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Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India

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Abstract An attempt has been made to understand the hydrogeochemical parameters to develop water quality index in Thirumanimuttar sub-basin. A total of 148 groundwater samples were collected and analyzed for major cations and anions. The domination of cations and anions was in the order of Na>Mg>Ca>K for cations and $Cl>HCO_3>SO_4$ in anions. The hydrogeochemical facies indicate alkalis (Na and K) exceed alkaline earths (Ca and Mg) and strong acids (Cl and SO_4) exceed weak acid (HCO_3). Water quality index rating was calculated to quantify overall water quality for human consumption. The PRM samples exhibit poor quality in greater percentage when compared with POM due to effective leaching of ions, over exploitation of groundwater, direct discharge of effluents and agricultural impact. The overlay of WQI with chloride and EC correspond to the same locations indicating the poor quality of groundwater in the study area. SAR, Na%, and TH were noted higher during both the seasons indicating most of the groundwater locations not suitable for irrigation purposes.

Keywords Groundwater geochemistry · Anthropogenic · Water quality index · Sodium percentage · Sodium adsorption ratio

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Introduction

Groundwater occurs almost everywhere beneath the earth surface not in a single widespread aquifer but in thousands of local aquifer systems and compartments that have similar characters. Knowledge of the occurrence, replenishment, and recovery of groundwater has special significance in arid and semi-arid regions due to discrepancy in monsoonal rainfall, insufficient surface waters and over drafting of groundwater resources. Groundwater quality depends on the quality of recharged water, atmospheric precipitation, inland surface water, and on sub-surface geochemical processes. Temporal changes in the origin and constitution of the recharged water, hydrologic and human factors, may cause periodic changes in groundwater quality.

Water pollution not only affects water quality but also threats human health, economic development, and social prosperity (Milovanovic 2007). River basins are highly vulnerable to pollution due to absorption and transportation of domes-

tic, industrial, and agricultural waste water; therefore, it is significant to control water pollution and monitor water quality (Simeonov et al. 2003; Simeonova et al. 2003). Various geostatistical concepts are used for the interpretation of complex data sets which allows a better understanding of the water quality parameters (Kumar and Ahmed 2003; Suk and Lee 1999; Isaaks and Srivastava 1989). Assessing risk involves identifying the hazard associated with a particular occurrence, action, or circumstance and determining the probability of that hazard occurring (Smith 2001). Hence, evaluation of groundwater quantity and quality is important for the development of further civilization and to establish database for planning future water resources development strategies.

The study area, Thirumanimuttar sub-basin, a hard rock terrain receives major part of rainfall from northeast monsoon. The surface water sources are generally precarious to get their supply during monsoon seasons and during nonmonsoonal periods people have to largely depend on groundwater resources for their domestic, agricultural, and industrial activities. About 70% of study area is dominated by local human activities and agricultural activities, the rest by industries manufacturing chemicals, paints, dying, bleaching, and bus body building which dispose industrial and hazardous wastes nearby agricultural lands which craft a major threat to the adjoining groundwater environments. Therefore, the study of behavior of aquifer in the study area results to be of priority importance. Hence, it has been proposed to characterize the hydrogeochemical processes activated in the study area, with reference to natural and manmade activities and to classify water on the basis of sodium percentage (Na%), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), total hardness (TH), and water quality index (WQI). A complete test to determine the WQI of a local body is vital to establish a continuing record for possible water remediation.

Study area

Thirumanimuttar sub-basin lies between North Latitudes 10°58′ and 11°48′ and East Longitudes 77°53′ and 78°28′ with a total drainage of about 2,438 km^2. River originates at Manjavadi in Salem district and configures river Cauvery at Paramathi velur in Namakkal district (Fig. 1). The mean annual temperature varies between 33°C to 45°C. The normal annual rainfall over the study area is about 1,590 mm. The geology of the area is underlined by rocks representing metasediments of Achaean age with charnockites, granitic gneiss, calc granulites, syenites, and ultra basics as major exposures. Thickness of weathered zone varies from 5 to 15 m along upstream and 3 to 30 m due downstream. The occurrence and movement of groundwater in the hard rocks are controlled by secondary porosity and groundwater occurs under water table to semi-confined condition. Hills, undulating plains, plateaus, pediments, and bazadas are the mixture of geomorphic units distributed throughout the study area. The water table fluctuation map was prepared by using map info (Version 8) GIS software for two different seasons (pre-monsoon (PRM) and post-monsoon (POM) season). During PRM, shallow water table are confined to granitic gneiss in the centre part of the basin, deep water table are noted along NE, NW, and southern part of the study area, dominated by charnockite, calc granulite and in regions of maximum groundwater extraction by urban, agricultural, and industrial activities. During POM increasing water table is noted in majority of locations due to precipitation during monsoon, but deeper groundwater levels are confined to the same location as in PRM indicating the massiveness of aquifers in charnockite and calc granulite region.

Materials and methods

A total of 148 groundwater samples were collected from bore holes ranging in depth between 20 and 120 m below ground level, for two different seasons, pre-monsoon and post-monsoon during January 2008 and May 2008, respectively. The samples were analyzed for Ca, Mg, Na, K, HCO_3, Cl, SO_4, PO_4, H_4SiO_4, F, pH, EC, and TDS by using standard procedures (APHA 1995). The pH, TDS, and EC were measured by Systronics Water Quality Analyzer 371. F was analyzed using portable Consort electrochemical analyzer model

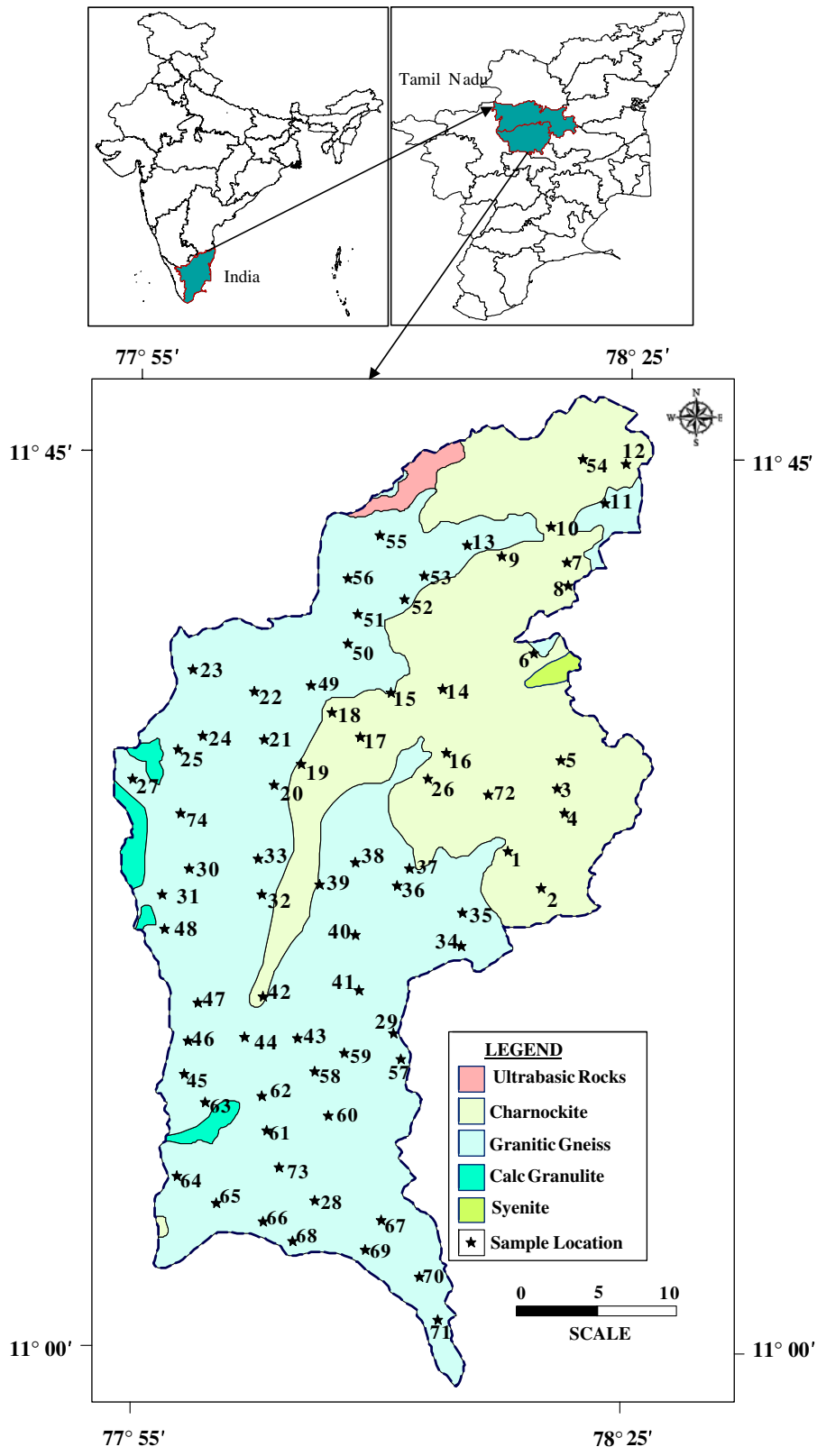

Fig. 1 Groundwater sample location and geology map of the study area

C933. SO_4, PO_4, and H_4SiO_4 were determined by digital spectrophotometer model GSS 700A (Electronic Corporation of India). Na and K were determined by using flame photometer (Systronics mk-1/mk-III). Ca, Mg, HCO_3, and Cl were analyzed by titrimetric method. The charge balance calculated was generally <10% and ratio of TDS/EC are within acceptable limits (0.8), confirming the reliability of the analytical results. Geochemical facies type, WQI, Na %, SAR, RSC, and TH were also determined.

Results and discussion

The statistics of the water chemistry is represented in Table 1. The EC values ranges from 473 to 5,453 μS/cm and 638 to 5,826 μS/cm during PRM and POM. EC showed increasing trend along the groundwater flow direction. Groundwater was generally acidic to alkaline with pH ranging from 6.9 to 9.22 and 7 to 8 during PRM and POM seasons, respectively. HCO_3 was higher during POM (1,068 mg/l) may be due to action of CO_2 upon the basic material of soil and granitic rock. Cl was higher in POM (1,730 mg/l) due to leaching from upper soil layers derived from industrial and domestic activities and dry climates (Srinivasamoorthy et al. 2008). SO_4 was higher in POM (758 mg/l) may be due to action of leaching and anthropogenic activities in a metamorphic environment by release of sulfur gases from industries and urban utilities get oxidized and enter into the groundwater system (Saxena 2004). PO_4 was within the permissible limit (1.5 mg/l) during both the seasons.

Fluoride was higher during PRM (4.2 mg/l) due to leaching of fluoride rich minerals like apatite, fluorspar, flourapatite, and biotite from rocks like charnockite, calc, and granulite gneiss dominantly present in the study area (Srinivasamoorthy et al. 2007). The easier accessibility of rainwater to weathered rock, long-term irrigation processes, semi-arid climate, and long residence time of groundwater enriches the fluoride in the groundwater of the study area (Srinivasamoorthy et al. 2008). The effect of dilution was well noted during POM. NO_3 was higher during POM (136 mg/l) and along highly agricultural areas maybe due to leaching from plant nutrient and nitrate fertilizers (Freeze and Cherry 1979; Madison and Brunett 1984).

Na was higher during PRM (1,497 mg/l) indicating weathering from plagioclase bearing rocks and also due to over exploitation (Hem 1985). K is higher in POM (322 mg/l) due to weathering of feldspar and clay minerals from aquifer matrix. Ca was higher during POM (464 mg/l) due to dissolution of precipitates of $CaCO_3$ and Ca Mg $CO_3)_2$ during recharge (Datta and Tyagi 1996; Lakshmanan et al. 2003). Mg was higher during POM (377 mg/l), which might have been derived from dissolution of magnesium calcite, gypsum, and dolomite from source rock (Garrels

Table 1 Statistics of chemical parameters (all in mg/l and EC in μS/cm) in groundwater for PRM and POM seasons, respectively

Parameters	PRM ($n = 148$)			POM ($n = 148$)		
	Min	Max	Std. Dev	Min	Max	Std. Dev.
pH	6.9	9.22	0.35	7.4	8.2	0.18
Ca	16	179.16	33.99	8	464	57.89
Mg	11.91	158.4	28.89	4.86	376.65	89.89
Na	0.8	1,497	330.71	8	598	164.52
K	0.8	277	55.53	1	322	60.86
HCO_3	73.22	893.84	164.10	91.5	1,067.5	24.04
PO_4	0.48	1.5	0.16	0.48	3.47	0.61
SiO_4	2	33	5.59	7	37	5.51
Cl	86.84	1,602.27	356.64	24	1,730	357.2
SO_4	1	126.8	27.90	25	758	180.4
NO_3	4	133	29.08	1	136	39.53
F	0.03	4.2	0.78	0.34	1	0.18
TDS	303	3,489.74	754.45	408	3,729	764
EC	473	5,452.71	1,178.71	638	5,826	1,193

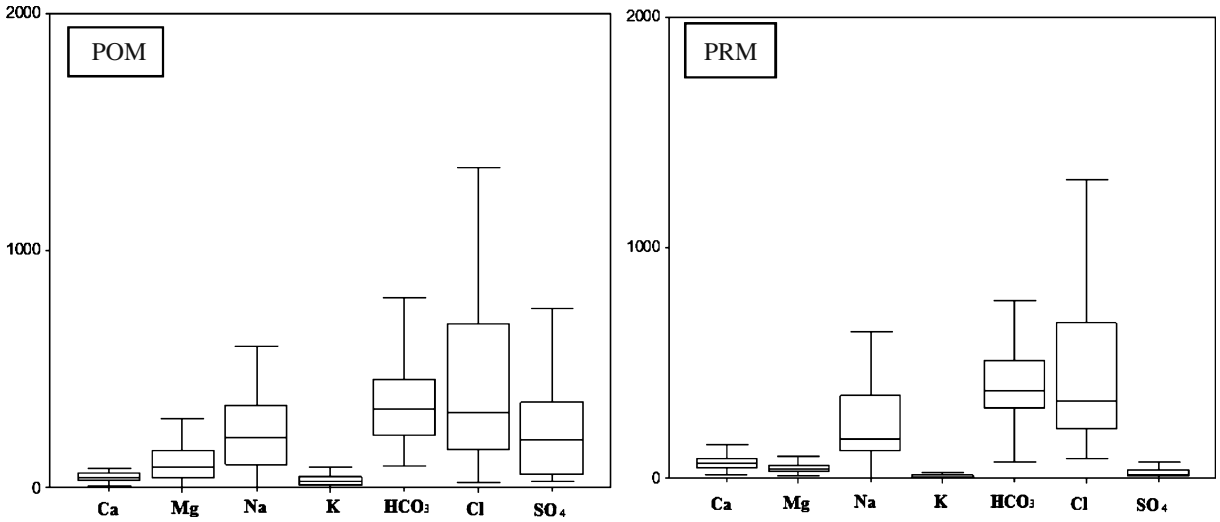

Fig. 2 Box plots for major ions (in mg/L) in POM and PRM seasons respectively

and Christ 1965). Total hardness of the groundwater ranges from 36.95–1,508.33 mg/l as $CaCO_3$.

Box plots were used to represent temporal concentration of the major ions (Fig. 2). The upper and lower quartiles of the data define the top and the bottom of a rectangle box. The line inside the box represents the median value and the size of the box represents the spread of the central value (Taheri Tizro and Voudouris 2008). Mg, K, and SO_4 shows increasing trend during POM, due to the effective leaching from rock matrix along with anthropogenic activities. Magnesium is derived

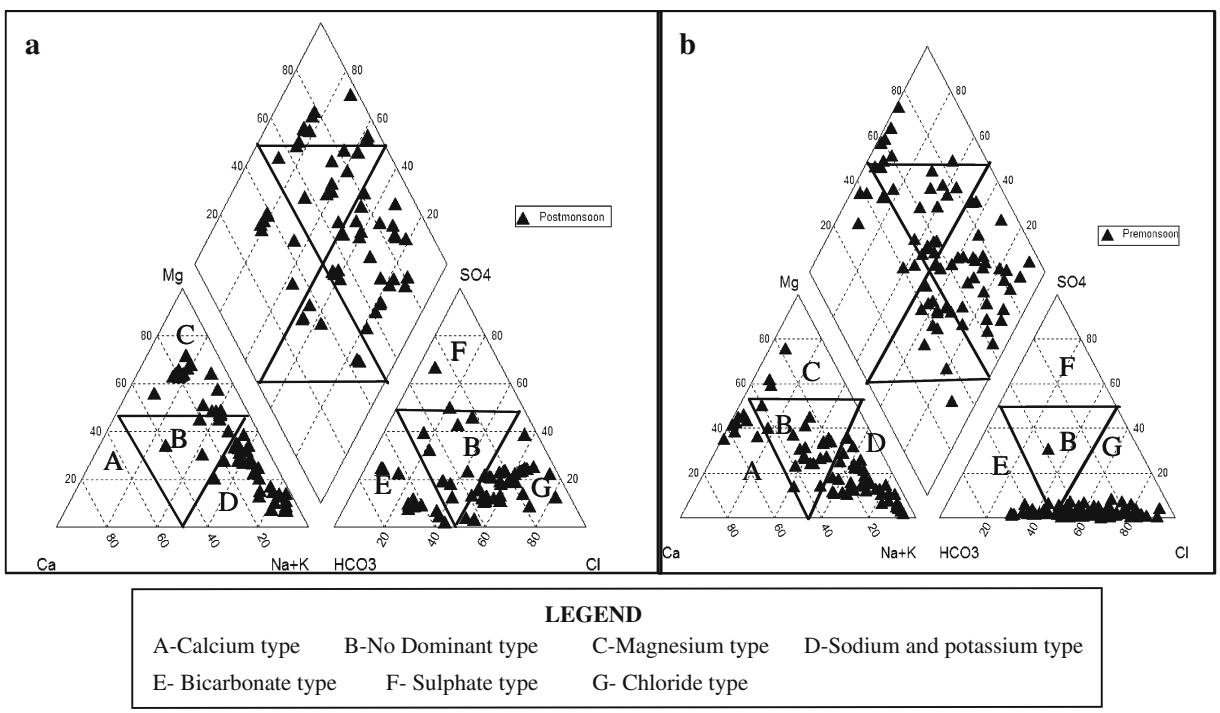

Fig. 3 **a**, **b** Piper trilinear diagram for POM and PRM seasons respectively

from calcium magnesium silicates chiefly from plagioclase feldspars, K derived from K-feldspars or K-bearing minerals like orthoclase, microcline, and biotite found in metasediments (Howari and Banat 2002) which are the major minerals identified from the litho units of the study area. Furthermore, the sources of SO_4 is known to derive from industrial effluents, automobile emissions, and phosphatic fertilizers in urban environments (Subbarao et al. 1996), since no lithogenic sources of sulfate noted in the study area.

Hydrochemical concepts can help to elucidate mechanisms of flow and transport in groundwater systems, and unlock an archive of paleoenvironmental information (Pierre et al. 2005; Ophori and Toth 1989; Hem 1992). Hill Piper plot (Piper 1953) is used to infer hydrogeochemical facies of groundwater. The plot shows majority of water samples irrespective of seasons fall in mixed Na-Cl type (Fig. 3a, b) with minor representations from mixed Ca-Mg-Cl, mixed Ca-Na-HCO_3, Ca-Cl, and Ca-HCO_3 types. From the plot, alkalis (Na and K) exceeds alkaline earths (Ca and Mg) and strong acids (Cl and SO_4) exceeds weak acid (HCO_3).

Groundwater quality parameters

Water quality for drinking purposes

Groundwater chemistry has been utilized as a tool to outlook water quality for drinking and irrigation purposes (Subba Rao 2006; Edmunds et al. 2002). WQI is an important parameter for demarcating groundwater quality and its suitability for drinking purposes (Tiwari and Mishra 1985; Singh 1992; Subba Rao 1997; Mishra and Patel 2001; Naik and Purohit 2001; Avvannavar and Shrihari 2008). WQI is defined as a technique of rating that provides the composite influence of individual water quality parameters on the overall quality of water (Mitra and ASABE Member 1998) for human consumption. The standards for drinking purposes as recommended by WHO (1993) and BIS 10500 (1991) have been considered for the calculation of WQI. For computing WQI three steps are followed. In the first step, each of the 12 parameters (TDS, HCO_3, Cl, SO_4, PO_4, NO_3, F, Ca, Mg, Na, K, and Si) has been assigned a weight (w_i) according to its relative importance in the overall quality of water for drinking purposes (Table 2).

The maximum weight of 5 has been assigned to the parameters like nitrate, total dissolved solids, chloride, fluoride, and sulfate due to their major importance in water quality assessment (Srinivasamoorthy et al. 2008). Bicarbonate and phosphate is given the minimum weight of 1 as it plays an insignificant role in the water quality assessment. Other parameters like calcium, magnesium, sodium, and potassium were assigned weight between 1 and 5 depending on their importance in water quality determination. In the second step, the relative

Table 2 Relative weight of chemical parameters

Chemical parameters	Indian Standard (BIS 10500 1991)	Weight (wi)	Relative weight $W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}$,
Total dissolved solids	500	5	0.116
Bicarbonate (mg/l)	–	1	0.023
Chloride (mg/l)	250	5	0.116
Sulphate (mg/l)	200	5	0.116
Phosphate (mg/l)	–	1	0.023
Nitrate (mg/l)	45	5	0.116
Fluoride (mg/l)	1	5	0.116
Calcium (mg/l)	75	3	0.070
Magnesium (mg/l)	30	3	0.070
Sodium (mg/l)	–	4	0.093
Potassium (mg/l)	–	2	0.047
Silicate (mg/l)	–	2	0.047
		$\Sigma w_i = 41$	$\Sigma w_i = 0.953$

Table 3 Comparison of groundwater quality with drinking water standards (Indian and WHO)

Parameters	ISI	Percent compliance		WHO	Percent compliance	
		POM	PRM	limits	POM	PRM
pH	6.5–8.5	100	98.6	7.0–8.0	97.30	85.14
Sp. conductivity (mS/cm at 25°C)	–	–	–	–	–	–
Total dissolved solids	500	97.29		1,000	28.38	32.43
Total hardness as $CaCO_3$ (mg/l)	300	59.46	36.50	–	–	–
Bicarbonate (mg/l)	–	–	–	–	–	–
Chloride (mg/l)	250	40.54	29.73	250	40.54	29.73
Sulphate (mg/l)	200	48.65	100	250	66.22	100
Phosphate (mg/l)	–	–	–	–	–	–
Nitrate (mg/l)	45	67.57	66.21	50	32.43	68.92
Fluoride (mg/l)	1	60.23	45.95	–	–	–
Calcium (mg/l)	75	85.14	59.46	75	85.14	59.46
Magnesium (mg/l)	30	9.46	25.68	30	9.46	25.68
Sodium (mg/l)	–	–	–	200	48.65	51.35
Potassium (mg/l)	–	–	–	–	–	–
Silicate (mg/l)	–	–	–	–	–	–

weight (W_i) is computed from the following equation:

$$W_i = w_i / \sum_{i=1}^{n} w_i$$

where

W_i is the relative weight
w_i is the weight of each parameter
n is the number of parameters

Calculated relative weight (W_i) values of each parameter are given in Table 3. In the third step, 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 in the BIS 10500 (1991) and the result is multiplied by 100:

$$q_i = (C_i / S_i) \times 100$$

where

q_i is the quality rating
C_i is the concentration of each chemical parameter in each water sample in milligrams per liter
S_i is the Indian drinking water standard for each chemical parameter in milligrams per liter according to the guidelines of the BIS 10500 (1991).

For computing the WQI, the SI is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation

$$\mathrm{SI}_i = W_i \times q_i$$
$$\mathrm{WQI} = \sum \mathrm{SI}_i$$

where

SI_i is the sub-index of ith parameter
q_i is the rating based on concentration of ith parameter
n is the number of parameters

Water quality types, were determined on the basis of WQI. The computed WQI values ranges from 37.94 to 298.96 and 41.35 to 291.94 for POM and PRM, respectively. The WQI range and type of water can be classified in below:

Range	Type of water
< 50	Excellent water
50–100.1	Good water
100–200.1	Poor water
200–300.1	Very poor water
> 300	Water unsuitable for drinking purposes

The chemical analysis of groundwater and the percent compliance with ISI and WHO is represented in Table 3, which indicates that majority

of the sample exceeds the permissible limit set by ISI and WHO. Calculation of WQI for individual samples is represented in Table 4. During POM, 4% of groundwater samples represent "excellent water", 41% indicate "good water", 35% shows "poor water", and 5% shows "very poor water". During PRM, only one sample signify "excellent water", 36% shows "good water", 48.6% shows "poor water", and remaining 13.5% of samples shows "very poor water". The PRM samples exhibit poor quality in grater percentage (60%) when compared with POM. This may be due to effective leaching of ions, over exploitation of groundwater, direct discharge of effluents, and agricultural impact (Sahu and Sikdar 2008).

The water quality index was tested with chloride and EC selected as pollution indicators. The observed high values of chloride and EC correspond to the same WQI, indicating the poor quality of groundwater in the study area. During PRM season, bad quality water is observed in locations 28, 29, 43, 44, 46, 45, 58, 59, 60, 61, 62, 63, 64, 67,

Table 4 Calculation of WQI for individual water samples

S. no.	POM		PRM		S. no.	POM		PRM	
1	140.63	Poor water	149.20	Poor water	38	171.57	Poor water	139.73	Poor water
2	72.51	Good water	104.38	Poor water	39	120.46	Poor water	120.03	Poor water
3	126.52	Poor water	192.06	Poor water	40	203.95	Very poor water	184.19	Poor water
4	126.86	Poor water	110.91	Poor water	41	125.31	Poor water	153.44	Poor water
5	112.21	Poor water	71.18	Good water	42	73.47	Good water	156.96	Poor water
6	43.51	Excellent water	70.86	Good water	43	162.39	Poor water	85.21	Good water
7	92.18	Good water	68.61	Good water	44	96.63	Good water	249.01	Very poor water
8	61.40	Good water	101.70	Poor water	45	69.66	Good water	84.36	Good water
9	117.67	Poor water	111.74	Poor water	46	165.24	Poor water	90.96	Good water
10	91.32	Good water	104.14	Poor water	47	163.42	Poor water	133.24	Poor water
11	114.30	Poor water	211.93	Very poor water	48	298.96	Very poor water	139.63	Very poor water
12	53.29	Good water	106.01	Poor water	49	73.63	Good water	231.82	Very poor water
13	61.33	Good water	171.74	Poor water	50	156.13	Poor water	251.97	Very poor water
14	163.89	Poor water	122.09	Poor water	51	121.63	Poor water	199.48	Poor water
15	95.45	Good water	41.35	Excellent water	52	82.02	Good water	199.42	Poor water
16	139.72	Poor water	90.87	Good water	53	111.44	Poor water	87.12	Good water
17	105.94	Poor water	77.83	Good water	54	53.16	Good water	108.34	Poor water
18	53.40	Good water	87.58	Good water	55	70.47	Good water	68.89	Good water
19	124.23	Poor water	253.06	Very poor water	56	112.72	Poor water	223.16	Very poor water
20	88.14	Good water	135.73	Poor water	57	83.32	Good water	85.94	Good water
21	70.57	Good water	120.29	Poor water	58	156.13	Poor water	105.18	Poor water
22	156.01	Poor water	107.59	Poor water	59	83.32	Good water	82.44	Good water
23	96.77	Good water	71.98	Good water	60	156.13	Poor water	93.55	Good water
24	120.08	Poor water	134.64	Poor water	61	110.63	Poor water	74.13	Good water
25	61.87	Good water	98.88	Good water	62	38.13	Excellent water	158.21	Poor water
26	260.47	Very poor water	66.65	Good water	63	125.54	Poor water	76.38	Good water
27	63.45	Good water	97.03	Good water	64	117.04	Poor water	127.36	Poor water
28	62.15	Good water	109.34	Poor water	65	102.11	Poor water	94.71	Good water
29	138.57	Poor water	126.56	Poor water	66	103.27	Poor water	110.43	Poor water
30	298.96	Very poor water	181.83	Poor water	67	39.50	Excellent water	92.80	Good water
31	73.22	Good water	65.75	Good water	68	112.72	Poor water	103.68	Poor water
32	37.94	Excellent water	169.57	Poor water	69	54.69	Good water	95.02	Good water
33	123.86	Poor water	291.94	Very poor water	70	70.24	Good water	74.93	Good water
34	204.88	Very poor water	170.64	Poor water	71	112.72	Poor water	116.03	Poor water
35	73.30	Good water	142.81	Poor water	72	133.32	Poor water	199.87	Poor water
36	165.87	Poor water	250.75	Very poor water	73	89.24	Good water	93.79	Good water
37	162.39	Poor water	218.48	Very poor water	74	69.90	Good water	96.21	Good water

69, 70, 73, and 74 along NE part of the study area, dominated by agricultural activities. Poor water quality is noted in locations 23, 24, 25, 27, 30, 31, 32, 33, 48, and 74 along the NW part of the study area, dominated by calc gneiss due to the influence of land fill and domestic activities. Water quality was also poor in locations 2, 3, 4, 5, 6, 7, 8, 9, 14, 15, 16, 17, 22, 26, 34, 35, 36, 37, 38, and 39 along the southern part of the study area composed of granulite gneiss region, where industrial activities are dominant. The same is also confirmed with deeper water tables in same locations identified by WQI, EC, and Cl. During POM season very poor water quality is confined along the same locations like PRM with deeper water levels, but the effect of dilution and increasing water table is noted in granulite gneiss along the downstream of the study area due to precipitation during monsoon period (Figs. 4 and 5).

Water quality for irrigation purposes

Sodium adsorption ratio

SAR and EC reciprocally can be used to evaluate irrigation water quality. The SAR recommended by the salinity laboratory of the US Department of Agriculture (Wilcox 1955) is calculated using the formula:

$$\mathrm{SAR} = \mathrm{Na}^{+} / \left\{ \sqrt{(\mathrm{Ca} + \mathrm{Mg})} / 2 \right\}$$

SAR values greater than 2 indicate groundwater is unsuitable for irrigation purposes. During POM, SAR was ranging from <0.5 to 37 meq/l indicating 48.65% of samples are not suitable for irrigation purposes. In PRM season, SAR greater than 1 to 44 mg/l was observed in 85% of the samples which are not suitable for irrigation purposes. Frequently, Na derived from weathering of feldspar and clay minerals disseminated from the litho units of the study area (Table 5).

Residual sodium carbonate

RSC is an important parameter to evaluate the suitability of irrigation water (Siddiqui et al. 2005), calculated using the formula

$$\mathrm{RSC} = \left[(\mathrm{HCO_3} + \mathrm{CO_3}) - (\mathrm{Ca} + \mathrm{Mg}) \right] \ (\mathrm{meq/l})$$

Generally, >2.5 meq/l of RSC is unsuitable for irrigation purposes. During PRM, RSC ranging from −12.23 to 11.73 was observed, and 75% of samples were within the permissible limit. In POM, RSC ranging from 28.67 to 15.56 was observed with an increase in the percentage of samples when compared with PRM.

Sodium percentage

Sodium in soil is considered vital for determining groundwater suitability for irrigation purpose because Na reacts with soil to reduce its permeability and support little or no plant growth. Sodium content is usually expressed in terms of percentage sodium calculated by:

$$\mathrm{Na\%} = (\mathrm{Na} + \mathrm{K}) \times 100 \Big/ \left\{ (\mathrm{Ca} + \mathrm{Mg} + \mathrm{Na} + \mathrm{K}) \right\} (\mathrm{meq/l})$$

Based on Na%, <35 meq/l in groundwater is suitable for irrigation purposes. During POM, Na% is ranging from <0.5 to 94 and 74.32% of samples represent over range and not suitable for irrigation. During PRM, three samples (7, 23, and 29) recorded Na% within permissible limit and the others exceed the permissible limit. The Na% was higher during PRM when compared with POM, due to long residence time of water, dissolution of minerals from lithological composition, and the addition of chemical fertilizers by the irrigation waters (Subba Rao et al. 2002; Qiyan and Baoping 2002).

Total Hardness

Water hardness has no known adverse effects; however, some evidence indicates its role in heart diseases (Schroeder 1960). Hard water is unsuitable for domestic use and it is a measure of the calcium and magnesium content, customarily expressed as the equivalent of calcium carbonate. Hardness of water is defined as the inhibition of soap action in water due to precipitation of magnesium and calcium salts such as carbonates, sulfates, and chlorides. It can be temporary or permanent hardness. Temporary hardness is mainly due to the presence of calcium carbonate and is

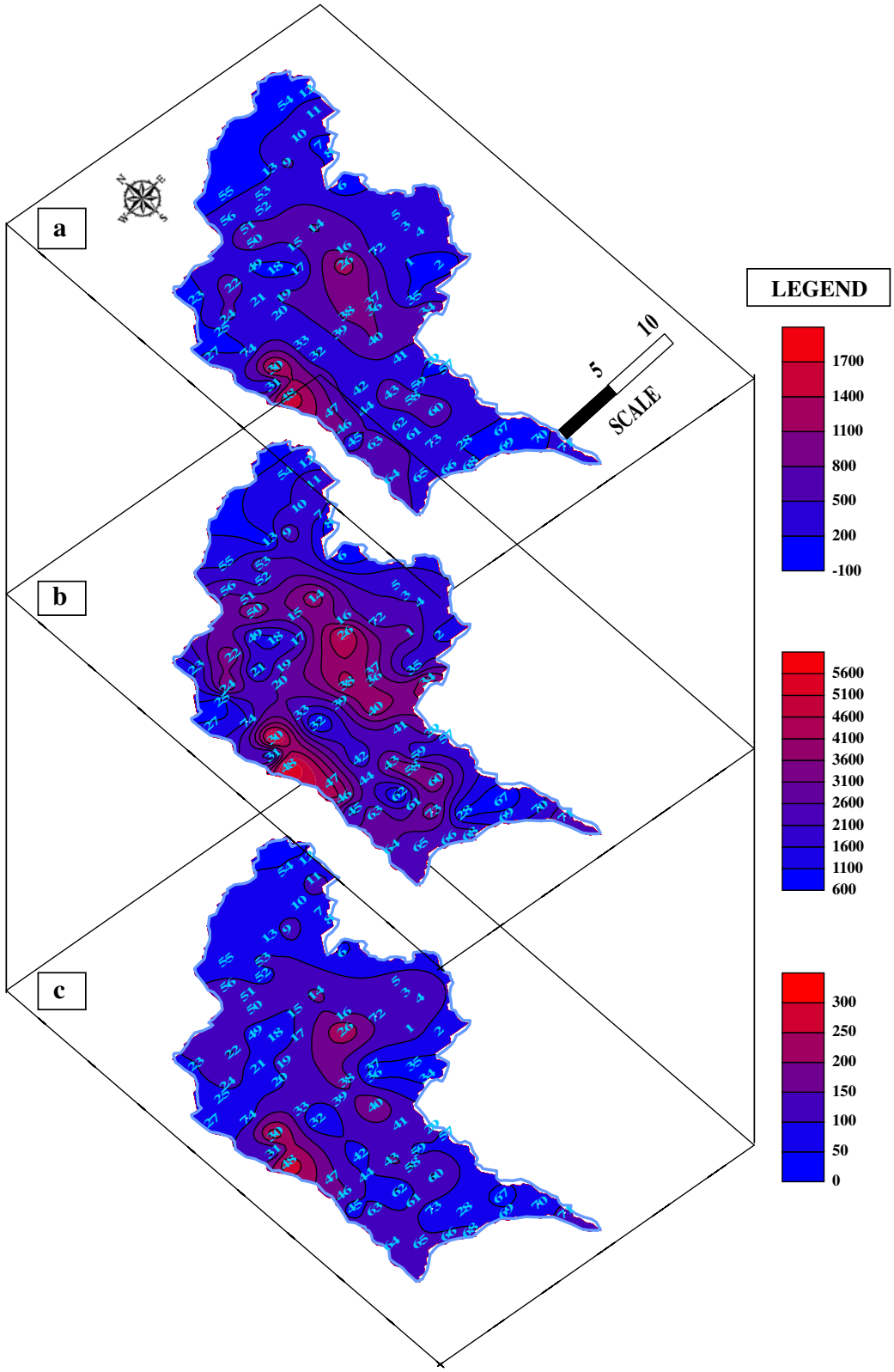

Fig. 4 Spatial distribution map of **a** chloride, **b** EC, and **c** WQI of the study area during POM season

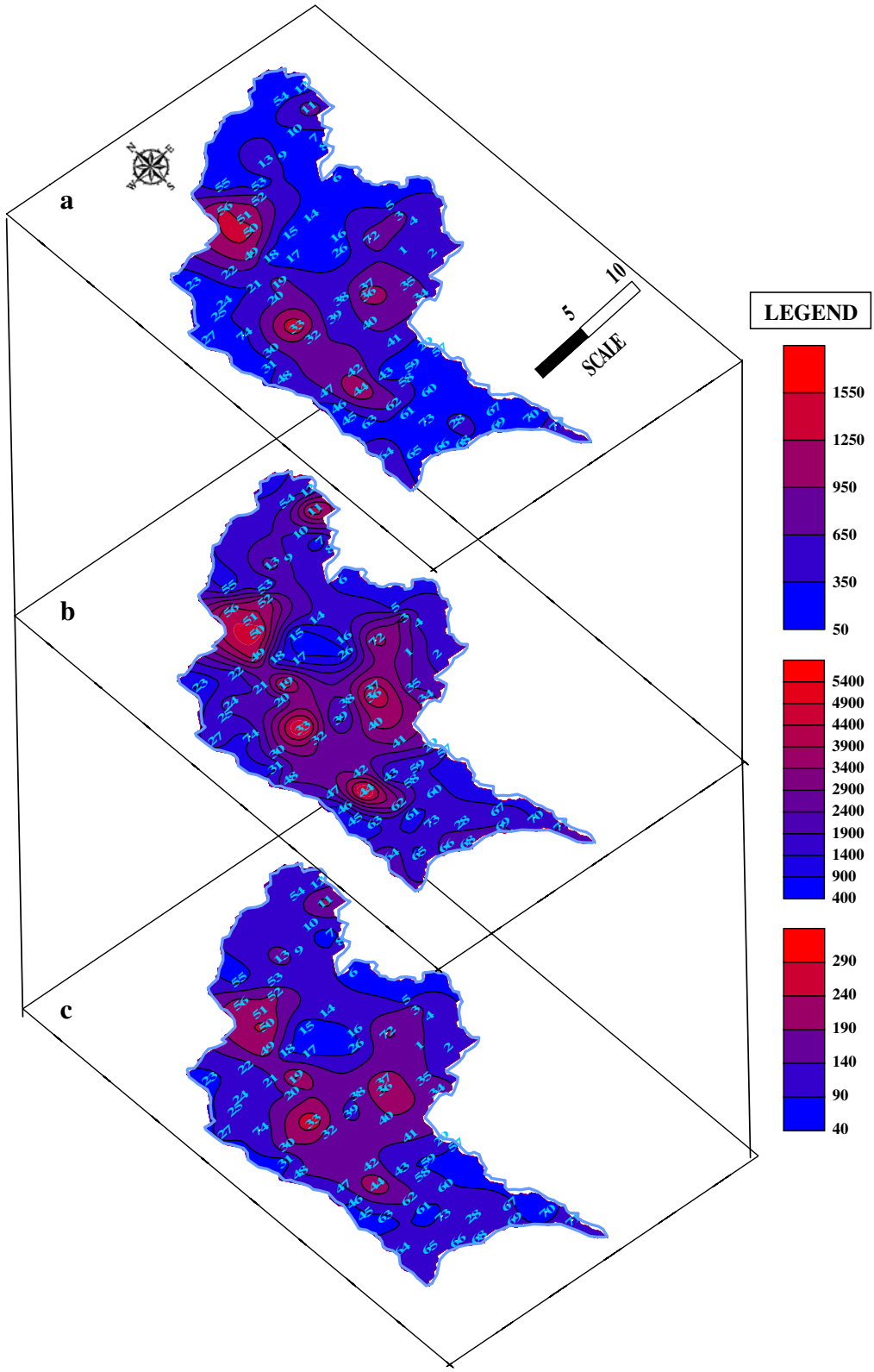

Fig. 5 Spatial distribution map of **a** chloride, **b** EC, and **c** WQI of the study area during PRM season

Table 5 Summary of important hydrogeophysical parameters for groundwater in PRM and POM season (SAR, RSC and Na% expressed in meq/L and TH is expressed in mg/l)

Sample No.	SAR		RSC		Na%		TH	
	POM	PRM	POM	PRM	POM	PRM	POM	PRM
1	5.05	31.92	1.48	0.37	53.85	86.10	445.90	237.30
2	2.21	2.74	−7.29	2.06	30.17	43.62	604.32	273.10
3	6.71	3.03	−12.23	−6.04	53.31	38.80	851.50	506.28
4	2.47	3.03	−5.60	−5.57	35.08	38.80	510.00	506.28
5	2.70	8.39	−0.61	−2.56	43.60	69.66	286.57	307.76
6	0.11	3.86	−6.05	1.32	2.34	61.94	515.00	104.66
7	0.16	1.05	−3.09	−2.82	3.86	18.04	404.50	480.73
8	9.76	1.91	6.23	−1.61	79.91	40.59	148.50	190.02
9	5.65	26.89	3.05	0.35	62.59	90.58	277.59	123.25
10	6.98	6.69	2.63	−0.54	63.89	63.98	218.47	267.03
11	36.68	8.39	11.78	−2.56	93.75	69.66	143.50	307.76
12	5.65	8.77	6.23	4.67	64.90	77.25	228.50	116.25
13	10.96	1.91	−1.73	−1.61	72.58	40.59	416.55	190.02
14	2.83	43.29	0.86	4.75	41.74	89.28	368.50	121.42
15	1.18	21.67	−1.48	6.72	32.01	76.42	154.03	128.78
16	0.82	20.88	−2.71	−2.44	16.81	86.43	409.50	237.18
17	0.58	13.01	−2.13	3.54	12.90	82.32	368.00	163.02
18	5.07	11.62	3.03	5.85	63.74	82.12	198.58	102.50
19	25.78	21.68	9.18	−0.27	88.80	87.08	253.50	189.54
20	2.10	41.21	−7.68	11.58	28.44	95.35	674.50	76.06
21	2.61	6.77	−1.10	−0.27	36.70	71.58	495.00	178.29
22	6.84	8.14	−3.42	4.89	67.97	61.16	231.00	540.54
23	0.02	1.15	−3.30	−4.95	0.68	18.38	314.00	400.01
24	7.57	30.13	3.86	11.99	66.65	82.17	346.76	150.16
25	11.79	1.85	1.60	−1.86	81.94	39.09	158.98	202.50
26	0.18	7.41	−1.76	−28.67	5.82	48.47	208.03	1,508.33
27	3.17	8.33	−0.95	0.84	45.10	75.98	357.30	157.39
28	2.60	1.82	−3.11	−2.01	38.41	38.24	415.50	209.99
29	18.22	2.17	10.42	−1.70	89.25	21.12	111.50	433.05
30	7.04	15.69	−2.71	−16.35	60.70	68.28	485.61	982.63
31	3.76	2.57	2.00	1.85	53.23	40.69	209.70	310.53
32	11.03	13.12	−2.33	2.13	72.08	88.66	436.27	36.95
33	36.90	3.03	5.88	−3.23	91.05	38.80	311.50	506.28
34	4.33	11.75	−11.26	−10.72	42.67	64.82	812.92	631.17
35	2.87	2.62	−10.29	2.09	34.65	41.62	704.73	298.05
36	21.92	12.40	0.19	−5.86	84.40	72.37	400.00	508.17
37	28.15	12.40	5.50	−5.86	90.21	72.37	205.50	508.17
38	8.46	37.76	−0.08	7.02	68.75	88.02	344.00	159.60
39	0.02	21.58	−9.66	0.11	0.43	86.99	695.50	191.28
40	19.67	11.75	5.55	−10.72	85.51	64.82	256.50	631.17
41	9.06	9.80	−0.98	−2.67	61.12	70.61	459.04	343.64
42	6.12	2.82	−8.65	4.54	54.23	44.92	632.31	258.13
43	4.29	12.40	2.62	−5.86	57.09	72.37	188.94	508.17
44	25.98	19.51	2.89	3.35	77.65	87.58	315.50	153.55
45	0.14	12.01	−5.07	4.08	2.85	79.98	533.50	171.02
46	0.21	41.24	−4.55	4.72	4.56	88.87	467.50	133.77
47	2.85	44.23	−6.06	6.25	34.72	89.45	577.29	116.31
48	7.93	15.69	−1.75	−16.35	64.84	68.28	387.56	982.63
49	10.51	2.60	−9.99	1.46	63.33	41.24	909.50	303.04
50	19.01	8.14	−2.84	4.89	78.61	61.16	581.96	540.54
51	15.59	21.72	−0.14	0.16	72.37	87.11	317.05	188.90

Table 5 (continued)

Sample No.	SAR		RSC		Na%		TH	
	POM	PRM	POM	PRM	POM	PRM	POM	PRM
52	15.67	9.54	1.45	1.15	77.98	72.59	467.62	222.53
53	4.08	13.33	2.05	−0.50	55.97	76.96	237.56	289.96
54	3.97	8.77	1.87	4.67	51.82	77.25	326.58	116.25
55	0.42	11.00	−1.35	3.20	9.12	80.76	427.50	144.93
56	30.08	13.33	0.18	−0.50	90.45	76.96	231.00	289.96
57	3.22	5.47	−0.15	1.61	47.89	58.52	297.63	299.40
58	3.44	8.14	−0.79	4.89	45.85	61.16	391.72	540.54
59	3.46	5.47	1.05	1.61	41.07	58.52	207.50	299.40
60	2.91	8.14	0.25	4.89	43.61	61.16	347.30	540.54
61	0.07	12.14	−1.30	1.02	1.95	71.14	267.50	224.15
62	6.83	13.12	−0.71	2.13	50.90	88.66	397.50	36.95
63	0.02	20.73	−5.11	0.60	0.34	83.35	505.50	269.71
64	7.46	11.59	−1.15	−3.90	64.67	72.18	377.43	435.22
65	2.18	13.00	−0.19	1.59	38.31	72.78	248.26	195.40
66	4.68	12.80	4.55	1.67	55.87	72.41	340.00	201.71
67	2.63	13.12	0.69	1.34	37.90	88.66	270.52	36.95
68	6.05	13.33	3.50	−0.50	44.17	76.96	247.99	289.96
69	5.06	8.77	3.84	4.67	51.63	77.25	227.99	116.25
70	4.22	11.09	0.47	3.25	57.72	81.01	226.50	142.43
71	5.59	13.33	−1.16	−0.50	58.96	76.96	358.15	289.96
72	29.34	7.48	6.52	−4.22	91.48	63.38	146.77	441.01
73	2.58	34.59	1.47	15.56	38.62	82.08	415.50	96.86
74	0.35	10.98	−4.53	3.19	7.12	80.71	485.54	145.44

removed by boiling water. Permanent hardness is caused by the presence of calcium, magnesium chlorides, and sulfates and can be cured only with ion exchange processes. Hardness of water limits its use for industrial purposes; it causes scaling of pots and boilers, closure to irrigation pipes, and may cause health problems to humans, such as kidney failure. TH is calculated as follows (Todd 1980):

$$\text{TH (CaCO3) mg/l} = (2.497)\,\text{Ca} + (4.115)\,\text{Mg}$$

During POM, TH was ranging from 49.96 to 2,158.55; about 63.51% of the groundwater samples exceed the permissible limit. During PRM, TH was ranging from 111.56 to 910.02 representing 32.43% of samples. TH is due to weathering of carbonates minerals such as calcium and magnesium. Higher TH was observed during POM when compared with PRM, due to dissolution of minerals by infiltration of young groundwater into the aquifer system.

Conclusion

The chemical composition of groundwater of the study area is strongly influenced by effective weathering and leaching action of feldspars and magnesium calcite found in the litho units of the study area along with anthropogenic activities like industrial effluents, automobile emissions, and phosphatic fertilizers in urban environments. The hydrochemical facies infer groundwater samples irrespective of seasons fall in mixed Na-Cl type with minor representations from Ca-Mg-Cl, Ca-Na-HCO3, Ca-Cl, and Ca-HCO_3 types. The box plot indicates Mg, K, and SO_4 are higher during POM due to the effective leaching and anthropogenic activities.

The WQI calculated for PRM exhibit poor quality in greater percentage when compared with POM indicating the effective ionic leaching, over exploitation, and anthropogenic activities from discharge of effluents from industrial, agricultural, and domestic uses. The WQI compared with Cl

and EC observed high values same as WQI indicating the poor quality of groundwater along the NE, NW, and southern parts of the study area underlined by charnockite, calc, and granulite gneiss dominated by agricultural, industrial, and domestic activities. Higher SAR, RSC, Na%, and TH refers 75% of samples are not suitable for irrigation purposes when compared with POM due to long residence time of water, dissolution of minerals from lithological composition, and the addition of chemical fertilizers by the irrigation waters. Water quality in the study area is slowly reaching alarming stage so that proper planning is essential in this venture to preserve the fragile ecosystem.

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