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GIS Integrated Evaluation of Groundwater Quality Index (GwQI) for Granitic Aquifers and its Relation with Zone of Lineaments in Parts of Bundelkhand Granite Complex (BGC), Central India

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Abstract : Groundwater is an important source for drinking. In Bundelkhand Granitic Complex (BGC) of central India, however, its quality is diminishing due to various geological processes. The study evaluates groundwater quality incorporating the GwQI tool based on GIS techniques by defining its relation with lineaments/weak zones for the demarcation of safe and 'good quality' zones for exploitation of groundwater in the studied area. Twelve 'quality parameters' namely pH, EC, TDS, H_T, Ca^{+2}, Mg^{+2}, Na^+, K^+, Cl^-, F^-, HCO_3^-, and SO_4^{-2} for each of the 41 groundwater samples have been assigned weightage through 'decision-making' and validating our knowledge as per their effects on human health for the computation of GwQI scores and groundwater quality assessment as per the Bureau of Indian Standards (BIS, 2015). The spatial variability of 'quality parameters' generated through IDW Interpolation along with their correlation analyses have been determined with influence of geological and hydrogeological attributes. The study shows that 'poor quality' (F^- above 1.5 mg/l) in groundwater in the zone extending from central to north-western parts of the area (demarcated by GwQI scores mapping) has a direct relation with the underlying 'unconfined granitic aquifers' along the major NW-SE trending lineaments.

Key Words: Groundwater Quality Index, Bundelkhand Granite Complex, lineaments, granites.

Introduction

The role of groundwater is critical in present time, although 'it is' diminishing at local as well as regional levels in aquifer systems in different geological settings. India, amongst all countries, is the largest user of groundwater (230 km^3/year) as per the World Bank News (TWB, 2012). Groundwater is getting polluted/contaminated because of increase in urbanisation, deforestation, population explosion, excessive use of fertilizers, huge evaporation, low rainfall, besides geological reasons (Subba Rao *et al.,* 2017; Adimalla *et al.,* 2018; Adimalla and Qian, 2019). Around 80% of human diseases are caused through polluted/contaminated groundwater (World Health Organization, WHO, 2017). Studies on pollution, quality assessment for potability, hydrogeochemical characterisation and distribution of groundwater are gaining importance for socio-economic developments.

Geographic Information System (GIS) techniques, coupled with the Inverse Distancing Weightage (IDW) interpolation, are emerging as spatial analyst's tool used to monitor and assesswater quality (Aravindan *et al.,* 2010; Shankar *et al.,* 2010; Venkateswaran *et al.,* 2012; Selvam *et al.,* 2013; Magesh and Elango, 2019; Soujanya *et al.,* 2020; Ram *et al.,* 2021). Genesis, evolution and future validity of 'the' WQI tool endorse the potability of water and the Groundwater Quality Index (GwQI) for drinking purposes for groundwater by calculating the score for each sample station that reflects the combined influence of discrete physico-chemical parameters involved in the calculation that adversely affect human beings consuming water beyond permissible limits (Brown *et al.,* 1970; Smith, 1990; Dojlido *et al.,* 1994; Stambuk-Giljanvoic, 1999; Pesce and Wunderlin, 2000; Nagel *et al.,* 2001; Sargaonkar and Deshpande, 2003; Kannel *et al.,* 2007; Nasirian, 2007; Singh *et al.,* 2008; Chaurasia *et al.,* 2018; Filho and Brandão de Oliveira, 2021; Gupta and Gupta, 2021).

The present work aims to bring out the suitability of groundwater for its consumption in Bundelkhand, central India, based on the hydrogeochemical analysis of 41 pre-monsoon (May-June, 2017) groundwater samples using GwQI integrated with the GIS techniques with IDW interpolation.

Study Area

The area falls in Jhansi (Uttar Pradesh) and Tikamgarh (Madhya Pradesh) sub-humid regions of Bundelkhand, central India, spreading over 1150 km^2 (254'15” N - 2522'00” N and 7854'20” E - 7915'00” E

(Toposheets 54K/15, 54K/16, 54O/3 and 54O/4, Survey of India), and are traversed by Sukhnai, Saprar, Kurar and Ur rivers (Fig. 1). Topographically, homogenous dissected uplands representnorth-eastern slopes on older eroded-surfaces ingranites/granitoidsof the Bundelkhand Gneissic Complex (BGC) of Archaean to Proterozoic times, covered by Newer Alluvium consisting of sand, silt and clay of Holocene times (Fig. 2; Basu 1986; Singh *et al.,* 2018; Ranjan, 2020).

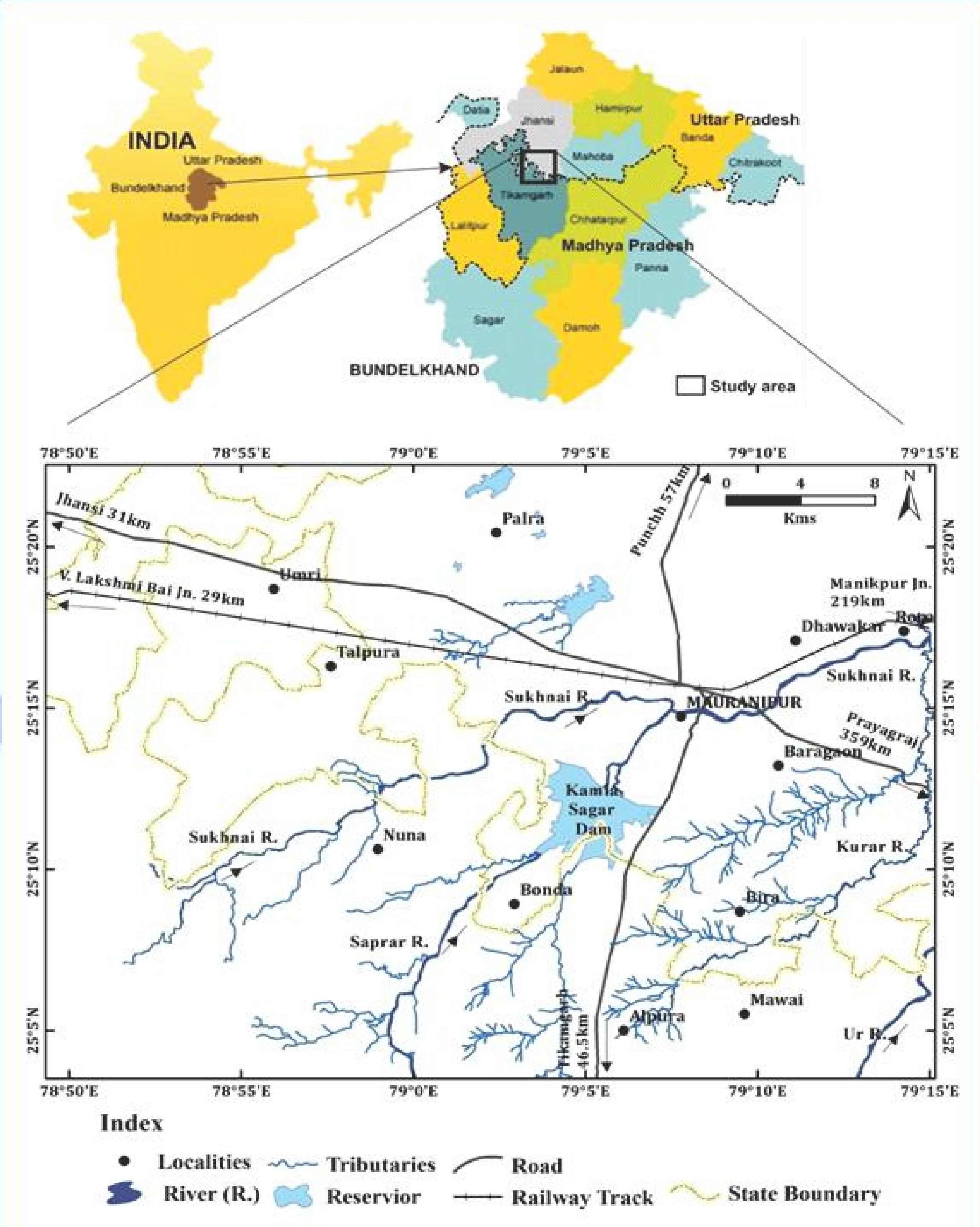


Fig. - 1. Map showing location map of the study area.

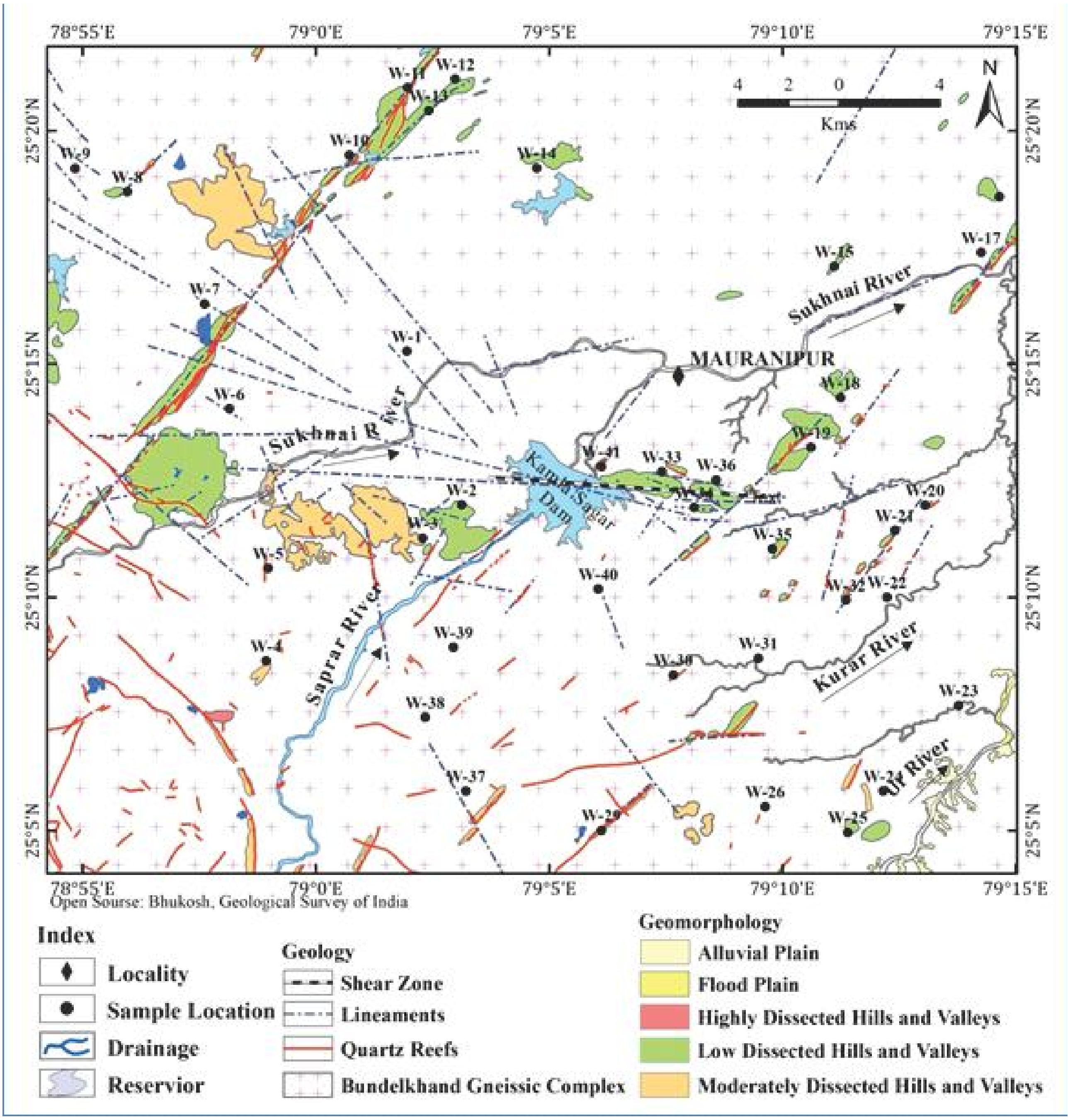


Fig.- 2. Map showing lithology, geomorphology and sample locations of the study area.

Material and Methodology

Forty-one groundwater samples were collected during pre-monsoon (June, 2017) in high-density polypropylene bottles (rinsed thoroughly with the water being sampled), drafted from tube/bore-wells and recorded the 'GPS co-ordinates' of sample location. Standard procedures (APHA 2005) were followed to analyse physico-chemical parameters using soil/water analyser for pH, 'electrical conductivity' (EC) and 'total dissolved solids (TDS), colourimetric titrations for 'total hardness' (TH), Ca^{+2}, Mg^{+2} and HCO_3^-, Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) for Na^+ and K^+, Spectrophotometer for SO_4^{-2} and Ion Selective Electrodes (for fluoride F^- and Cl^-). The zonation map has been prepared to show groundwater quality using 'spatial analyst's tool' using multi-user licenced ESRI Arc-GIS (10.2 version). Table 1 and Table 3 show detailed statistical summary of the analysed samples and the 'correlation matrix' of the analysed physico-chemical parameters, respectively.

Table - 1. Brief statistical summary of groundwater quality parameters.

S. No.	Parameters (in mg/l except pH and EC)	Minimum	Maximum	Mean	Standard Deviation
1	pH	6.5	**8.8**	7.35	0.52
2	EC (µS/cm)	257	**4250**	917.21	671.61
3	TDS	129	**2120**	458.63	335.77
4	T.H.	48	**924**	177.75	151.87
5	Ca^{2+}	9.6	182.4	38.43	36.77
6	Mg^{2+}	1.92	**112.32**	19.59	17.93
7	Na^{+}	15	148	64.38	33.31
8	K^{+}	BDL	**161**	6.23	25.28
9	Cl^{-}	12.6	865	129.34	157.96
10	HCO_3^{-}	262.3	**835.7**	539.18	156.43
11	SO_4^{2-}	6	303	48.51	54.10
12	F^{-}	**0.13**	**2.55**	1.09	0.67
Note: BDL= Below Detection Limit and Values above permissible limits are shown in **bold** letters.					

Table -2. F^{-} values exceeding maximum permissible limit (>1.5 ppm) in groundwater samples.

S. No.	Districts	Name of Locality	F-values (>1.5 mg/l)
1.	Jhansi (U.P.)	Harkanpura (GWS-1)	2.39
		Basari (GWS-2)	2.55
		Bagora (GWS-3)	2.09
		Talpura (GWS-7)	1.89
		Khadiyan (GWS-33)	2.01
		Narayach (GWS-6)	1.84
		Rora (GWS-17)	1.55
		Baragaon (GWS-19)	1.53
		Mathupura (GWS-22)	1.80
		Bijarwara (GWS-30)	1.58
		Chitaud (GWS-34)	1.74
2.	Tikamgarh (M.P.)	Kalothara (GWS-9)	1.83
		Kanera (GWS-40)	2.28

Table -3. Correlation matrix of groundwater quality parameters.

Variables	pH	EC	TDS	T.H.	Ca	Mg	Na	K	Cl	HCO_3	SO_4	F
pH	1											
EC	*-0.52*	1										
TDS	*-0.52*	1	1									
T.H.	*-0.45*	**0.95**	**0.95**	1								
Ca	*-0.45*	**0.86**	**0.86**	**0.93**	1							
Mg	*-0.36*	**0.88**	**0.88**	**0.89**	**0.66**	1						
Na	-0.13	**0.45**	**0.45**	**0.31**	0.20	**0.38**	1					
K	0.17	-0.04	-0.04	-0.07	-0.11	-0.01	**0.44**	1				
Cl	*-0.52*	**0.98**	**0.98**	**0.95**	**0.90**	**0.82**	**0.45**	-0.03	1			
HCO_3	-0.12	0.15	0.15	0.02	-0.11	0.17	0.24	-0.10	0.01	1		
SO_4	*-0.47*	**0.96**	**0.96**	**0.92**	**0.85**	**0.82**	**0.45**	0.02	**0.96**	0.01	1	
F	**0.34**	-0.26	-0.26	*-0.34*	*-0.51*	-0.08	0.15	0.22	-0.31	0.24	-0.26	1
Note: **Bold**= Positively correlated; and *Italic* = Negatively correlated												

Groundwater Quality Parameters

As per the standards defined by the BIS (2015), the values of pH in the samples from Basari (25°11'59"N, 79°03'07"E), Umri (25°18'42"N, 79°55'58"E), and Rora (25°17'24"N, 79°14'16"E) are above the permissible limit of 8.5. The EC in the samples range from 257 to 4250 µS/cm around Chikara (25°18'35"N, 79°14'40"E) and Bonda (25°08'56"N, 79°02'57"E), which are beyond the permissible limits (300 µS/cm). TDS in the samples, in general, vary from 129 to 2120 mg/l except Chikara and Bonda where it becomes nearly 'brackish' (>2000mg/l). The HT in samples ranges from 48 to 924 mg/l except Bonda where it is beyond the permissible limits (2000 mg/l). Calcium(Ca^{+2}) in samples ranges from 9.6 to 182.4 mg/l (within permissible limits, i.e., 200 mg/l), whereas Magnesium (Mg^{+2}) ranges from 1.92 to 112.30 mg/l, i.e., beyond the permissible limit (30 mg/l) at Chikara, Birpura (25°07'26"N, 79°02'21"E), Bijarwara (25°08'20"N, 79°07'40"E) and Bonda. Sodium (Na^{+}) values range from 15 to 148 mg/l, i.e., within permissible limit (200 mg/l), whereas Potassium (K^{+}) remains below detection limits in one but ranges above 161 mg/l, i.e., much above the standard limit of 12 mg/l at Bagora (25°11'16"N, 79°02'18"E) and Umri. Concentration of bicarbonate (HCO_3^{-}) ions ranges from 262.3 to 835.7 mg/l, except Panchampura (25°11'26"N, 79°12'25"E) and Dhawakar (25°17'06" N, 79°11'07"E) where its concentration is above the permissible limit (300 mg/l). Chloride (Cl^{-}) ranges from 12.6 to 865 mg/l, i.e., within permissible limits (250-1000 mg/l). Sulphate (SO_4^{-2}) ranges from 6 to 303 mg/l. Fluoride (F^{-}) spatially varies from 0.13 to 2.55 mg/l going beyond tolerance limits (1 to 1.5 mg/l) at 13 localities (Table 2).

Computation of GwQI

GwQI was computed considering 12 determinants as 'groundwater quality parameters' to determine their values compared to the BIS (2015) standards following the 'weighted arithmetic index method' (Brown *et. al.,* 1972) for calculating GwQI of the samples in 4 stages (Raju *et al.,* 2015; and Chaurasia *et al.,* 2018).

(i) **Calculation of Relative Weight (W):** The weightage (w_i) was assigned to the key physico-chemical parameters as per its importance in affecting the potability of groundwater. The maximum weightage of 5 was assigned to F^{-} due to its prevailing deleterious impacts on human health and vital role in the water quality assessment. The relative weight (W_i) is calculated using:

where, w_i= weight of each parameter and n = number of parameters

(ii) **Calculation of Unit Weight (W_n):** The W_n shows inverse relation to specified permissible/standard values of S_n for each parameter, which is calculated using:

$$W_n = K/S_n$$

where, K= proportionality constant

The w_i and W_i values of proportionality constant (K value) and W_n for each parameter are shown in Table 4.

(iii) **Calculation of Quality Rating or Sub Index (q_n):** The value of q_n for each parameter was calculated by dividing its concentration in each groundwater sample (V_n) by the standard upper/permissible limit (S_n) of respective BIS (2015) parameter (in mg/l) and the resultant is multiplied by 100:

$$q_n = (V_n/S_n) \times 100$$

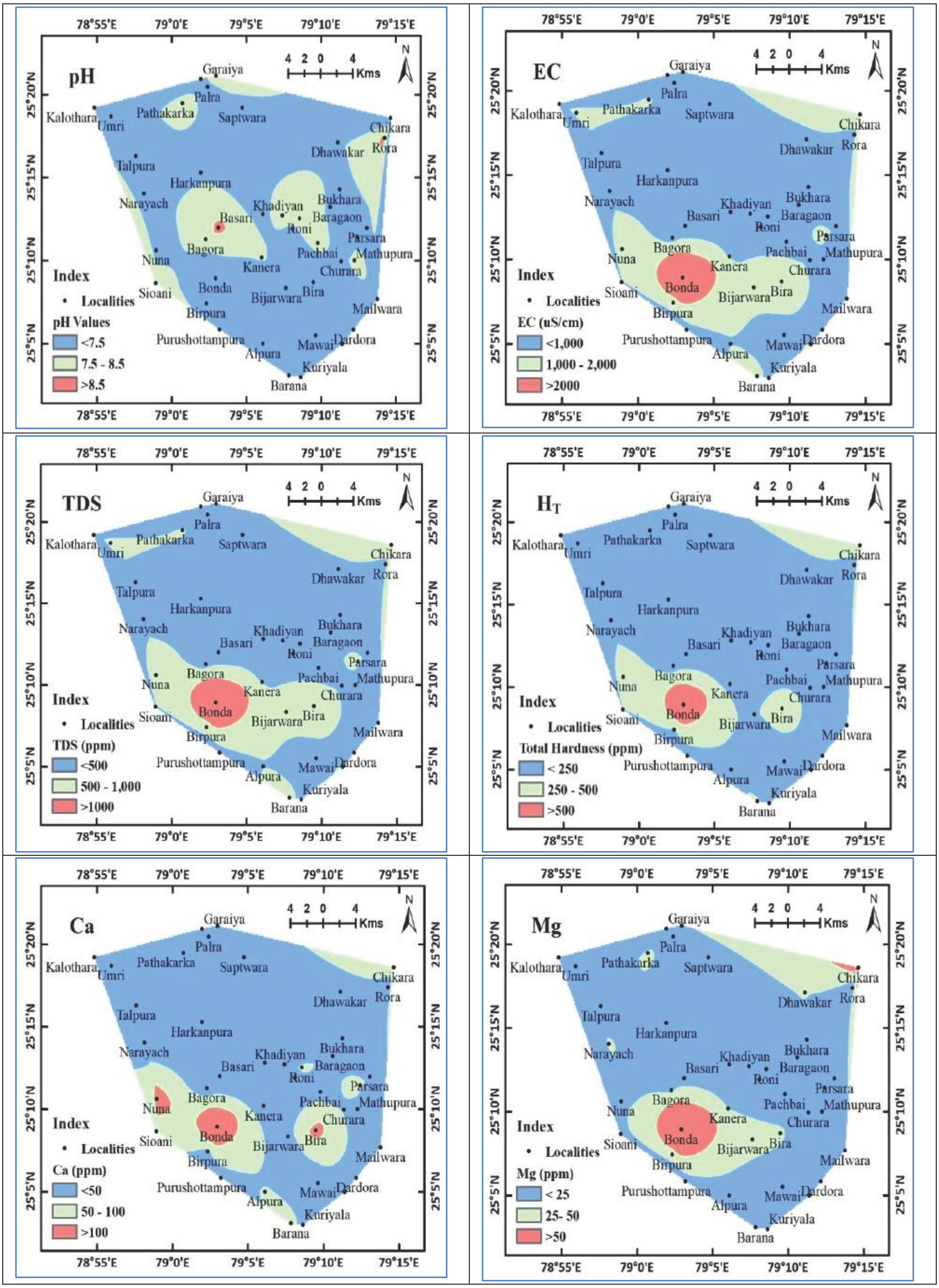
(iv) **Calculation of GwQI:** Hence, GwQI is the sum of the aggregation of Quality Rating with Unit Weight.

$$GwQI = \Sigma(q_n \times W_n) / \Sigma W_n$$

Result and Discussion

The spatial distribution maps of parameters like pH, EC, TDS, H_T, Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, HCO_3^{-}, SO_4^{-2}, Cl^{-}, and F^{-} were considered for groundwater quality assessment using IDW spatial interpolation method. The zonation in the spatial distribution maps (Fig. 3) is categorised on the basis of equal intervals among concentrations of determinants. It shows that except $Ca^{+2,}$ Na^{+}, SO_4^{-2} and Cl^{-} (in a few samples), other determinants are beyond upper acceptable BIS limits (2015) with F^{-} as the most contaminant anion, crucial for the assessment of groundwater quality index (Table 2). The ionic dominancy trend of cations and anions in the samples is $Na^{+} > Ca^{+2} > Mg^{+2} > K^{+}$ and $HCO_3^{-} > Cl^{-} > SO_4^{-2}$.

The correlation matrix (Table 3) calculated for all 12 parameters reveals that EC displays positive correlation with the groundwater quality influencing chemical parameters (TH, Ca^{+2}, Mg^{+2}, Na^{+}, Cl^{-}, and SO_4^{-2}). F^{-}, however, has been found directly proportional to alkalinity (pH >7.5) and inversely proportional to Ca^{+2}. It also attests that alkaline water (>7.5 pH) dissolves more F^{-}.



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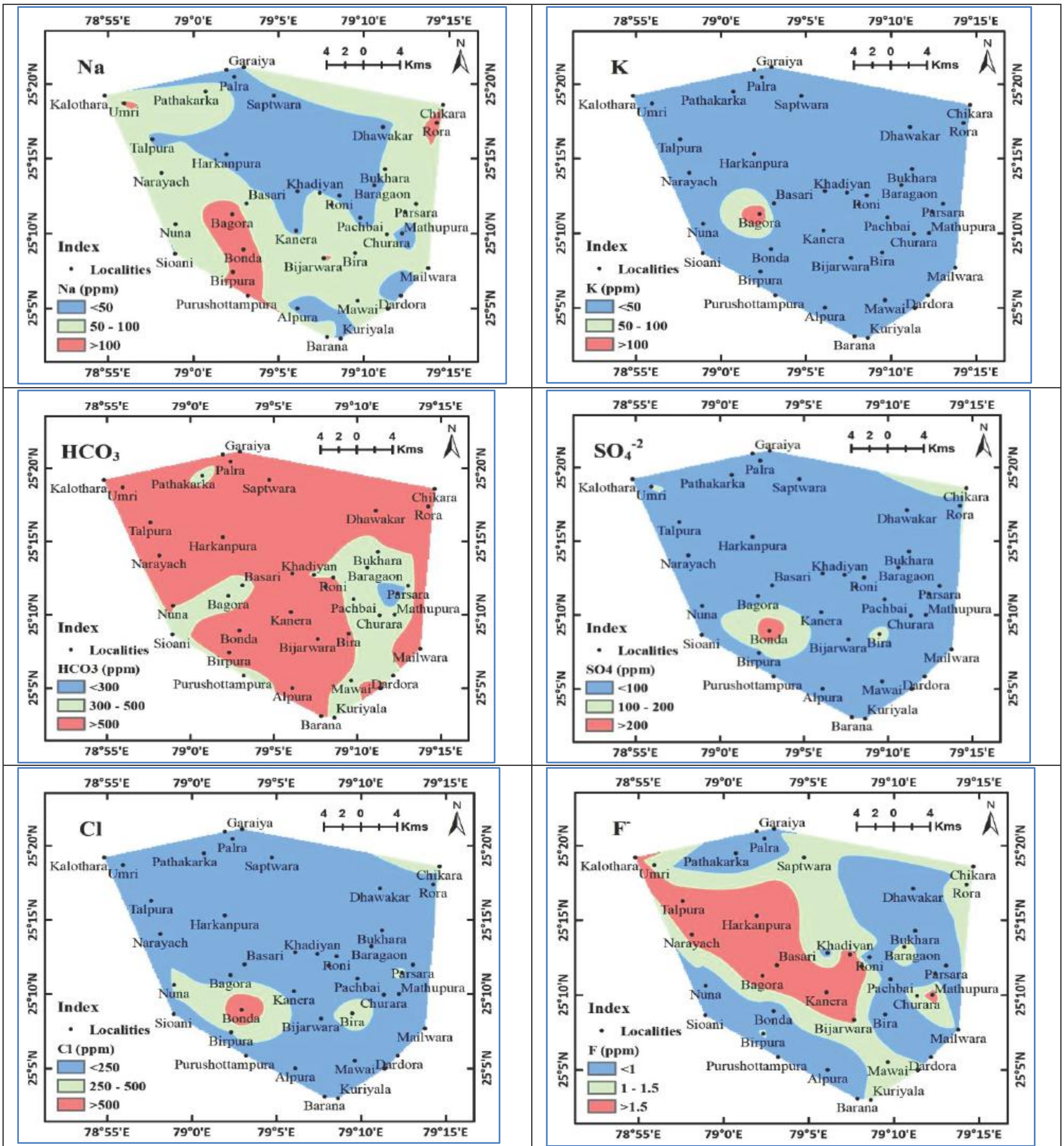

Continue to Fig. 3. Spatial distribution maps of Na^+, K^+, HCO_3^-, SO_4^{-2}, Cl^- and F^-

Fig.-3. Spatial distribution maps of pH, EC, TDS, H_T, Ca^{+2}, and Mg^{+2}

Fig.3 reveals undesirable concentrations of all concerned quality parameters from 'unconfined granitic aquifer' around Bonda, Basari, Bagara and Birpura (south-western part of the area). It shows that 'low-precipitation' of the region is the main reason for increase in salinity in groundwater, which in turn dissolves more 'undesirable solids' and affects its drinking quality. Moreover, the areas affected with undesirable concentrations of constituents lie on the left flank or the down-stream of Saprar river (Fig. 2) where the stream laid down significant amounts of salts and precipitates due to weathering and evaporation of surficial waters into the shallow depth aquifers through percolation and down tickling process. As such, the F-values (>1.5 mg/l) occur in the shallow aquifers underlying in the central parts (Fig. 3), along the NW-SE lineaments (joint, fracture and shear zones), across the course of Saprar and Sukhnai rivers (Fig. 2).

When plotted on the Piper's diagram (Piper, 1944), the 'quality-indicating parameters' and correlation of analytical data revealassociation of 'high F^- values' with 'Na-K-HCO_3', 'Na-HCO_3', 'Ca-Mg-HCO_3' and 'Ca-Mg-Na-K-HCO_3' type of hydrogeochemical facies under alkaline medium (>7.5 pH) (Khatik *et al.,* 2012 and 2015) causing incessant release of F^- from minerals such as apatite, biotite, muscovite, hornblende, sericite, kaolinite and chlorite (hosting F) into subsurface water through ion-exchange processes, rock-water interaction amid longer retention of groundwater in the aquifers facing dryer conditions in the pre-monsoon season.

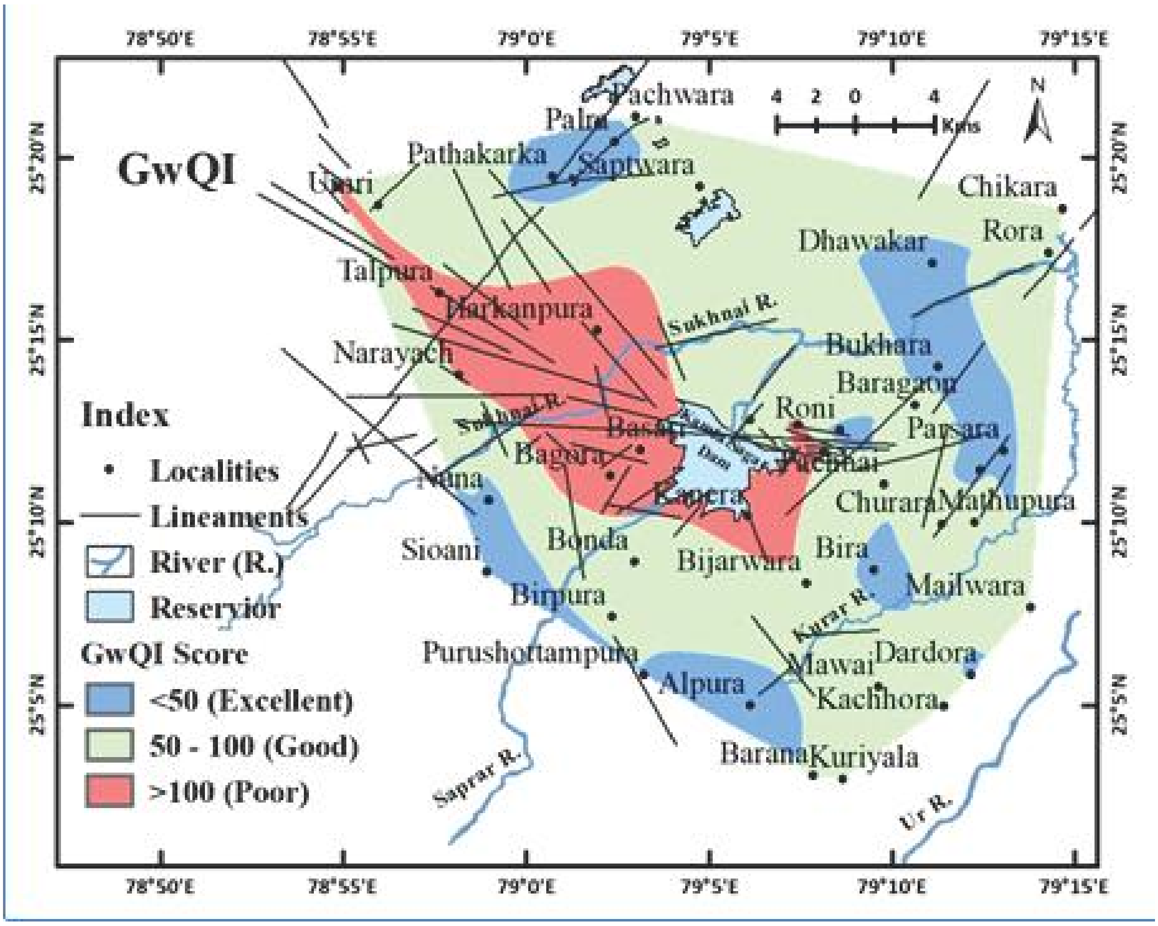

Fig. - 4. Groundwater Quality Index (GwQI) Map of study area.

Table - 4. Weightage (w_i), Relative Weight (W_i), Constant of proportionality (*K* value), and Unit Weight (W_n) for each parameters.

S. No.	Paramete rs	BIS Standard (2015)	Permissible Limit (S_n)	Weighta ge (w_i)	Relative Weight (W_i)	*K* value	Unit Weight (W_n)
1	pH	6.5-8.5	8.5	1	0.04	1.113197	0.130964334
2	EC	300	300	1	0.04	1.113197	0.003710656
3	TDS	500-2000	2000	3	0.12	1.113197	0.000556598
4	TH	200-600	600	2	0.08	1.113197	0.001855328
5	Ca^{2+}	75-200	200	2	0.08	1.113197	0.005565984
6	Mg^{2+}	30-100	100	1	0.04	1.113197	0.011131968
7	Na^+	50-200	200	2	0.08	1.113197	0.005565984
8	K^+	10-12	12	1	0.04	1.113197	0.092766403
9	HCO_3^-	300-600	600	1	0.04	1.113197	0.001855328
10	Cl^-	250-1000	1000	3	0.12	1.113197	0.001113197
11		1-1.5	1.5	5	0.2	1.113197	0.742131226
12	SO_4^{2-}	200-400	400	3	0.12	1.113197	0.002782992
				Σw_i=25	ΣW_i= 1		ΣW_n= 1

Table-5. Water quality classification based on Groundwater Quality Index (GwQI) Score (Ramakrishnaiah *et al*. 2009).

GwQI	Suitability
<50	Excellent Water
50-100	Good Water
100-200	Poor Water
200-300	Very Poor Water
>300	Not suitable for drinking

Table - 6. Classification of groundwater based on Groundwater Quality Index (GwQI).

Sr. No.	Sample Id	Locality	F^{-} (ppm)	GwQI Score	Water Quality
1	GWS-1	Harkanpura	2.39	136.48	Poor
2	GWS-2	Basari	2.55	141.51	Poor
3	GWS-3	Bagora	2.09	156.11	Poor
4	GWS-4	Sioani	0.36	32.86	Excellent
5	GWS-5	Nuna	0.38	34.21	Excellent
6	GWS-6	Narayach	1.84	104.52	Poor
7	GWS-7	Talpura	1.89	108.34	Poor
8	GWS-8	Umri	1.01	88.21	Good
9	GWS-9	Kalothara	1.83	103.59	Poor
10	GWS-10	Pathakarka	0.32	30.37	Excellent
11	GWS-11	Garaiya	0.38	31.77	Excellent
12	GWS-12	Pachwara	0.97	62.21	Good
13	GWS-13	Palra	0.38	32.02	Excellent
14	GWS-14	Saptwara	1.22	73.09	Good
15	GWS-15	Dhawakar	0.37	34.81	Excellent
16	GWS-16	Chikara	1.22	76.66	Good
17	GWS-17	Rora	1.55	92.43	Good
18	GWS-18	Bukhara	0.32	28.92	Excellent
19	GWS-19	Baragaon	1.53	88.43	Good
20	GWS-20	Parsara	0.42	33.74	Excellent
21	GWS-21	Panchampura	0.42	34.53	Excellent
22	GWS-22	Mathupura	1.80	102.22	Poor
23	GWS-23	Mailwara	0.94	59.99	Good
24	GWS-24	Dardora	0.69	46.48	Excellent
25	GWS-25	Kachhora	1.32	79.82	Good
26	GWS-26	Mawai	1.29	79.36	Good
27	GWS-27	Barana	0.81	55.00	Good
28	GWS-28	Kuriyala	1.22	73.63	Good
29	GWS-29	Alpura	0.29	27.66	Excellent
30	GWS-30	Bijarwara	1.58	92.86	Good
31	GWS-31	Bira	0.21	32.86	Excellent
32	GWS-32	Churara	1.27	76.10	Good
33	GWS-33	Khadiyan	2.01	113.85	Poor
34	GWS-34	Chitaud	1.74	99.60	Good
35	GWS-35	Pachbai	0.79	52.49	Good
36	GWS-36	Roni	0.14	23.17	Excellent
37	GWS-37	Purushottampura	0.70	47.89	Excellent
38	GWS-38	Birpura	1.10	68.70	Good
39	GWS-39	Bonda	0.58	47.77	Excellent
40	GWS-40	Kanera	2.28	126.77	Poor
41	GWS-41	Kuraincha	0.76	50.85	Good

Fig. 4, a zonation map, shows IDW interpolation of GwQI data using spatial analyses that helped in categorizing 'Excellent', 'Good' and 'Poor' (Table 5) groundwater conditions on the basis plotting of 12 quality parameters (Table 6). In general, groundwater is suitable for drinking purpose except along a NW-SE lineament zone passing through Harkanpura (GWS-1), Basari (GWS-2), Bagora (GWS-3), (GWS-6), Talpura (GWS-7), Kalothara (GWS-9), Mathupura (GWS-22), Khadiyan (GWS-33) and Kanera (GWS-40) localities where 'Poor' conditions are existing due to high F^- (>1.5 mg/l, Fig. 3 and 4).

Conclusion

For evaluation of groundwater quality, analysis and GIS framework based GwQI model has been developed for 41 groundwater samples from the Bundelkhand craton in order to match their qualities as per the BIS standards (2015).

At first, 12 parameters were analysed for developing 'spatial distribution patterns' using IDW interpolation (geo-statistical analyses). The hydrogeochemistry based on these parameters showed that the concentration of Na^+ is more than alkali earth metals, whereas, bicarbonates are more than anions that make the groundwater quality to range from 'neutral' to 'slightly alkaline' and pH, EC, TDS, H_T, Mg^{+2}, K^+ and HCO_3^- show prognostic relation with F^-. Thus, using such concerned 'quality parameters' developed GwQI model by assigning each of them a weightage through 'decision-making' and validating our knowledge as per their effect on the human health. Later, such mathematical algorithm was used to calculate the 'Relative Weight', 'Unit Weight', 'Quality Rating' and finally compute the 'GwQI' Score. Accordingly, each groundwater sample was recognized as 'Excellent', 'Good' or 'Poor' for drinking as per its 'GwQI' score (Table 5 and Table 6). The GwQI zonation maps were developed based on the three categories, which helped revealing that the habitants dwelling in the 'zone of poor quality groundwater (central to north-western parts)' are exposed to high F^-.

The study also shows that in shallow aquifers along the weathered/weak-zones (jointed, fractured, and sheared parts), incidences of high F^- are causing fluorosis because of longer 'rock-water interaction', particularly under alkaline conditions that dissolve F^- minerals. Apart from the affected parts, groundwater may be withdrawn from remaining studied area for drinking and domestic uses.

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