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Assessment of Groundwater Quality in Central India

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Abstract

The groundwater is widely used for irrigation of rice crops. The overuse of groundwater causes depletion of the water quality (*i.e.* enormous increase in conductivity, hardness and ion and metal contents, etc.) in several regions of the country and world. In this work, the quality of the groundwater in the densestrice cropping area, Saraipali, Chhattisgarh, Central India is discussed. The water is sodic in nature with extremely high electrical conductivity. The mean concentration (n = 30) of F^-, Cl^-, NO_3^-, SO_4^{2-}, NH_4^+, Na^+, K^+, Mg^{2+}, Ca^{2+} and Fe in the water was 1.2 ± 0.2, 98 ± 31, 46 ± 15, 56 ± 9, 19 ± 4, 206 ± 25, 9.2 ± 2.3, 39 ± 6, 114 ± 19 and 1.7 ± 0.6 mg/L, respectively. The sources of the contaminants are apportioned by using the factor analysis model. The suitability of the groundwater for the drinking and irrigation purposes is assessed.

Keywords

Groundwater, Indices, Sources

1. Introduction

The urban groundwater has emerged as one of the world's most challenging issues due to large users and contamination with chemicals of geogenic and anthropogenic origins [1]. The quality of available groundwater was degraded enormously by enhancing conductivity, alkalinity, hardness and contaminant levels [2]-[15]. Hence, in this work, the groundwater quality of the rice growing area, Saraipali block, Mahasamund, Chhattisgarh, India was selected for the assessment and rating.

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2. Materials and Methods

2.1. Study Area

Saraipali (21.33˚N 83.0˚E) is a block in Mahasamund district, Chhattisgarh state, India, including 299 town and villages inclusive of Saraipali town with population of ≈0.3 million. The rice is a main crop of the area with use surplus amount of groundwater to take the multiple crops in a year. The water is hard and become turbid on the storage due to precipitation of the metals *i.e.* Mg, Ca and Fe into oxides and hydroxides. The health problems (*i.e.* tiredness, diarrhea, stone formation in kidney and spleen, etc.) in the residence of the studied area due to intake of the groundwater were marked. Therefore, in the present work, the water quality assessment of Saraipali area was chosen.

2.2. Sample Collection

The groundwater samples were collected from 30 locations of the town and nearby villages, **Figure 1**. The water was collected in the post monsoon period, January, 2014 in a 1-L cleaned polyethylene bottle by using established methodology [16]. The bottle was ringed thrice with the sampling water prior to collection and filled up to the mouth with the water. The physical parameters *i.e.* pH, temperature (T), electrical conductivity (EC), reduction potential (RP) and dissolved oxygen (DO) were measured at the spot.

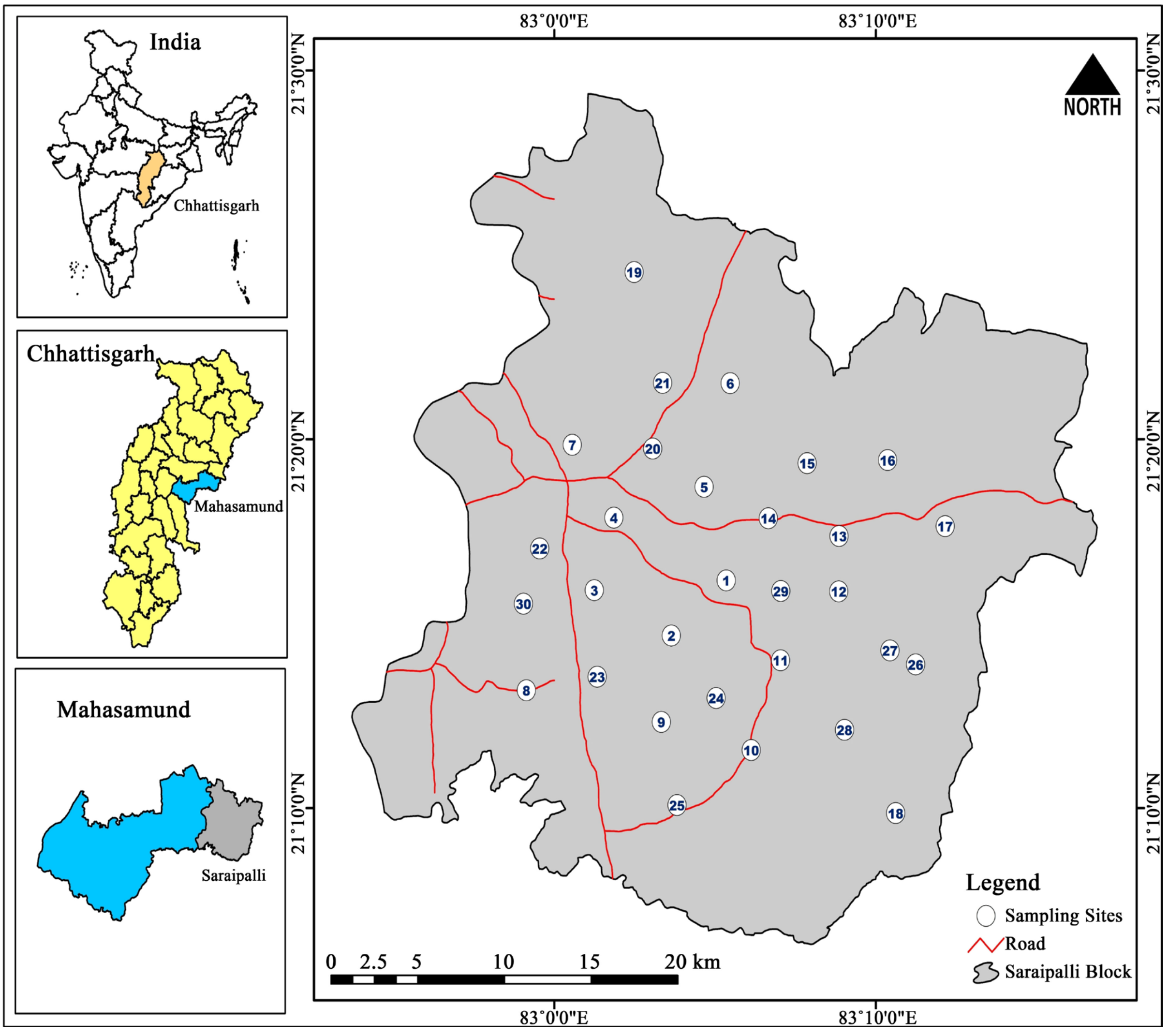

Figure 1. Representation of sampling locations in Chhattisgarh, India.

2.3. Analysis

The Hanna water analyzer kits was used for the measurement of the physical parameters. The total dissolved solid (TDS) value was determined by evaporation method by prior filtering the water through glass fiber with subsequent drying at the constant weight [16]. The total hardness (TH) and total alkalinity (TA) values were analyzed by titration methods [17]. The Metrohm ion meter-781 was used for monitoring of F^- by using the buffer in a 1:1 volume ratio. The Dionex ion chromatography-1100 was used for the quantification of the ions. Multivariate statistical model *i.e.* factor analysis (FA) was used for the source apportionment of ions and metals [18]. The statistical software STATISTICA 7.1 was employed for the multivariate statistical calculations.

The various water quality indices *i.e.* sodium adsorption ratio (SAR), sodium hazard (SH) and water quality index (WQI) were used for rating of the water quality. The weighed arithmetic method was employed for computation of the WQI of the groundwater by using four parameters *i.e.* pH, DO, EC and TDS [19] [20]. The following equations were used for calculation of the indices.

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

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

The equivalent concentrations of cations were used.

$$\text{WQI} = \sum q_n W_n \Big/ \sum W_n$$

$$q_n = 100\left(V_n - V_{io}\right)/\left(S_n - V_{io}\right)$$

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.

3. Results and Discussion

3.1. Geology

Chhattisgarh basin is characterized by rocks belonging to Proterozoic aged sandstone, limestone, and dolomite, conglomerate, etc. Siliciclastic-carbonates are deposited in muddy shelf and platformer environment, indicative of more stable tectonic condition. Its deposition is controlled by several cycles of transgressions and regressions. The Proterozoic grouprocks are found to spread over the studied area. The gypsum minerals are found to be more intense than calcareous minerals, containing both toxic and precious elements at traces.

The physical characteristics of 30 tube well of Saraipali area is summarized in **Table 1**. The depth of tube well (n = 30) is moderate, ranging from 24 - 63 m with mean value of 32 ± 2 m. The ionic contamination of the water was found to be related with the depth profile of the tube wells and increased as the depth profile was increased (r = 0.59). The age of tube wells was ranged from 7 - 25 Yr with mean value of 17 ± 2 Yr. The water quality was also found to be influenced by the age of tube wells.

3.2. Physical Characteristics of Water

The chemical characteristics of the groundwater are presented in **Table 2**. The T, DO, RP and pH value of water (n = 30) was ranged from 19˚C - 22˚C, 4.8 - 5.4 mg/L, 117 - 238 mV and 6.2 - 8.3 with mean value of 20.9˚C ± 0.3˚C, 5.1 ± 0.1 mg/L, 187 ± 9 mV and 6.88 ± 0.13, respectively. In some locations, the water was found to be slightly acidic due to higher Cl^- and NO_3^- contents. The EC, TDS, TA and TH value of water was ranged from 785 - 4589 µS/cm, 651 - 2836 mg/L, 159 - 610 mg/L and 186 - 864 mg/L with mean value of 1946 ± 363 µS/cm, 1411 ± 221 mg/L, 352 ± 45 mg/L and 355 ± 58 mg/L, respectively. The EC value was mainly contributed by the ions *i.e.* Na^+, K^+, Cl^-, NO_3^- and SO_4^{2-} (r = 0.93).

Table 1. Geophysical characteristics of tube well and groundwater during January, 2014.

S. No.	Location	Age, Yr	Depth, m	T, ˚C	pH	EC, µS/cm	RP, mV	DO, mg/L
1	Joganipalidipa	22	30	22	7.1	1169	200	5.2
2	Joganipali	10	30	22	6.2	1776	187	5.3
3	Kejuan	18	33	21	6.9	966	170	5.2
4	Harratar	13	27	21	7.2	1433	212	5.0
5	Kutela	15	24	21	7.1	1099	139	5.4
6	Bastisaraipali	19	27	22	7.0	2097	165	5.0
7	Madhopali	17	27	22	7.0	1190	238	5.1
8	Parsada	16	24	22	7.2	1127	186	5.3
9	Telidipa	12	27	21	6.8	888	180	5.0
10	Lukapara	7	63	21	6.8	3770	187	4.8
11	Lakhanpali	21	33	20	6.8	1209	218	5.3
12	Barihapali	10	48	20	6.8	2545	191	4.9
13	Mokhaputka	25	33	21	6.6	2467	181	4.9
14	Kumhardipa	17	36	22	6.5	1375	214	5.1
15	Saraipali	20	30	22	6.7	1100	183	5.0
16	Paterapali	15	33	22	6.9	4589	161	5.3
17	Balsi	25	33	22	6.5	1928	172	5.1
18	Kendudhar	24	30	21	7.2	1910	219	5.1
19	Bichhiyan	22	33	21	7.0	4082	205	5.2
20	Sagarpali	18	39	20	6.8	3666	194	5.1
21	Amarkot	22	24	21	6.6	1080	188	5.0
22	Mohda	20	27	20	6.3	1888	163	5.4
23	Navrangpur	18	33	20	7.1	1251	172	5.3
24	Patsendri	16	36	20	7.1	2730	194	5.2
25	Bonda	17	36	20	7.0	3094	201	5.1
26	Girsa	15	33	19	8.3	2045	117	5.1
27	Jambahlin	20	27	20	6.9	1806	213	5.1
28	Baitari	15	30	21	6.8	1340	226	5.4
29	Chattigirhola	16	33	21	7.0	785	157	5.2
30	Echchhapur	18	30	20	7.1	1968	170	5.2

Table 2. Chemical characteristics of groundwater during January, 2014, mg/L.

S. No.	TDS	TA	TH	F^-	Cl^-	NO_3^-	SO_4^{2-}	NH_4^+	Na^+	K^+	Ca^{2+}	Mg^{2+}	Fe
1	748	353	210	0.8	27	22	27	13	156	9.5	57	34	2.4
2	1183	298	318	0.9	92	29	44	15	246	5.5	99	39	3.8
3	857	286	243	0.6	18	21	69	12	118	6.0	75	30	2.4
4	896	420	306	1.2	36	28	31	14	163	6.5	101	31	0.5
5	651	286	207	0.8	18	18	38	11	125	4.0	68	22	1.1
6	1310	311	330	1.3	129	18	53	17	218	17.0	101	42	0.7
7	1028	335	246	0.9	27	14	42	31	146	5.5	75	31	1.1
8	1071	237	246	1.0	42	104	34	7	118	6.5	75	31	0.4
9	978	347	408	1.6	23	29	39	9	102	8.5	130	47	2.1
10	2588	585	693	1.8	190	120	40	31	311	4.0	226	74	0.4

Continued

11	906	280	258	0.8	36	32	69	7	163	4.5	86	26	0.8
12	1731	384	501	1.9	125	23	57	26	254	9.5	164	53	0.9
13	1868	317	471	1.8	134	67	79	19	233	3.0	153	51	1.5
14	1554	170	186	0.8	65	163	38	23	175	7.0	62	18	1.2
15	805	213	222	0.7	51	15	36	11	156	14.0	73	23	2.7
16	2836	464	864	2.2	374	42	47	12	351	5.5	286	88	0.6
17	1646	183	471	1.9	166	34	46	13	251	11.0	156	48	1.4
18	1106	573	276	0.8	42	22	79	15	260	36.0	83	36	0.6
19	2626	543	513	1.7	254	120	68	29	311	5.0	151	72	1.9
20	2207	610	438	1.6	231	68	42	33	317	13.5	138	52	0.4
21	1212	244	348	1.2	36	22	88	17	155	8.5	117	34	7
22	1960	159	327	1.1	120	153	100	13	248	5.5	112	30	6.9
23	963	268	222	1.0	47	25	85	12	131	8.0	70	26	2.1
24	1854	360	543	1.8	161	32	39	28	282	13.0	179	56	1.1
25	1948	329	552	1.9	231	28	35	19	257	20.0	182	57	1.2
26	2022	372	231	1.1	116	21	140	57	226	6.0	75	25	0.3
27	1097	433	354	1.2	47	21	43	18	179	5.0	117	36	1.1
28	945	402	219	0.8	34	26	61	18	152	12.0	70	25	3.1
29	792	244	216	0.9	35	31	46	12	122	8.0	73	21	1.5
30	956	549	228	0.7	47	31	60	16	260	7.5	73	26	0.9

3.3. Chemical Characteristics of Water

The concentration of F^-, Cl^-, NO_3^-, SO_4^{2-}, NH_4^+, Na^+, K^+, Mg^{2+}, Ca^{2+} and Fe was ranged from 0.6 - 2.2, 18 - 374, 14 - 163, 27 - 140, 7.0 - 57, 102 - 351, 3.0 - 36, 18 - 88, 57 - 286 and 0.3 - 7.0 mg/L with mean value of 1.2 ± 0.2, 98 ± 31, 46 ± 15, 56 ± 9, 19 ± 4, 206 ± 25, 9.2 ± 2.3, 39 ± 6, 114 ± 19 and 1.7 ± 0.6 mg/L, respectively. Among them, Na^+ showed the highest content followed by Ca^{2+} and Cl^-. The highest ionic content was marked at locations lying close to at the highway junctions and water reservoirs due to their increased mineralization in the groundwater, **Figure 2**.

3.4. Source

The correlation coefficient matrix of the water variables are shown in **Table 3**. Among them, ions *i.e.* F^-, Cl^-, Na^+, Mg^{2+} and Ca^{2+} were found to be well correlated, showing origin from the common sources. The molar ratio of $[Na^+]/[Cl^-]$ was ranged from 1.5 - 11 with mean value of 5 ± 1, indicating both geogenic and anthropogenic origins of Na in the water.

The FA model showed the extraction of six factors with account for 84.04% of total variance, **Table 4**. Factor-1 accounts for 39.27% of the total variance with strong positive loadings of TH, Ca^{2+}, Mg^{2+}, F^-, Cl^-, EC and TDS; related to hardness depending on the weathering of fluoride bearing materials such as CaF_2. Factor-2 explains 14.79% of the total variance with high positive loading of SO_4^{2-}, correlated to evaporation of the water. Factor-3 explains 9.06% of the total variance with high positive loading of alkalinity in opposition to Fe. Factor-4 accounts for 8.32% of the total variance with a negative loading of DO. Factor 5 explains 6.87% of the total variance with a negative loading of the variable Age of the tube wells. Factor-6 accounts for 5.74% of the total variance with a high positive loading of NO_3^-, indicating agricultural impacts in the water.

3.5. Water Quality

The value of TA, TH, Mg, Ca and Fe content was found to be higher than recommended value of 120, 200, 30, 75 and 0.30 mg/L, respectively [19] [20]. The value of SAR, SH and WQI was ranged from 1.8% - 28%, 19% - 84% and 86% - 713% with mean value of 6.6% ± 1.7%, 50% ± 5% and 275% ± 60%, respectively. The

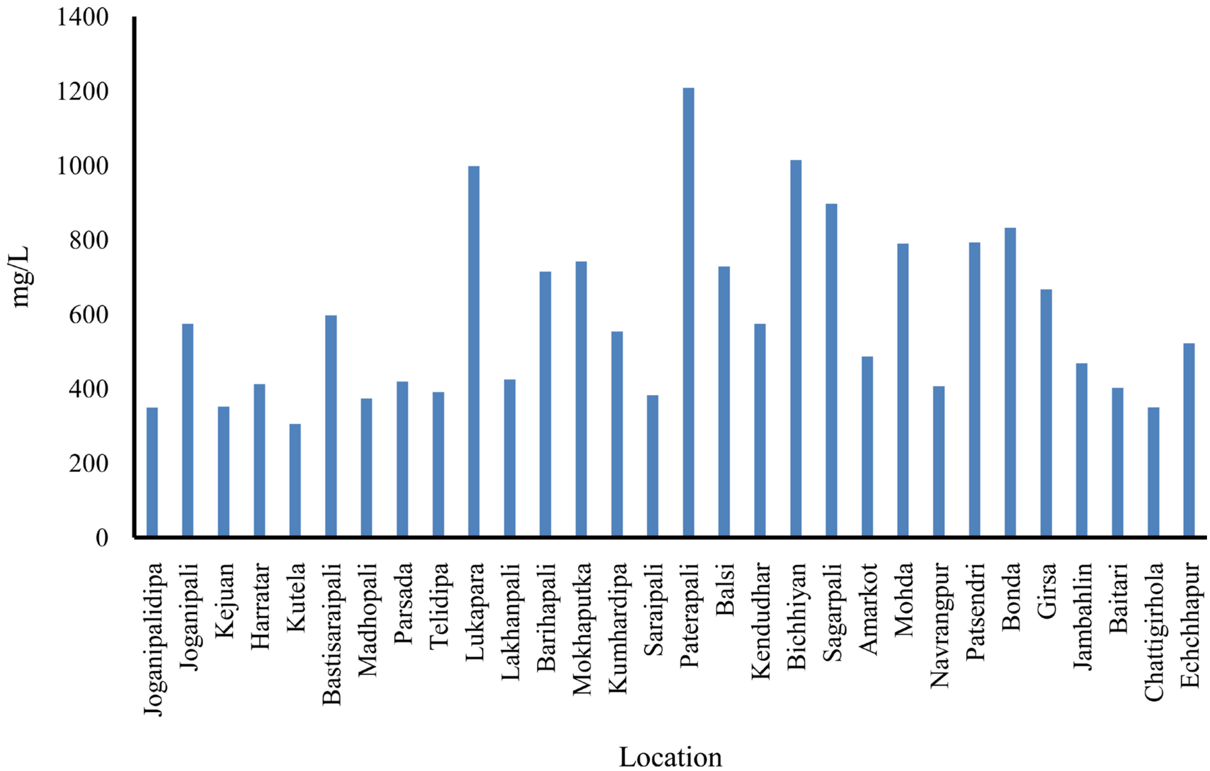

Figure 2. Spatial variations in sum of total concentration of the ions.

Table 3. Correlation coefficient matrix of elements in water.

	F^-	Cl^-	NO_3^-	SO_4^{2-}	NH_4^+	Na^+	K^+	Ca^{2+}	Mg^{2+}	Fe
F^-	1									
Cl^-	0.81	1								
NO_3^-	0.15	0.29	1							
SO_4^{2-}	−0.11	−0.01	0.03	1						
NH_4^+	0.24	0.32	0.11	0.40	1					
Na^+	0.65	0.86	0.29	0.09	0.42	1				
K^+	−0.02	0.02	−0.26	−0.02	−0.05	0.18	1			
Ca^{2+}	0.91	0.85	0.17	−0.14	0.15	0.73	−0.05	1		
Mg^{2+}	0.88	0.86	0.18	−0.17	0.19	0.75	0.01	0.93	1	
Fe	−0.20	−0.20	0.13	0.31	−0.25	−0.18	−0.12	−0.15	−0.21	1

Table 4. Eigenvalues and factor loadings of groundwater.

Variable	Factor-1	Factor-2	Factor-3	Factor-4	Factor-5	Factor-6
Age	−0.10	0.02	−0.18	−0.20	**−0.83**	0.04
Depth	0.41	0.06	0.19	0.57	0.32	0.32
T	−0.06	−0.67	−0.20	−0.01	−0.11	0.09
pH	−0.09	0.55	0.64	−0.12	0.14	−0.30
EC	**0.88**	0.14	0.31	0.02	−0.03	0.25
RP	−0.15	−0.59	0.33	0.22	−0.35	0.30
DO	−0.08	0.03	0.09	**−0.90**	0.07	0.10
TDS	**0.85**	0.30	0.10	0.07	0.02	0.40

Continued

TA	0.43	0.10	**0.76**	0.04	−0.05	0.05
TH	**0.97**	−0.02	0.09	0.07	0.14	0.00
F^-	**0.91**	0.08	0.04	0.15	0.11	−0.07
Cl^-	**0.91**	0.10	0.07	−0.02	−0.05	0.19
NO_3^-	0.21	−0.02	−0.17	−0.08	0.10	**0.85**
SO_4^{2-}	−0.03	**0.87**	−0.15	−0.12	−0.21	0.08
NH_4^+	0.18	0.67	0.44	0.32	0.06	0.33
Na^+	0.29	0.66	0.40	0.31	0.00	0.36
K^+	−0.08	−0.10	−0.04	0.40	−0.69	−0.28
Ca^{2+}	**0.96**	−0.01	0.06	0.07	0.16	−0.01
Mg^{2+}	**0.95**	−0.05	0.19	0.06	0.06	0.04
Fe	−0.24	−0.01	**−0.76**	0.06	−0.33	0.15
Eigenvalue	7.85	2.96	1.81	1.66	1.37	1.15
% Total variance	39.27	14.79	9.06	8.32	6.87	5.74
Cumulative %	39.27	54.05	63.11	71.43	78.30	84.04

classification of groundwater was grouped on the basis of SH values, excellent (<20%), good (20% - 40%), permissible (40% - 60%), doubtful (60% - 80%) and unsuitable (>80%). It means the water of the studied area was found to be sodic and hard in nature, being unsuitable for the drinking purposes. They could be used for the irrigation purposes but prolonged excessive extraction of the water may cause adverse impacts in rice yields in near future.

4. Conclusion

The groundwater of Saraipali area is deteriorated rapidly due to its excessive extraction for the irrigation purposes. The water is sodic and hard in nature. The values of EC, TH, TA, Na, Mg, Ca and Fe were observed to be above reported permissible limits. The water is seemed to be unsuitable for the drinking purposes due to high mineralization of the bed-rock elements in the aquifer. The water could be used for the irrigation of the new varieties rice crops required less water with lower ripping life.

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