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Evaluation of Groundwater Quality Index (GwQI) of Groundwater in Chhindwara District, Central India

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Abstract : Groundwater Quality Index (GwQI) provides a 'single number' that expresses overall quality of groundwater at a 'location and time' based on several 'water quality parameters'. The objective is to turn 'complex quality data' into information that is understandable and usable by the people and the agencies monitoring the quality of groundwater. Twelve hydrogeochemical parameters (pH, EC, TDS, TH, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, F^{-} -HCO_3 and SO_4^{2-}) were selected to calculate the GwQI in order to assess, for the first time, the impact of both 'geogenic' as well as 'anthropogenic' activities for better monitoring of the quality of groundwater in Chhindwara district of Madhya Pradesh, India.

Key Words: Hydrogeochemical parameters, Groundwater Quality Index (GwQI), groundwater and Chhindwara.

Introduction

Groundwater is a vital source of drinking water throughout the earth but its resources are diminishing fast due to its ever-rising consumption in agriculture, industry and domestic areas. Besides, increasing concentrations of certain elements, beyond the permissible limits as defined by the World Health Organisation (WHO), is rendering it unpotable for drinking purposes. As per an estimate, ~80% of the diseases in the world are due to consumption of 'poor-quality/unhygienic water' (WHO, 1984).

Qualitatively, the groundwater conditions in Madhya Pradesh were supposed to be better compared to the rest of India, but the 'upcoming reports' are showing that many districts of the state are getting affected by 'water-borne ailments' (Chaterjee and Mohabey, 1998) despite the fact that there are no major industries in the region. Groundwater quality in Chhindwara district is deteriorating more by increase in fluoride (F_{-}) due to its release from granitic rocks under 'alkaline groundwater-soil regime' (Khatik *et al.,* 2012 and 2015).

Assessment of the suitability of water for drinking-purposes requires evaluation of its quality. Different methods developed to express water quality include the Water Quality Index (WQI, i.e., a rating reflecting the composite influence of different water quality parameters, is an effective way). Horton (1965) showed suitability of water for 'human consumption' in a 'single score'- 'Excellent', 'Good', 'Poor', 'Very Poor' and 'Unsuitable'- that people/policy-makers can understand better. The concept was furthered by Brown *et al*. (1970). More methods were developed to derive 'WQI scores' (Tyagi, *et al.,* 2013). A 'Weighted WQI' score is used in which the 'ratios of concentrations' of 'water-quality parameters' and their 'recommended standard values' are weighted and combined into a single-number. 'Groundwater quality studies' have been attempted for applications of the 'Weighted Groundwater Quality Index' (GwQI; Alastal *et al.,* 2015; Sahu and Sikdar 2008; Rabeiy, 2018; Kawo and Karuppannan, 2018). The other methods used to derive WQI/GwQI scores are similar except the 'number of parameters' (observations) used and their corresponding 'Weights'.

Genesis, evolution and future validity of the tool endorse the potability of water and the GwQI for its drinking purposes by calculating the score for each sample that reflects the 'combined-influence' of discrete 'physicochemical parameters' involved in the calculation that adversely affect human beings who consume 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 study aimed to assess the 'geochemical quality' of groundwater obtained from analysis of water through samples collected from bore-wells from 21 villages in Chhindwara in the pre- and post-monsoon seasons (2008-09) to:

(i) evaluate their suitability for human consumption using the GwQI method;

(ii) find out 'spatial-distribution' of the groundwater-quality; and

(iii) evaluate the 'evolution of groundwater quality' in both the seasons.

The groundwater-quality of the study area has been attempted based on 12 quality parameters *viz.* hydrogen ion-concentration (pH), electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), sulphate (SO_4^{2-}), chloride (Cl^{-}), fluoride (F^{-}) and bicarbonate (HCO_3)in the water-samples, using the 'weighted arithmetic index method' (Tiwari and Mishra, 1985).

Materials and Methods

The groundwater-samples were collected from the various parts of Chhidwara district (Fig. 1) as per the standard operating procedures prescribed by APHA (1995) in the pre- and post-monsoon periods in 2008-09. The locations were marked on the map using 'global positioning system' (GPS). The values of TH and concentrations of Ca^{2+}, Mg^{2+}, HCO_3^{-} and Cl^{-} were detected through 'titrimetric/colorimetric-methods'; Na^{+} and K^{+} - using flame-photometer; and SO_4^{2-}; NO_3^{-} using 'ultraviolet' (UV) spectrophotometer and F^{-} using ion-meter in the Earth Science Laboratory of the Indian Institute of Technology (IIT), Mumbai and in the Central Water Commission Laboratory, New Delhi. The statistical analysis of the analyzed groundwater samples is given in Table 1.

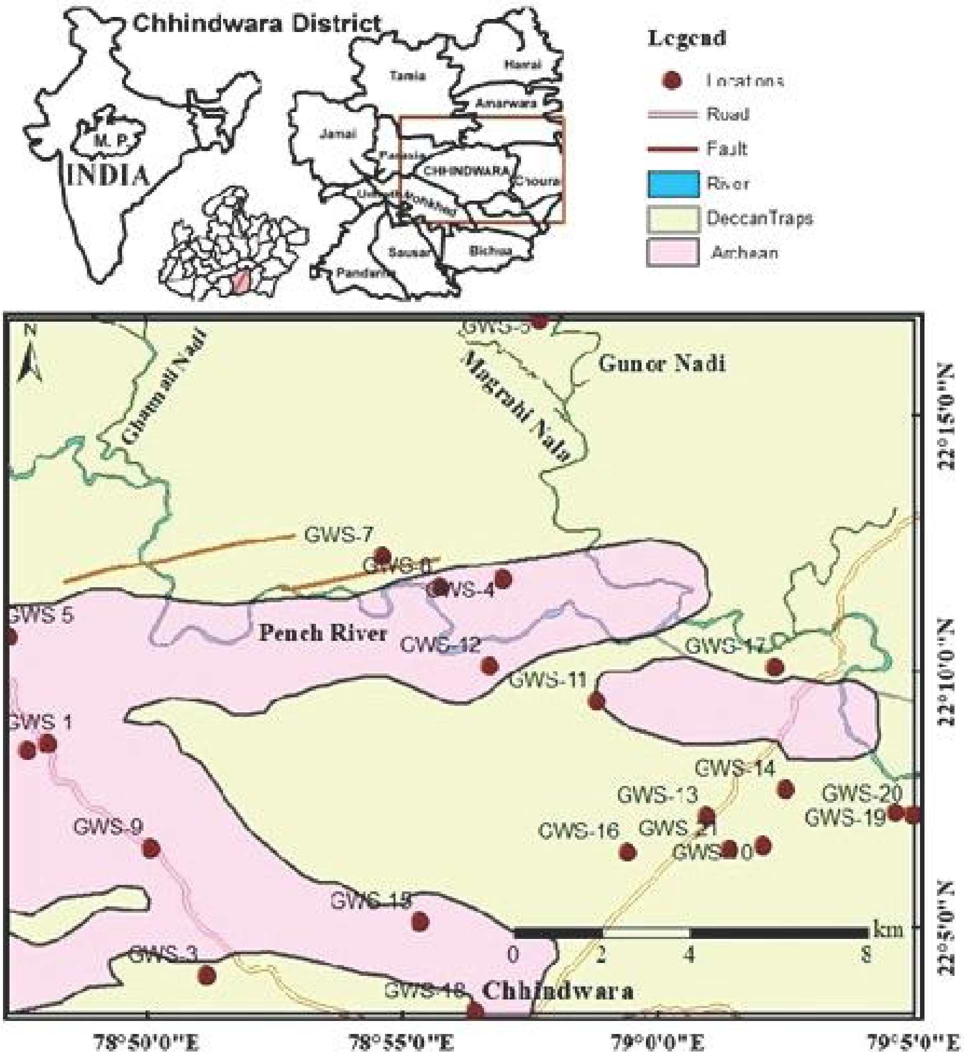

Fig. 1: Location map of the study area.

Table -1. The parameter of statistical analysis of the physico-chemical groundwater quality parameters in the pre- and post-monsoon seasons.

S. No.	Parameter In mg/l except pH & EC (µS/cm)	Pre-monsoon Period				Post-monsoon Period			
		Min.	Max.	Mean	Std. Dev.	Min.	Max.	Mean	Std. Dev.
1	pH	6.5	8	7.486	0.345	6.4	9.3	7.389	0.91734
2	EC	201	1031	558.41	248.099	348	1236	711.86	274.581
3	TDS	128.64	659.84	357.38	158.784	222.72	791.1	455.593	175.732
4	TH	28.5	522.5	301.86	131.381	49.4	604.2	295.018	176.621
5	Ca^{2+}	19	98.8	57	22.343	6.08	91.2	41.847	27.865
6	Mg^{2+}	BD	70.68	38.456	19.217	8.21	93.02	45.695	27.277
7	Na^{+}	8.1	116.7	38.078	26.671	11.83	112	46.061	32.187
8	K^{+}	0.34	22.15	4.839	5.558	0.15	99.4	6.8345	27.007
9	HCO_3^-	228.7	594.75	393.725	77.583	36.6	384.3	185.46	95.035
10	SO_4^{2-}	1.8	210	48.514	48.245	2.9	62	32.918	18.808
11	Cl^-	5.54	85.28	29.765	22.557	5.54	31.4	17.035	9.0373
12	F^-	0.11	7.9	1.085	1.712	0.27	17	3.8245	5.1487

Note: Min.-minimum, Max.-maximum and Std. Dev.-Standard Deviation.

Result and Discussion

Major ion chemistry reveals that the concentrations of Ca^{2+}, Mg^{2+}, Na^+, K^+, F^-, Cl^-, HCO_3^- and SO_4^{2-} in groundwater are affected by the 'lithology', 'rate of flow' and 'duration of the rock-water interaction'. The statistical analysis shows that Ca^{2+} and $Mg^{2+}$are getting exchanged by Na^+ causing increase in F^- values in the water from the 'deep tube-wells' in the area (Table 1).

The 'groundwater quality parameters' *viz*. pH, EC, TH, TDS, Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, Cl^-, $SO_4^{2-}$and F^- were analyzed to evaluate the GwQI of groundwater from 21 villages along with the potability of groundwater for drinking purpose (Table 2 and 3).

Table 2: Weight (wi) and relative weight (Wi) of each parameter.

S. No.	Parameters	BIS Standard (2015)	Permissible Limit (S_n)	Weightage (w_i)	Relative Weight (W_i)
1	pH	6.5-8.5	8.5	3	0.09375
2	EC	300	300	3	0.09375
3	TDS	500-2000	2000	3	0.09375
4	TH	200-600	600	2	0.0625
5	Ca	75-200	200	2	0.0625
6	Mg	30-100	100	2	0.0625
7	Na	50-200	200	2	0.0625
8	K	10-12.00	12	3	0.09375
9	HCO3	300-600	600	1	0.03125
10	Cl	250-1000	1000	3	0.09375
11	F	1-1.5	1.5	5	0.15625
12	SO_4	200-400	400	3	0.09375
				Sw_i=32	SW_i=1

The 'hydrogeochemical facies' of the F^- bearing water, based on the trilinear/Piper-diagram (Piper, 1944), shows changes in 'groundwater geochemistry' in different aquifers in different seasons in Chhindwara district. The majority of samples show that 'Ca-Mg-HCO_3facies', in both the seasons, is associated with F^- rich (>1.5 mg/l) groundwater (Table 4 and Fig. 2).

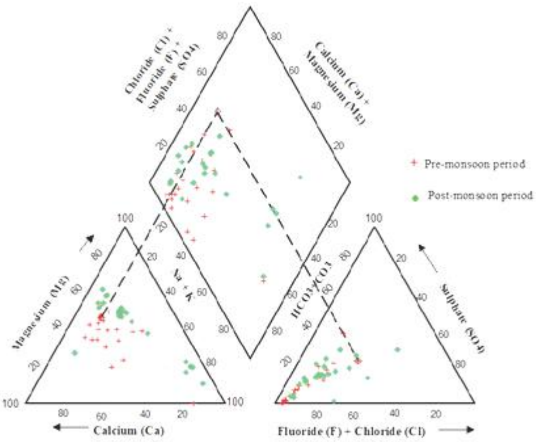

Fig.2 - Piper-plot showing the major ion composition of the groundwater samples in the pre- and post-monsoon seasons.

Table- 3. Classification of groundwater quality according to GwQI range with spatial distribution of GwQI in both the seasons.

WQI	Water Quality Class	Pre-monsoon periods		Post-monsoon periods	
		No. of samples	%	No. of samples	%
<50	Excellent	13	61.90	7	33.33
50-100	Good	4	19.05	5	23.81
100-200	Poor	3	14.28	2	9.52
200-300	Very Poo r	-	-	1	4.76
>300	Non-portable	1	4.76	6	28.57

Table – 4. Water quality index value with water-types for groundwater samples in the study area.

S. No.	SampleId	Locations	Pre-monsoon Period			Post-monsoon Period		
			WQI Value	Classification	Water-type	WQI Value	Classification	Water-type
1	GWS-1	Sonapipri	61.25	Good	Ca-Mg-HCO_3	154.65	Poor	Ca-Mg-HCO_3
2	GWS-2	Patha	177.02	Poor	Ca-Mg-CO_3	330.20	Non Potable	Ca-Mg-HCO_3
3	GWS-3	Kundalikalan	72.75	Good	Ca-Mg-HCO_3	73.75	Good	Ca-Mg-HCO_3
4	GWS-4	Babai	34.42	Excellent	Ca-Mg-HCO_3	37.95	Excellent	Ca-Mg-HCO_3
5	GWS-5	Khirsadoh	33.64	Excellent	Ca-Mg-HCO_3	45.73	Excellent	Ca-Mg-HCO_3
6	GWS-6	Urdhan	23.06	Excellent	Ca-Mg-sHCO_3	658.9	Non Potable	Na-HCO_3
7	GWS-7	Haranbhata	37.67	Excellent	Ca-Mg-HCO_3	87.971	Good	Ca-Mg-HCO_3
8	GWS-8	Palatwara	84.23	Good	Cl-Mg-K-HCO_3	559.35	Non Potable	Cl-Mg-K-HCO_3
9	GWS-9	Munga	101.05	Poor	Ca-Mg-HCO_3	357.15	Non Potable	Ca-Mg-HCO_3
10	GWS-10	Panjra	25.197	Excellent	Ca-Mg-HCO_3	293.24	Very Poor	Na-Cl
11	GWS-11	Seonimegha	45.631	Excellent	Ca-Mg-HCO_3	**856.28**	Non Potable	Ca-Mg-HCO_3
12	GWS-12	Kaparwari	83.627	Good	Ca-Mg-HCO_3	87.50	Good	Ca-Mg-HCO_3
13	GWS-13	Bangaon	**404.86**	Non Potable	Na-HCO_3	346.53	Non Potable	Cl-Mg-K-HCO_3
14	GWS-14	Ner	20.509	Excellent	Ca-Mg-HCO_3	33.82	Excellent	Ca-Mg-HCO_3
15	GWS-15	Khajri	25.514	Excellent	Cl -Mg-K-HCO_3	57.33	Good	Ca-Mg-HCO_3
16	GWS-16	Sarna	28.899	Excellent	Ca-Mg-HCO_3	31.73	Excellent	Ca-Mg-HCO_3
17	GWS-17	Rajakhoh	113.75	Poor	Ca-Mg-HCO_3	127.71	Poor	Ca-Mg-HCO_3
18	GWS-18	Chhindwara	30.835	Excellent	Ca-Mg-HCO_3	57.467	Good	Ca-Mg-HCO_3
19	GWS-19	Deverdhatolla	*19.324*	Excellent	Ca-Mg-HCO_3	30.4	Excellent	Ca-Mg-HCO_3
20	GWS-20	Karaghat	26.809	Excellent	Ca-Mg-HCO_3	*30.34*	Excellent	Ca-Mg-HCO_3
21	GWS-21	Khairibhutai	29.800	Excellent	Ca-Mg-HCO_3	34.54	Excellent	Ca-Mg-HCO_3

Note: Italic-Minimum and **Bold**.-Maximum.

Calculation of Groundwater Quality Index (GwQI)

Computation of GwQI has been done in the following 5 steps:

i. Each parameter is assigned a 'weight' (w_i) according to its 'relative-importance' in the overall quality of water for drinking purposes (Table 2) that ranges from 1 to 5 depending on the collective expert thoughts taken from previous studies. The F^-, due to its importance in 'water quality assessment' has been given the 'maximum weight', (i.e., 5), while the Cl^- being less-harmful was given 'minimum weight' (i.e., 1).

ii. The 'relative weight' (W_i) is computed using the equation (Horton, 1965; Brown, *et al*., 1972 and Tiwari and Manzoor, 1988):

$W_i = 1/\text{Sum of } w_i$

where, 'w_i' is the 'weight of each parameter 'for the 'number of parameters'. The W_i values of each parameter are given in Table 2.

iii. A 'quality rating scale' (q_i) for each parameter is assigned by dividing its concentration in each water-sample by its respective standard according to the guidelines laid down by BIS multiplied by 100 using the following equation and then by calculating the quality rating scale (q_i). Higher the value of q_i, more polluted will be the water.

$q_i = (C_i/S_i) \text{ X } 100$

where, 'C_i' is the 'concentration of each chemical parameter in each water sample (mg/l)' and the 'S_i' is the 'Indian Drinking Water Standard' for each chemical parameter (mg/l, BIS 10500 guidelines, 1991).

iv. The 'water quality sub-index' (SI) for each chemical parameter is determined using the equation:

$SI = W_i q_i$

v. Finally, the overall GwQI is calculated by adding together each SI value of each groundwater samples as per the equation (Ravi, *et al.,* 2013):

$GwQI = \sum SI_i$

where, 'SI' is the 'sub-index of i^{th} parameter'; the 'q_i' is the 'rating based on the concentration of i^{th} parameter' and 'n' is the 'number of parameters'. The interpretation of the calculated GwQI values is usually classified into five categories according to drinking purposes (Sahu and Sikdar 2008; Ramakrishnaiah *et al*., 2009; and Sharma and Patel, 2010, Table 3 of the study).

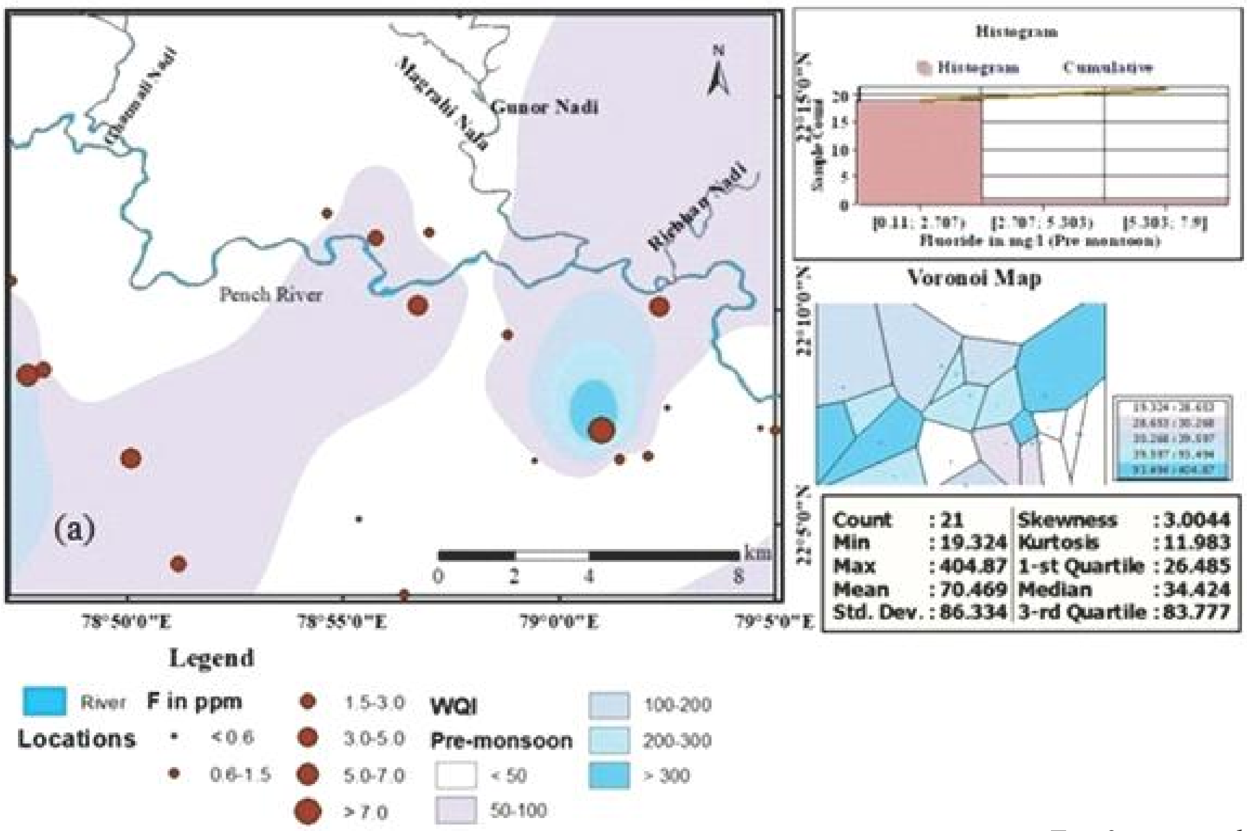

Fig. 3 continued ...

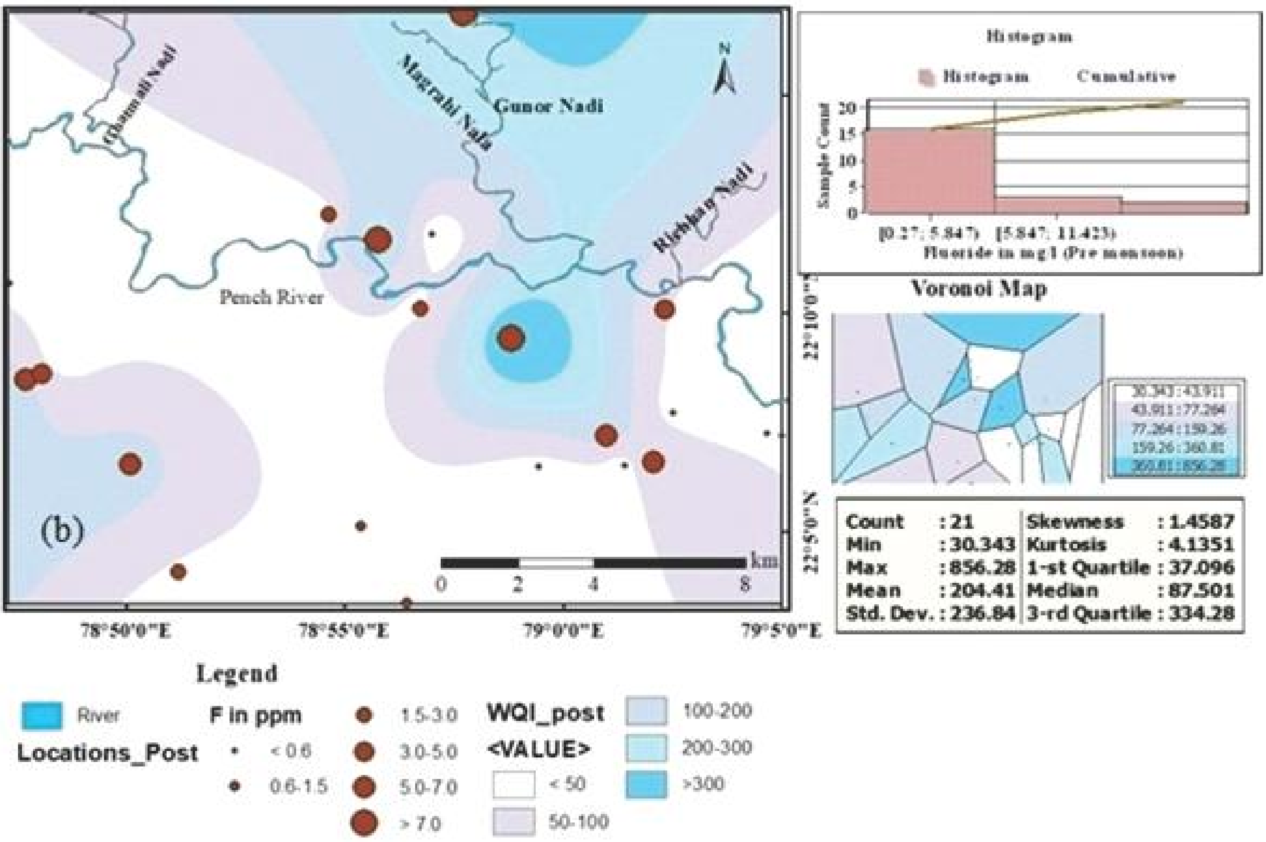

Fig. 3: Map of the spatial distribution of WQI scores based on data from (a) pre-monsoon season and (b) Post-monsoon seasons.

The GwQI spatial-distribution maps show that nearly 62% samples in the pre- and 33.33% in the post-monsoon seasons indicate 'Excellent' drinking-quality in the north-western and south-eastern areas (Fig. 3 and Table-4). However, 28% samples from the remaining area show 'Moderate' drinking-quality in both the seasons and 37% indicate 'Poor' drinking-quality (in the post-monsoon season, Table-3). The 'type of groundwater 'and ' GwQI' are shown in Table-4.

Conclusion

In this study, the reliable drinking GwQI system has been adopted to assess the water-quality using 12 relevant hydrogeochemical parameters for 'easy decision-making' by the monitoring bodies. It may be concluded that:

i) The chemical-weathering, occurring at relatively high-alkalinity (pH > 8.5 and above up to 9.5), is giving rise to release of more F^- ions in groundwater in both the seasons (Table 1);

ii) The extent of the 'Excellent' category water in the area is more in the pre-monsoon season compared to the post-monsoon. Nearly 29% samples show 'Poor' drinking quality in the post-monsoon season;

iii) The 'Excellent' drinking-quality occurs in the southern part (Fig. 3).

iv) The F_- concentration, is the main cause of deterioration in quality of groundwater in both the seasons and the north-eastern part the area is more prone to contamination compared to its southern part (Fig. 3); and

v) The GwQI shows sympathetic relation with 'shallow groundwater level' in southern part.

It may be suggested that priority be given to 'water quality monitoring and its management' in order to protect the groundwater resources getting contaminated, particularly in north-eastern parts of Chhindwara district.

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