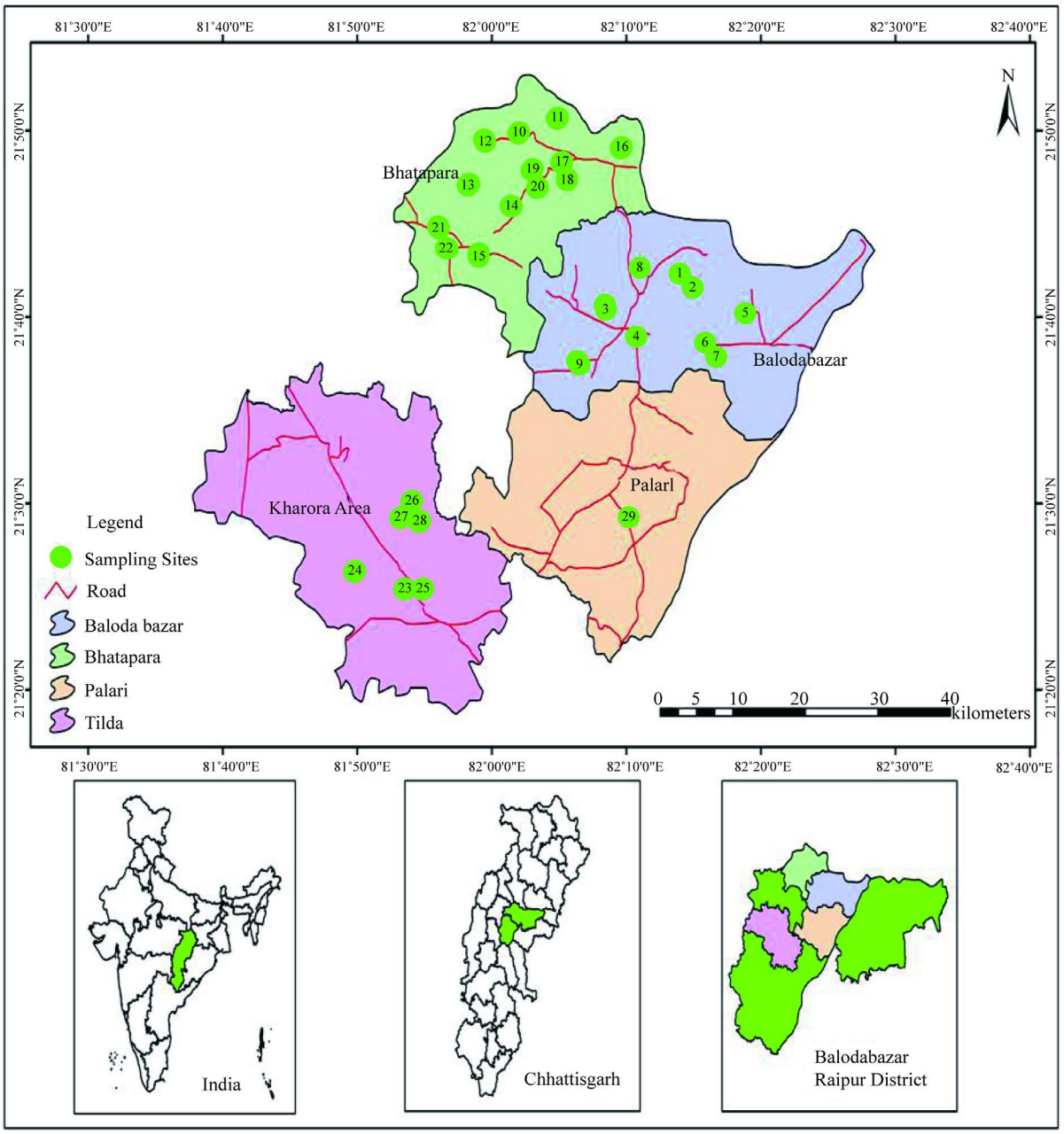

Figure 1. Sampling location of pit lakes in Raipur and Baloda Bazar areas, Chhattisgarh, India.

2.3. Analytical Methods

The total dissolved solid (TDS) of the water was measured by the evaporation method [15]. The total hardness (TH) and total alkalinity (TA) values of the water were determined by the titration methods [16]. The detergent was analyzed in the term of widely used surfactant *i.e*. sodium lauryl sulfate by the flow injection method [17]. The fluoride content of the water was analyzed by the Metrohlm-781 ion selective meter using the buffer in 1:1 volume ratio. The content of ions *i.e*. Cl^-, NO_3^-, SO_4^{2-}, NH_4^+, Na^+, K^+, Mg^{2+} and Ca^{2+} in the water was quantified by the Dionex-1100 ion meter. The metal content of the water was monitored by the GBC flame AAS-932AA.

The indicative microbes *i.e*. total coliforms (TC), fecal coliforms (FC), *Pseudomonas* aeruginosa, yeast and fungi were tested by the plate method [18]. The bactaslyde (pre-sterilized slide) was coated with specially developed media of lactose and indicator. The slide no. BS-101, BS-102 and BS-103 were used for detection of *E. coli* + TC, *Pseudomonas* + TC and yeast-fungi + TC, respectively. The slide was plunged into the test water vertically for ≈ 20 sec. The slide was incubated for 24 hr at 37˚C. The colonies developed in the slide were compared with the standard chart. The Salmonella bacteria in the water were tested by the pouch pack method [18]. The content (10 g) of pouches (*i.e*. containing organics and sulfite material) were added into a 150-mL sterilized bottle filled with 100 mL of contaminated water, and incubated for 24 hr at 37˚C. The presence of Salmonella species was confirmed by changing of color from light blue to dark black due to reduction of the sulfite into sulfide. The water quality indices *i.e*. sodium hazard (SH), sodium adsorption ratio (SAR) and magnesium hazard (MH) were computed by using the following equations.

$$SH=\left(\left\{\left[Na^+\right]+\left[K^+\right]\right\}\Big/\left\{\left[Na^+\right]+\left[K^+\right]+\left[Mg^{2+}\right]+\left[Ca^{2+}\right]\right\}\right)\times 100$$

$$SAR=\left[Na^+\right]\Big/\sqrt{\left\{1/2\left(\left[Ca^{2+}\right]+\left[Mg^{2+}\right]\right)\right\}}$$

$$MH=\left\{\left\{\left[Mg^{2+}\right]/\left[Mg^{2+}\right]\right\}+\left[Ca^{2+}\right]\right\}\times 100$$

The equivalent concentration of cations was used.

3. Result and Discussion

3.1. Geographical Characteristics of Lakes

The pit lakes are occurred in the four blocks *i.e*. Baloda Bazar (BB), Bhatapara (BP), Kharora (KR) and Palari (PA) of districts: Raipur and Baloda Bazar, **Figure 1**. The geographical characteristics of 29 pit lakes are summarized in **Table 1**. Their age, depth and area were ranged from 14 - 32 Yr, 3.0 - 21 m and 1.3 - 13 × 10^4 m^2 with mean value of 21 ± 2 Yr, 7.5 ± 1.7 m and (2.8 ± 1.0) × 10^4 m^2, respectively. The age and depth of pit lakes located in the four blocks are found to be comparable. However, the area of the pit lakes in the BB block was found at least 2-flods higher than other blocks due to deposition of the lime stone over wide area.

3.2. Physical Characteristics of Water

The physical characteristics of lake waters are shown in **Table 2**. Generally, water is colorless except 9 lakes which are covered by green algal bloom due to over loadings of the nutrients. Measured temperature of pit lake waters was ranged from 23˚C - 27˚C with mean value of 24˚C ± 0.6˚C. The DO and RP value of the water of the lakes was ranged from 4.8 - 6.8 mg/L and 200 - 261 mV with mean value of 6.0 ± 0.3 mg/L and 231 ± 7 mV, respectively. The pH value of lake waters (n = 29) of studied area was observed in the range of 6.1 - 7.8 with mean value of 6.6 ± 0.2. Among them, the pH value of 20 lakes was found below 7.0, due to presence of HCO_3^- at excessive levels. The EC and TDS value of the pit lake water was seen in the range of 462 - 1396 µS/cm and 727 - 2177 mg/L with mean value of 702 ± 89 µS/cm and 932 ± 114 mg/L, respectively. The value of TH and TA was marked in the range of 119 - 455 and 85 - 546 mg/L with mean value of 192 ± 32 and 230 ± 38 mg/L, respectively. The water of all pit lakes was found to be hard as the TH value was found above 100 mg as $CaCO_3$ mg/L. The TH and TA values were correlated well (r = 0.82) due to buffering with HCO_3^-, **Figure 2**.

Table 1. Geographical characteristics of lake.

S. No.	Block	Location	Water Type	Age, Yr	Depth, m	Area, ($\times 10^4$) m^2
1		Rwan1	CL	32	13.5	8.7
2		Rwan2	CL	32	18	13
3		Mudhipar	CL	20	4.5	2.1
4		Rawan	CL	32	15	11
5	Baloda Bazar	Semaradih	A	18	3.0	1.8
6		Dhabadih1	A	20	4.5	1.6
7		Dhabadih2	A	20	4.5	2.2
8		Sonadih	CL	32	13.5	2.1
9		Murra1	CL	17	4.5	2.3
10		Turma	A	14	3.0	1.3
11		Matiya	A	17	6.0	2.1
12		Pharhed	CL	18	3.0	1.7
13		Ranijaroud	CL	18	3.0	2.1
14		Jaroud	A	17	6.0	2.1
15		Bhalukona	CL	17	6.0	1.7
16	Bhatapara	Suhela	CL	17	4.5	2.1
17		Lohari1	A	17	7.5	1.3
18		Lohari2	CL	17	9.0	1.7
19		Bitkuli1	CL	20	6.0	2.1
20		Bitkuli2	CL	20	6.0	1.3
21		Hirmi	CL	32	13.5	1.4
22		Chandi	A	18	4.5	1.7
23		Murra2	CL	17	6.0	2.3
24		Amlidih	CL	21	6.0	1.8
25	Kharora	Murra3	CL	17	9.0	1.9
26		Dhansuli1	CL	20	6.0	2.2
27		Dhansuli2	CL	18	6.0	2.5
28		Dhansuli3	CL	18	21	2.4
29	Palari	Amakoni	A	18	6.0	1.9

A = Algal, CL = Colorless.

3.3. Chemical Characteristics of Water

The chemical characteristics of 29 pit lakes are summarized in **Table 3**. Sodium concentration of in the water of 29 lakes was ranged from 14 - 34 mg/L with mean value of 22 ± 2 mg/L. Fluoride and chloride levels in the pit lakes was observed in the range of 1.6 - 3.8 and 10 - 29 mg/L with mean value of 2.3 ± 0.2 and 17 ± 2 mg/L, respectively. Potassium concentration of the studied lakes was seen in the range of 1.4 - 8.4 mg/L with mean value of 3.2 ± 0.6 mg/L. Magnesium and Ca concentrations were observed in the range of 10 - 31 and 28 - 95 mg/L with mean value of 18 ± 2 and 52 ± 6 mg/L, respectively. The sulfate concentration was ranged from 15 - 80 mg/L with mean value 38 ± 5 mg/L. Nitrate level was detected in the range from 10 - 192 mg/L with mean value of 40 ± 16 mg/L. The Fe and Mn concentration was seen in the range of 0.37 - 0.84 and 0.15 - 0.42 mg/L with mean value of 0.50 ± 0.05 and 0.24 ± 0.03 mg/L, respectively. The value of DO, Fe and Mn was found to be relatively higher in the Baloda Bazar and Batapara blocks. However, the value of other parameters observed was found to be comparable, **Figure 3**.

Table 2. Physical characteristics of lake water.

S. No.	T,˚C	pH	EC, µS/cm	TDS, mg/L	DO, mg/L	RP, mV	TH, mg/L	TA, mg/L
1	23	6.3	738	833	6.1	227	182	223
2	24	6.1	773	850	6.5	205	175	214
3	23	6.4	1032	1130	6.6	214	238	248
4	23	6.4	844	1026	6.4	238	189	256
5	23	6.1	532	809	6.0	224	140	393
6	23	6.4	745	911	6.6	235	203	273
7	23	7.3	623	813	6.5	255	168	234
8	23	6.5	815	2177	5.9	230	196	265
9	23	6.2	738	1823	6.3	227	182	256
10	24	6.2	529	902	6.4	250	119	154
11	23	7.8	1331	855	6.0	261	420	521
12	23	7.6	1396	750	6.4	256	455	546
13	23	6.4	515	797	6.0	242	210	179
14	26	6.2	622	780	5.5	212	140	179
15	23	6.2	497	760	6.3	223	154	171
16	23	6.2	812	727	6.0	200	189	256
17	23	6.1	531	770	6.6	214	161	162
18	23	7.4	1088	816	6.7	205	406	316
19	23	6.2	582	1077	6.0	235	147	162
20	27	6.3	622	972	6.8	214	175	204
21	23	6.2	490	816	6.8	238	126	101
22	23	6.2	484	878	6.6	251	119	162
23	27	7.3	571	798	4.9	261	147	129
24	27	7.4	462	801	4.8	247	133	85
25	27	7.4	487	777	5.0	224	119	154
26	27	7.6	672	791	5.2	214	196	204
27	27	6.2	661	920	5.0	227	126	223
28	27	7.3	703	820	5.3	211	189	188
29	23	6.3	475	860	5.0	257	175	204

All pit lakes were found contaminated with surfactants *i.e*. sodium lauryl sulfate (SLS) in the range of 3.3 - 8.0 mg/L with mean value of 5.4 ± 0.4 mg/L. The mean SLS content was found to increase > 26% (6.8 mg/L) in the summer (*i.e*. May-June) due to increase of the water temperature (≈10˚C) and reduction of water levels (> 50%).

3.4. Microbe Contamination

Microbes cause many types of diseases *i.e*. diarrheal diseases, including Cholera, and other serious illnesses such as Guinea worm disease, Typhoid, and Dysentery. In this work the indicative microbe *i.e*. facial coliforms, facial streptococci, *Salmonella*, algae and fungi were determined, and the results shown in **Table 4**. The chromatograms of indicative bacteria (*i.e*. total coliform, *E. coli* and *Pseudomonas*), yeast and fungi are shown in **Figure 4**. Their concentrations were ranged from 10^2 - 10^7 count/mL. The positive test for *Salmonella* bacteria was marked for all water reservoirs as shown in **Figure 4**.

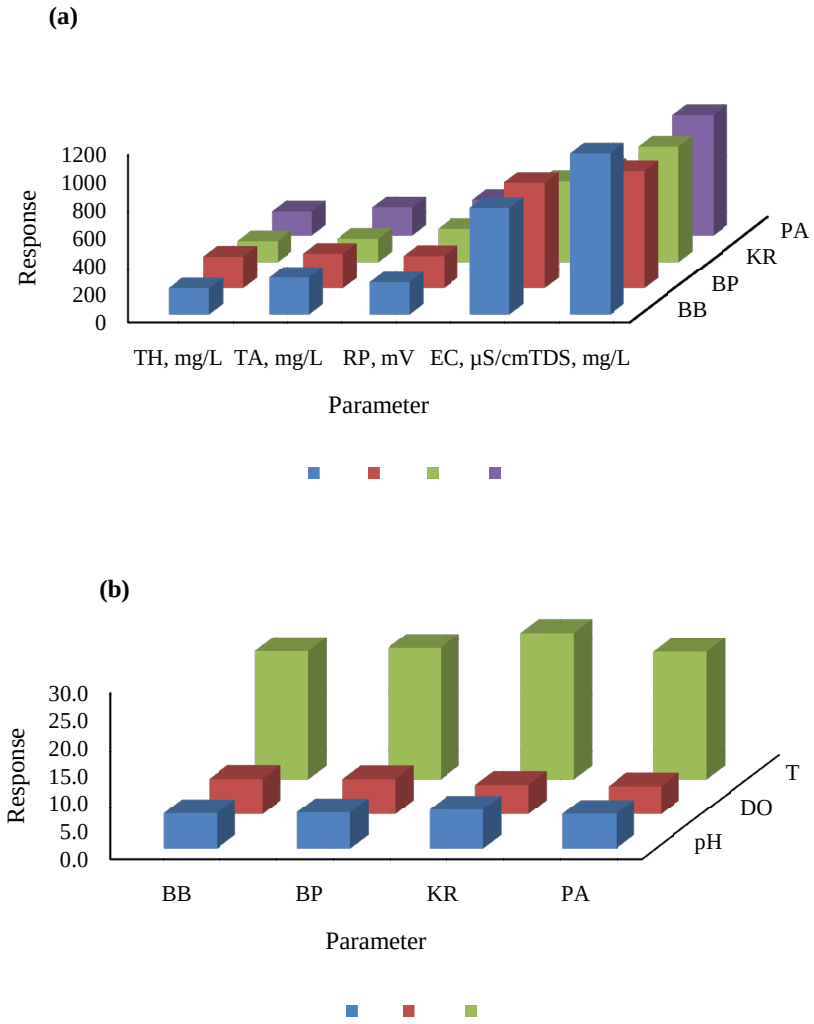

Figure 2. Spatial variation of physical parameters of water in ponds of Baloda Bazar (BB), Bhatapara (BP), Kharora (KR) and Palari (PA) blocks.

3.5. Water Quality Assessment

As per Piper diagram (**Figure 5**), the Na + Mg + Ca + HCO_3 type water was commonly available in the pit lakes of the studied areas. The pit lake water was contaminated with F^-, Fe, Mn and SLS beyond the permissible limit of 1.5, 0.30, 0.05 and 1 mg/L, respectively [19] [20]. In addition, the EC, TDS and TA values of the water were found above the recommended limits of 300 µS/cm, 500 mg/L and 120 mg/L, respectively. All pit lakes were found to be contaminated with microbes *i.e.* facial coliforms, facial streptococci, *Salmonella*, algae and fungi beyond permissible limits [19] [20]. The pit lake water is not found suitable for drinking purposes.

The SAR, SH and MH values of the water of the studied area were ranged from 0.5 - 1.9, 11% - 39% and 16% - 80% with mean value of 1.0 ± 0.1, 22% ± 3% and 41% ± 6%, respectively, **Table 4**. Generally, the SAR, SH and MH value of < 1, <20, and < 40 were considered good for the irrigation purposes [21] [22]. The water quality of the pit lakes was assessed by using the salinity and Wilcox diagrams as shown in **Figure 6**, **Figure 7**. They could be used for irrigation purposes.

3.6. Sources of Contaminants

The correlation matrix of the variables is summarized in **Table 5**. Among them, F^-, Mg^{2+} and Ca^{2+} were found to be correlated well, showing origin from the similar sources *i.e.* leaching from the lime stone. The Na^+ content was correlated well with the SLS contents, indicating origin from the use of sodium lauryl sulfate as detergent.

Table 3. Chemical characteristics of Lake water, mg/L.

S. No.	Na^+	K^+	Mg^{2+}	Ca^{2+}	F^-	Cl^-	NO_3^-	SO_4^{2-}	Fe	Mn	SLS
1	22	2.9	27	73	3.1	20	17	39	0.37	0.18	5.2
2	14	3.2	24	70	2.5	29	15	38	0.41	0.16	3.3
3	17	4.3	19	64	2.7	25	49	80	0.39	0.19	4.0
4	21	3.2	21	64	2.2	15	50	53	0.38	0.29	4.9
5	34	2.8	13	36	1.9	10	29	27	0.42	0.35	8.0
6	28	2.2	29	70	2.9	29	18	43	0.41	0.16	6.6
7	28	2.0	17	48	2.1	10	31	18	0.56	0.21	6.6
8	29	2.1	11	36	2.2	15	34	42	0.84	0.17	6.8
9	21	1.8	17	53	2.2	25	35	62	0.71	0.18	4.9
10	29	4.3	15	45	2.2	10	18	32	0.37	0.27	6.8
11	25	2.1	24	73	3.2	10	42	22	0.39	0.24	5.9
12	24	2.2	14	42	1.8	15	22	28	0.39	0.24	5.6
13	22	2.4	31	95	3.8	15	190	36	0.37	0.24	5.2
14	20	3.4	18	48	1.5	10	192	29	0.38	0.27	4.7
15	25	2.1	19	64	2.5	20	11	52	0.42	0.42	5.9
16	22	2.8	17	45	2.4	10	45	46	0.42	0.27	5.2
17	21	3.1	12	34	1.7	10	10	32	0.39	0.24	4.9
18	24	7.6	13	34	1.8	10	18	39	0.38	0.39	5.6
19	22	1.7	18	50	2.4	15	20	48	0.56	0.29	5.2
20	24	2.9	15	42	1.8	15	11	15	0.42	0.32	5.6
21	21	3.8	21	62	2.2	15	13	17	0.56	0.29	4.9
22	17	1.8	20	64	2.7	15	31	20	0.56	0.27	4.0
23	20	4.2	12	39	1.8	25	39	38	0.42	0.19	4.7
24	24	7.0	13	42	2.2	20	31	41	0.56	0.17	5.6
25	14	2.1	10	31	1.6	20	31	34	0.70	0.15	3.3
26	25	1.4	21	67	2.5	10	38	42	0.84	0.16	5.9
27	25	8.4	10	28	1.6	29	35	48	0.56	0.19	5.9
28	17	2.9	17	48	2.9	15	42	46	0.72	0.17	4.0
29	32	2.1	11	28	1.6	15	31	42	0.56	0.18	7.5

The origin of bacteria *i.e*. *E. coli*, *Pseudomonas* and *Salmonella* in the water was expected due to use of human, animals and birds for bathing and mixing of runoff and sewage water. Similarly, the origin of the algae and fungi was assumed from the nutrient overloading in the water from the mixing of agricultural and runoff waste. The ions *i.e*. Cl^-, SO_4^{2-} and NO_3^- were expected to originate from the multiple sources *i.e*. mixing of runoff, agricultural and sewage wastes.

4. Conclusion

The major contaminants of the pit lake waters were F^-, surfactant and microbe which imparted the water to be unsuitable for drinking purposes. However, the surfactant and microbe contaminations could be controlled by imposing restriction on bathing and laundry uses of the lake water. The physical properties *i.e*. acidity, conductivity, hardness, alkalinity and salinity of the water were found below the permissible limits and could be used for the irrigation purposes.

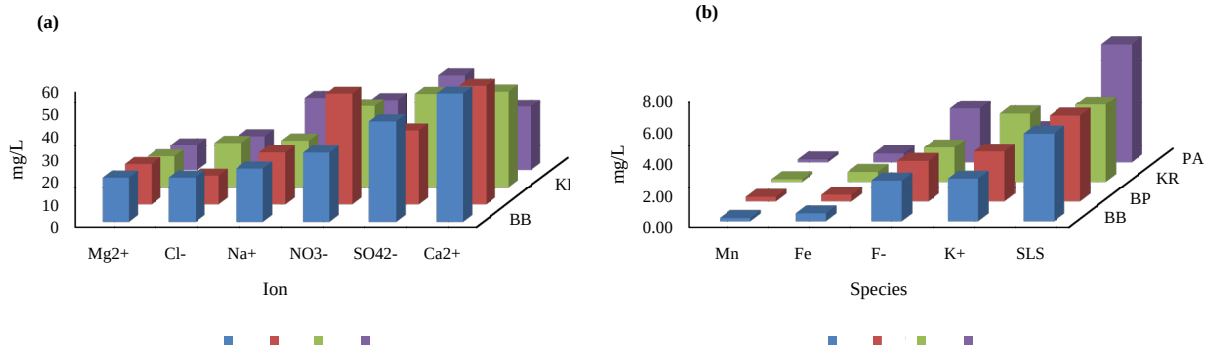

Figure 3. Spatial variation of chemical parameters of waterponds of Baloda Bazar (BB), Bhatapara (BP), Kharora (KR) and Palari (PR) blocks.

Table 4. WQI indices and microbe content of water, count/mL.

S. No.	WQI	SAR	SH	MH	*E. coli* + TC	PM+TC	Yeast + Fungi + TC	*Salmonella*
1	71	0.8	15	40	10^4	10^2	10^6	Positive
2	78	0.5	11	42	10^3	10^2	10^6	Positive
3	109	0.7	15	32	10^4	10^2	10^5	Positive
4	85	0.8	17	63	10^3	10^2	10^6	Positive
5	48	1.9	34	18	10^5	10^3	10^6	Positive
6	73	1.0	18	64	10^4	10^2	10^6	Positive
7	54	1.2	25	51	10^7	10^5	10^6	Positive
8	79	1.6	33	23	10^5	10^6	10^6	Positive
9	73	0.9	19	39	10^4	10^2	10^6	Positive
10	45	1.4	28	22	10^5	10^3	10^5	Positive
11	150	0.9	17	63	10^4	10^2	10^6	Positive
12	158	1.2	25	16	10^4	10^2	10^6	Positive
13	41	0.7	12	65	10^5	10^3	10^7	Positive
14	54	0.9	20	31	10^4	10^2	10^5	Positive
15	41	1.0	19	44	10^5	10^3	10^5	Positive
16	81	1.0	22	51	10^5	10^3	10^6	Positive
17	47	1.1	27	36	10^7	10^4	10^5	Positive
18	115	1.3	31	27	10^4	10^2	10^6	Positive
19	51	1.0	20	44	10^4	10^2	10^6	Positive
20	58	1.2	25	26	10^5	10^3	10^6	Positive
21	41	0.8	17	36	10^4	10^2	10^6	Positive
22	41	0.7	14	56	10^7	10^5	10^6	Positive
23	40	1.0	25	31	10^5	10^6	10^6	Positive
24	27	1.2	28	45	10^4	10^2	10^3	Positive
25	31	0.8	21	16	10^4	10^2	10^6	Positive
26	58	1.0	18	80	10^5	10^3	10^6	Positive
27	58	1.6	37	22	10^4	10^2	10^7	Positive
28	59	0.7	18	59	10^7	10^5	10^6	Positive
29	33	1.7	39	46	10^4	10^3	10^7	Positive

WQI = Water quality index, SAR = Sodium adsorption ratio, SH = Sodium hazard, MH = Magnesium hazard, TC = Total coliform, PM = *Pseudomonas*.

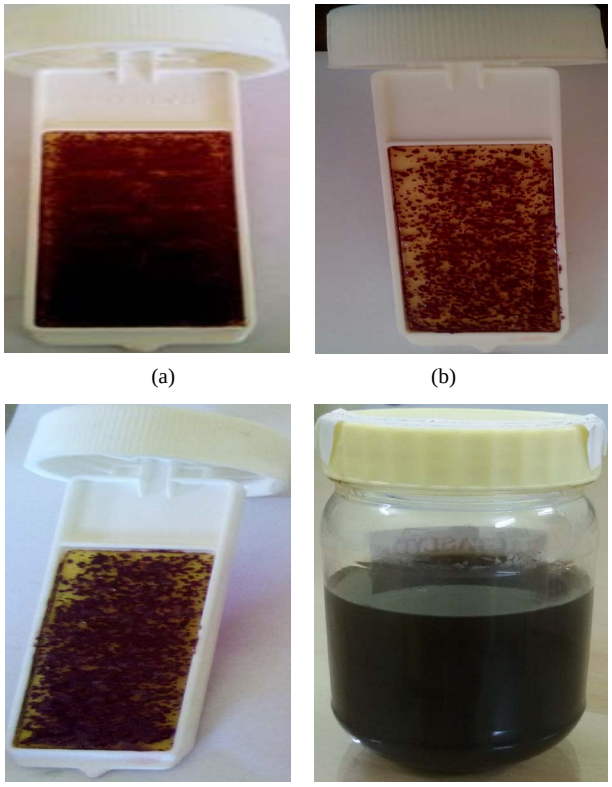

Figure 4. Microbes {*E. coli*, total coliform (TC), *Pseudomonas* (PM) and *Salmonella*} test for the studied water: A = *E. coli* + TC (10^7 count/mL), B = PM + TC (10^7 count/mL), C = Y + F (10^6 count/mL), D = *Salmonella* (positive).

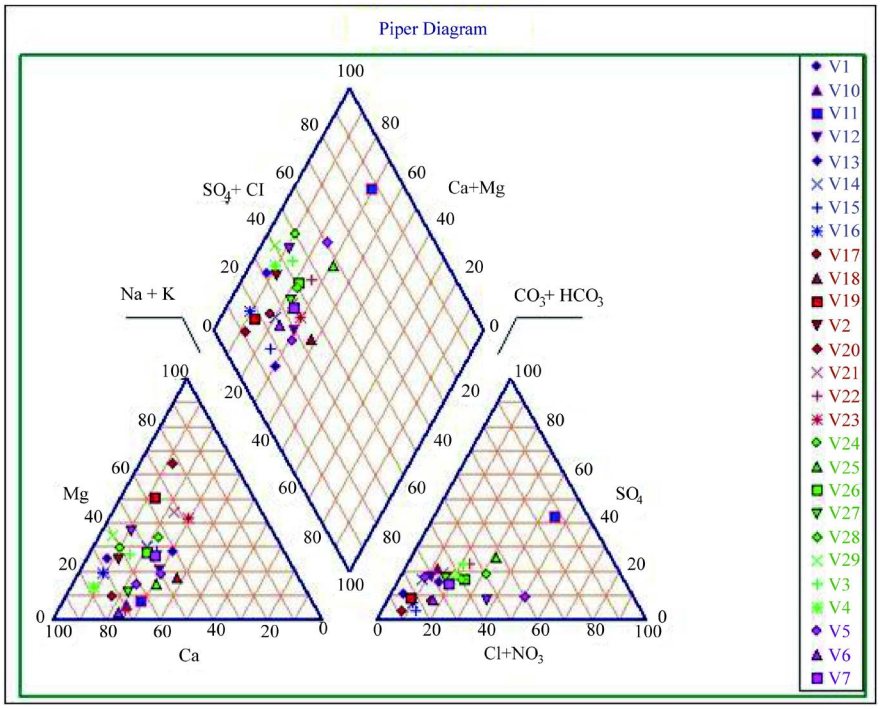

Figure 5. Piper diagram for water of pit lakes.

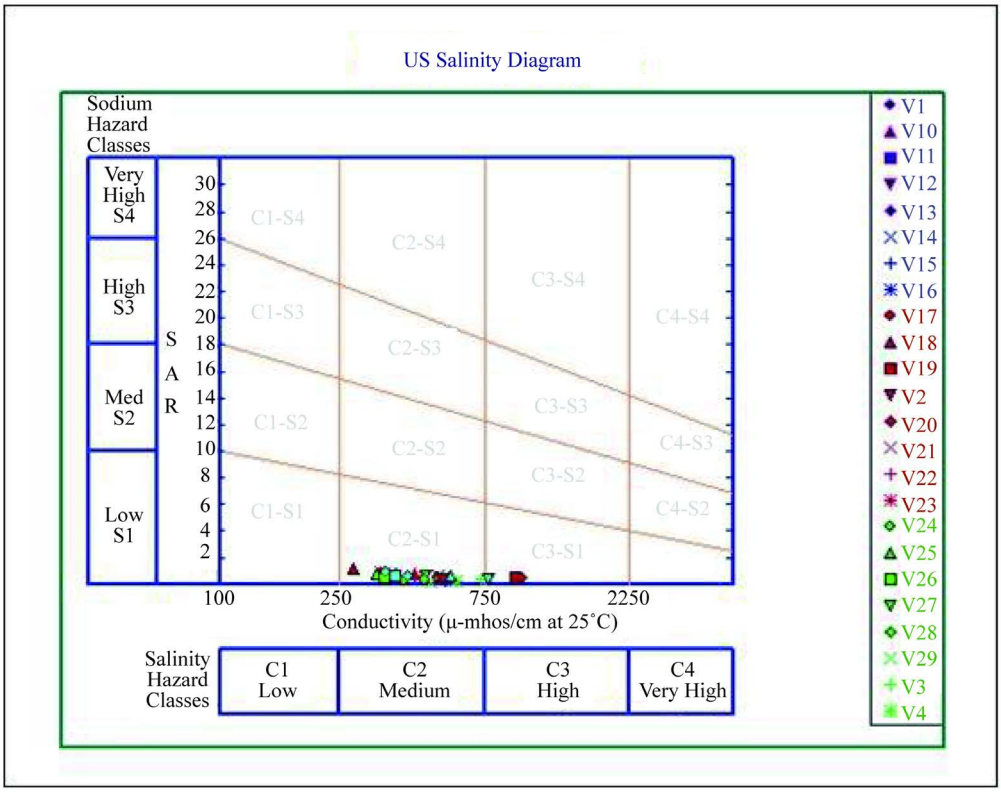

Figure 6. Salinity diagram for water of pit lakes.

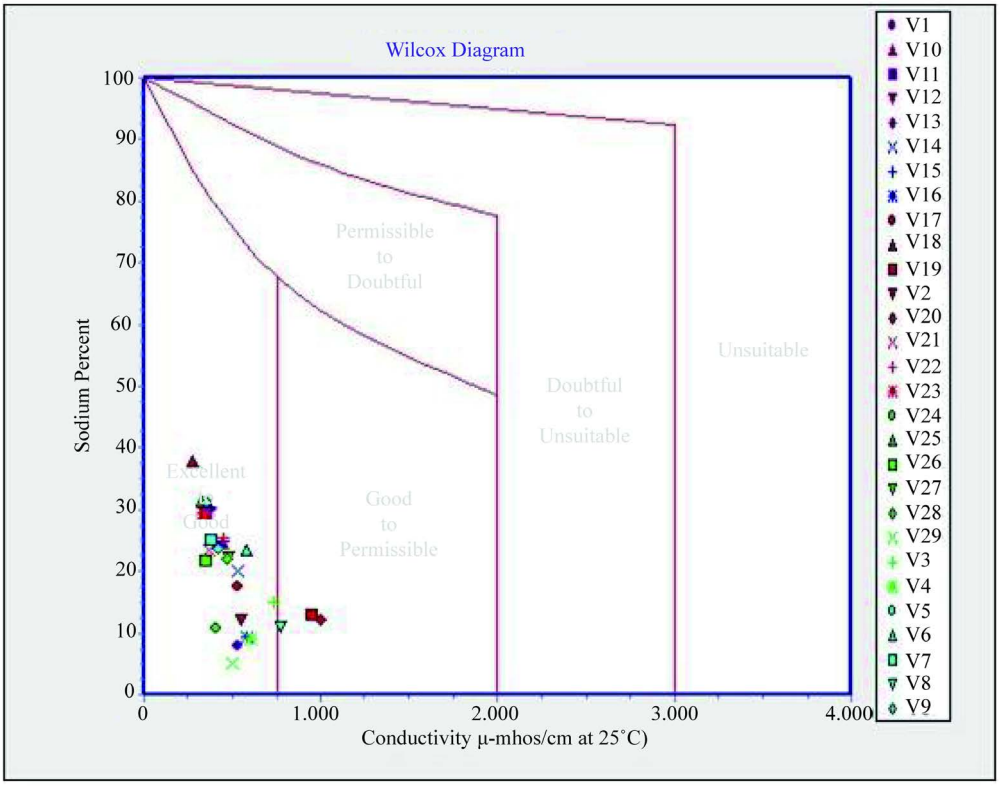

Figure 7. Wilcox diagram for water of pit lakes.

Table 5. Correlation matrix of elements.

	Na^+	K^+	Mg^{2+}	Ca^{2+}	F^-	Cl^-	NO_3^-	SO_4^{2-}	Fe	Mn	SLS
Na^+	1.00										
K^+	−0.01	1.00									
Mg^{2+}	−0.18	−0.34	1.00								
Ca^{2+}	−0.25	−0.35	**0.96**	1.00							
F^-	−0.09	−0.32	**0.86**	**0.89**	1.00						
Cl^-	−0.32	0.22	0.13	0.13	0.06	1.00					
NO_3^-	−0.14	−0.05	0.31	0.20	0.20	−0.17	1.00				
SO_4^{2-}	−0.18	0.14	0.02	0.08	0.09	0.48	0.01	1.00			
Fe	−0.01	−0.22	−0.30	−0.23	−0.23	0.02	−0.16	0.11	1.00		
Mn	0.22	0.09	−0.05	−0.03	0.00	−0.45	−0.02	−0.21	−0.46	1.00	
SLS	**1.00**	−0.01	−0.17	−0.24	−0.08	−0.32	−0.14	−0.18	−0.01	0.22	1.00

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