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Assessment of Groundwater Quality and its Spatial Variability for Drinking Use in Northeastern Karnataka, India

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ABSTRACT

This paper aimed to analyze the groundwater quality and its suitability for drinking in northeastern Karnataka, India. For this study, groundwater samples were collected from randomly selected sixty-five bore well. The standard analysis techniques used to analyze samples for physicochemical parameters like pH, EC, TDS, total alkalinity, total hardness, Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^-, F^-, NO_3^-, PO_4^{2-}, Na^+ and K^+. The suitability of groundwater for drinking is assessed based on the concentration of physicochemical parameters and water quality index. Groundwater quality index (GWQI) exhibited that about 61.53% of the samples belonged to the excellent-good category, and 38.47% belonged to the poor category for drinking purposes. The spatial variability map for all parameters prepared using ArcGIS ver. Xx.xxx software. Gibbs ratio confirmed that mineral content in the groundwater is from rock origin.

Key words : *Physicochemical parameter, Drinking water, Water quality indices, Geographical Information System*

Introduction

Water is considered an elixir of life as it is the essential liquid for health, hygiene, progress and prosperity. Generally, water occurs in its pure form. The rainwater, supposed to be pure, usually gets admixed with atmospheric contaminants and becomes impure. Rainwater, while percolating through soils and rocks, dissolves some minerals and salts and forms groundwater. Groundwater moves to subsurface through fractures or pores in the rocks and, during its travel, modify its composition. Groundwater is an essential resource over the years because of increased usage and demand for drinking, irrigation and industrial uses (Kambale *et al.,* 2017). The quality and quantity of groundwater are equally important. (Asadi *et al*., 2007). The groundwater quality readily relies on hydrological, physical, chemical and biological factors. The various properties of groundwater may vary spatially and temporally. Groundwater can become contaminated from natural sources and majorly from agricultural activities like fertilizers, chemical pesticides, and other products used for crops that affect the groundwater quality (Nag and Lahiri, 2012). Contamination of groundwater can reduce potable drinking water quality, high costs for alternative water supplies, and potential health risks (Bilgehan Nas and Ali Berktay, 2010). It can vary significantly in quality depending on the type and quantity of dissolved salts derived from interactions between water and the geological materials governing hydrochemistry (Hem, 1985). Similarly, dissolved salts must be present in irrigation water in small quantities. They originate from the rocks and soil, including dissolution of lime, gypsum and other slowly dissolved soil minerals (Sarath Prasanth *et al.,* 2012). Hence, water quality assessment is an integral part of the water supply system since the launch of the National Drinking Water Mission and the provision of safe drinking water to communities. Further, water quality analysis is one of the essential aspects of groundwater studies (Sadashivaiah *et al.,* 2008). Water quality analysis is the prerequisite for identifying sources that provide insight for selecting groundwater for human consumption and irrigation. This study carried out to know the suitability of groundwater for drinking use, and the spatial distribution of groundwater quality parameters in the northeastern Karnataka.

Materials and Methods

Study area

The study carried out in Shahapur taluk of Yadgir district of northeastern Karnataka (India). The study area lies between latitudes 16°22.30' N to 16°53.15 N and longitudes of 77°15.25 E to 77° 37.30 E. The study area experiences a temperature ranging from 12°C to 42°C, and the average annual rainfall is about 640 mm. The relative humidity varies from 26% in summer to 62% in winter. As per the Census 2011, Shahapur taluk had a population of 363,621. Out of which, 183,458 are males while 180,163 are females males. Out of the total population, 19% live in urban areas, while 81% lives in rural. The average literacy rate in urban is 72.4%, while that in rural areas is 46.5%.

Geology

The part of the study comprises the Peninsular Gneiss and granites. Central, the northeastern and southwestern part comprises sedimentary formations viz. sandstone, quartzite, shale, slate, limestone and dolomite. Deccan Trap basalts cover Northeastern parts of the area.

Occurrence of Groundwater

Major ground water-bearing formations are granite, gneiss, limestone and vesicular basalt. Groundwater occurs in weathered, fractured and jointed zones of these formations. In weathered zones, groundwater occurs in phreatic conditions, whereas, in the fractured & jointed formation, it occurs in semi-confined to confined conditions. The precipitation, followed by seepage from canals and return flow from irrigation considered a significant resource for groundwater recharge. A small portion of Deccan Trap basalts, which comprise different flows, fractures and interstitial pore spaces of the vesicular zone, are excellent repositories of groundwater. In limestone, solution cavities are considered to be more potent than weathered and fractured zones. Laterite has primary

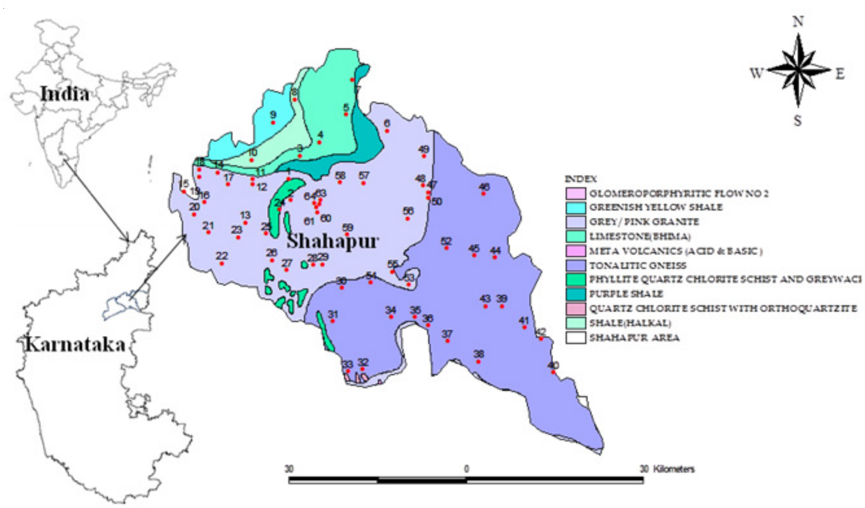


Fig. 1. Geology and sampling locations of the study area

porosity and is deemed to be a moderately good aquifer.

Groundwater sampling and analysis

A total of 65 groundwater samples collected from bore wells in the post-monsoon season during November 2013. The sampling location coordinates were recorded using GPS (Garmin). The recorded location of the sampling points is depicted in Fig. 1. The static water depth was ranging in between 10 and 20m below ground level. Samples were collected in high-density polyethene (HDPE) bottles after pumping for at least 10 minutes, labeled correctly and transported to the laboratory to analyze physicochemical parameters. The water samples analyzed for pH, electrical conductivity(EC), total dissolved solids(TDS), total alkalinity, total hardness, calcium (Ca^{2+}), magnesium (Mg^{2+}), sulphate (SO_4^{2-}), chloride (Cl^-), fluoride (F^-), nitrate (NO_3^-), phosphate (PO_4^{2-}), sodium(Na^+) and potassium(K^+) using standard procedures (APHA, 1998 and BIS, 1991).

Calculation of Ground Water Quality Index (GWQI)

The water quality index is a valuable and unique parameter for classifying water quality. It signifies the composite influence of various water quality parameters and provides water quality information to decide on the status of water (Sanigdha *et al*., 2018). For calculation WQI, three steps followed. In the first step, all individual parameters assigned a weight (wi) according to its relative importance in the overall quality of water for drinking purposes (Table 1). The maximum weight of 5 assigned to nitrate due to its significant importance in water quality assessment. Whereas calcium and magnesium are given the minimum weight of 2 as both parameters may not be harmful.

In the second step, the relative weight (Wi) computed from the following equation:

$$W_i = wi/\Sigma_{i=1}^{n}\ wi \quad .. (1)$$

Where W_i is the relative weight, wi is the weight of each parameter, and n is the number of parameters (Table 1).

In the third step, a quality rating scale (qi) for each parameter assigned by dividing its concentration in an individual water samples by standard according to the guidelines laid down in the BIS and the result multiplied by 100:

$$q_i = (C_i/S_i) \times 100 \quad .. (2)$$

Here, qi is the quality rating, Ci is the concentration of each parameter in the individual sample in mg/l, and Si the Indian drinking water standard for the separate parameter in mg/l according to the guidelines of the BIS 10500, 1991.

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

$$SIi = W_i \times q_i \quad .. (3)$$

$$WQI = \Sigma\, SI_i \quad .. (4)$$

Sri is the sub-index of the i^{th} parameter; qi is the rating based on the concentration of i^{th} parameter and n is the number of parameters. The computed WQI values are classified into five types, “excellent water” to “water, unsuitable for drinking”.

Table 1. Parameters, weight factors, and limit values considered for the water quality index (Ramakrishnaiah *et al*., 2009 and Sundara Kumar *et al*., 2010)

Parameter	Units	Weight (*wi*)	Relative weight (*Wi*)	Desirable limits value
pH	-	4	0.1176	8.5
TDS	mg/L	4	0.1176	500
Alkalinity	mg/L	3	0.0882	200
Hardness	mg/L	3	0.0882	300
Ca^{2+}	mg/L	2	0.0588	75
Mg^{2+}	mg/L	2	0.0588	30
Cl^-	mg/L	3	0.0882	250
SO_4^{2-}	mg/L	4	0.1176	200
F^-	mg/L	4	0.1176	1
NO_3^-	mg/L	5	0.1471	45
		$\Sigma w_i = 34$	$\Sigma W_i = 1$	

GIS-analysis

The spatial maps for physicochemical parameters were prepared using the ArcGIS ver. Xx.xxx software. The spatial interpolation of data was carried out using Inverse Distance Weighted (IDW) method (Basavaraja *et al*., 2018). This method interpolates a value for each grid node in the proximity data points that lie within a user-defined search radius (Burrough and McDonnell, 1998). All of the data points used in the interpolation process and the node value determined by averaging the weighted sum of all the points. The GIS database helps in identifying the most sensitive zones that need immediate attention.

Results and Discussion

The analytical results evaluated thoroughly to distinguish the quality of groundwater in the study area for drinking purposes presented in Table 2 & 3.

Groundwater suitability for drinking purpose

pH

The pH is an essential property of water since it calculates the appropriateness of water for several uses (Kiplangat, 2016). The pH observed in the range 6.08-7.94. All the analyzed samples pH observed within the range of WHO and BIS drinking water standards. The spatial distribution map of pH in the study area displayed in Fig. 2(a)

Electrical conductivity

Electrical conductivity is a measure of water capacity to conduct electricity. As per the drinking water standards of BIS, there is no standard for EC. However, the desirable limit of EC is 1,500 µS/cm as per the WHO standards (2004). EC ranged between 654 µS/cm and 22600 µS/cm with an average value of 2881.45 µS/cm. According to WHO standards, 67.69% of the samples were observed above the desirable limit. The spatial distribution map of EC in the study area shown in Fig. 2(b).

Total Dissolved Solids (TDS)

The total dissolved solids are a measure of the various minerals, including inorganic salts and a small amount of organic matter that influences the usability of water. TDS varies considerably in different geological regions owing to differences in the solubility of minerals (Adeyi and Majolagbe, 2014). Water with high dissolved solids is expected to pose problems like taste, laxative, gastrointestinal irritation and other associated problems with the individual minerals. If the water contains less than 500 mg/l of dissolved solids, it is generally satisfactory for domestic use (Balakrishnan *et al.,* 2011). In the present study, TDS ranges from 352 to 11500 mg/l, with an average value of 1530.08 mg/l. According to the BIS standards, the desirable limit for TDS is 500 mg/l. The TDS observed in the samples with 6% under desirable range, 32% in the permissible range, 20% useful for irrigation and 7% unfit for both drinking and irrigation purposes (Table 3). Figure 2(c) shows the spatial distribution map of total dissolved solids in the study area.

Total Alkalinity

The alkalinity of water is very important because it buffers pH changes that occur naturally during photosynthetic cycles, water exchanges, etc. (Nagaraju *et al*., 2014). Alkalinity varied between 136 and 848 mg/l with an average value of 420.62 mg/l. As per WHO and BIS standards, 12.30% samples were observed above the permissible limit. The excess of alkalinity may be due to the minerals, which dissolved in groundwater from mineral-rich soil (Prakash and Somashekar, 2006). The spatial distribution map of total alkalinity in the study area is shown in Fig. 2(d).

Total Hardness

Hardness value recorded in the range of 70 – 2150 mg/l with an average value of 539.09 mg/L. Sawyer and McCarty (1967) classified groundwater based on total hardness as soft, (0 to 750 mg/l), moderately hard(76 to 150 mg/l), hard (151 to 300 mg/l), and a very hard (>300 mg/l). Based on the above classification, 18 samples belong to hard water, and the remaining 46 samples belong to very hard water, and only one sample belongs to the soft category (Table 3). Similar results were reported by Sarath *et al*. (2012) in groundwater in the coastal stretch of Alappuzha District, Kerala. The spatial distribution map of the total hardness illustrated in Fig. 2(e).

Calcium (Ca^{2+})

Calcium content in the groundwater varied widely from 9.61 mg/l to 448.45 mg/l with a mean value of 105.47 mg/l. Khaiwal *et al*. (2019) reported similar results in groundwater of Ellenabad city of Haryana. As per the standards, about 89.22% of the samples appeared in desirable and permissible range, and 10.76% of the samples exceeded the permissible range and unsuitable for drinking purposes. The spatial distribution map of calcium displayed in Fig. 2(f).

Magnesium (Mg^{2+})

The desirable limit of magnesium in natural water is 30 mg/l. The observation of the Mg value in the study area ranges 5.78 mg/l to 267.06 mg/l. This Mg also observed 89.24% samples in the desirable and permissible range; with remaining 10.76% samples exceeded the range according to WHO & BIS drinking water standards. If the concentration of magnesium in drinking water is more than the permissible limit, it causes an unpleasant taste to the water (Sarala and Ravi Babu, 2012). The spatial distribution map of magnesium shown in Fig. 2(g)

Chloride(Cl^-)

Chlorides occur in all-natural waters in widely varying concentrations. The concentrations of chloride over about 250 mg/l can give rise to a detectable taste in water (WHO, 2004; Sawyer and Mccarty 1978). The chloride content in groundwater varied from 37.73 mg/l to 4446.31 mg/l with an average value of 416.41 mg/l. About 56.92% fall below the desirable limit (<250 mg/l), 35.38% exhibited in the range of 250-1000 mg/l and 7.69% of the samples were above 1000 mg/l of chloride. The chloride content may be due to minerals like apatite, mica, and hornblende and also from the liquid inclusions of igneous rocks (Das and Malik, 1988). The spatial variability map of chloride shown in Fig. 2(h).

Sulphate(SO_4^{2-})

Sulphates can naturally occur in water due to soil and rock formations. As water passes through the soil and the rocks, sulphates are picked, and they get dissolved in groundwater (Kiplangat *et al.*, 2016). The presence of sulphate in drinking water can cause a noticeable taste, and very high levels might cause a laxative effect in unaccustomed consumers (WHO, 2008). In the present study, concentrations of sulphate in water samples ranged from 45.70 to 1906.56 mg/l. About 78.46% of water samples complied with WHO and BIS permissible level (400 mg/l), and 21.53% exceeded the permissible level. The spatial distribution map of sulphate depicted in Fig. 2(i)

Fluoride(F^-)

Fluoride is an inorganic pollutant in groundwater, affecting human health (S Levin, 2016). Fluoride is perhaps the only element whose deficiency is less than 0.5 mg/l and, its presence over 1.5 mg/l in drinking water has serious health implications. It acts as an essential element up to 1.0 mg/l, helping in teeth formation and strengthening the skeleton. Beyond the limit, it negatively impacts human health, causing fluorosis problems (Mazhar and Ravikumar, 2013). In the present study, the fluoride level ranges from 0.00-2.30 mg/l. Among the samples collected, 50% of the total number of

Table 2. Statistics of chemical parameters (all in mg/L except pH and EC in μS/cm) in groundwater

Parameter	Min	Max	Average	Stdev	Variance	Kurtosis	Skewness	WHO		BIS	
								Desirable	Permissible	Desirable	Permissibl
pH	6.08	7.94	7.20	0.34	0.11	0.67	-0.39	6.5-8.5	-	6.5-9.2	-
EC	654	22600	2881.45	3269	10692101.34	20.65	3.99	-	-	-	-
TDS	352	11500	1530.08	1697	2881446.17	18.53	3.77	300	600	500	1000
Alkalinity	136	848	420.62	146.38	21426.49	0.34	0.67	200	600	200	600
Hardness	70	2150	539.09	434.57	188853.49	3.61	1.95	300	600	300	600
Ca_2+	9.61	448.45	105.47	87.60	7674.47	6.01	2.24	75	200	75	200
Mg_2^+	5.78	267.06	60.77	61.45	3776.51	3.08	1.92	50	150	30	100
Cl^-	37.73	4446.31	416.41	736	541703.88	19.21	4.19	200	600	250	1000
SO_4^{--}	45.70	1906.56	334.17	316.32	100055.24	10.04	2.88	200	400	200	400
F^-	0.00	2.93	0.38	0.52	0.27	9.93	2.85	0.5	1.0-1.5	0.62-1.2	1.5
NO_3^-	0.24	7.422	4.943	1.893	3.58	-0.67	-0.71	-	45	45	45
PO_4^{--}	0.001	0.197	0.011	0.025	0.00	51.7	6.92	-	-	-	-
Na^+	4.40	106.45	42.89	28.48	811.14	-0.50	0.73	200	-	-	-
K^+	0.31	170.30	41.79	45.59	2078.36	0.61	1.30	12	-	-	-

samples below the desirable level of drinking water standards. The fluoride concentration in samples S1, S25, S40 and S59 exceeded the permissible limit (Table 3). Fluoride at more than 1.5 mg/l the water should be defluoridated for drinking purposes (Basavarajappa and Manjunatha, 2015). The spatial variability of fluoride in the study area shown in Fig. 2(j)

Nitrate(NO_3^-)

Nitrate is found naturally in the environment and is an important plant nutrient. Some ground waters may also have nitrate contamination as a consequence of leaching from natural vegetation and agricultural fields. In large quantities of nitrate contributing to the syndrome known as methemoglobinaemia in infants (Sajal Singh and Athar Hussian. 2016), Its concentration ranged between 0.242 and 7.422 mg/l. High nitrate concentration (>1-2 mg/l) in groundwater may be the result of manure seepage and fertilizers through agricultural activities(Weiner, 2000). However, the nitrate level found within the permissible limit (45 mg/l). The spatial distribution map for nitrate depicted in Fig. 2(k)

Phosphate(PO_4^{2-})

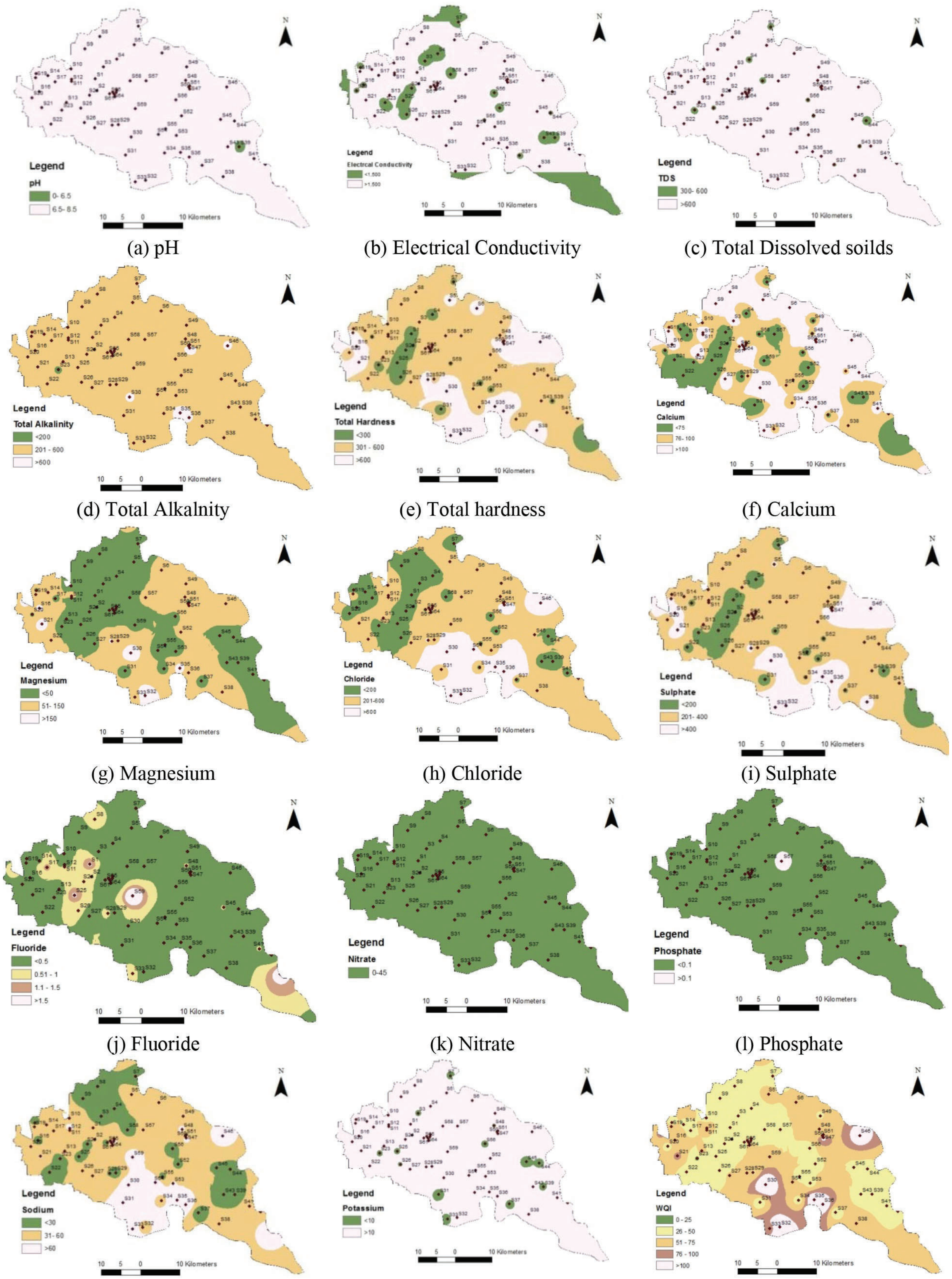
Natural phosphate sources include erosion (weathering) from phosphate-rich rocks and recycling of phosphorus from organic matter. Phosphate concentration recorded in the range of 0.001 mg/l to 0.197 mg/l. The spatial distribution of phosphate shown in Fig. 2(l).

Sodium(Na^+)

Sodium is the most abundant element in natural water. Sodium in the study area varied from 4.40 to 106.45 mg/l with an average value of 42.89 mg/l.

Table 3. Groundwater Classification for drinking based on indices

Parameter	Category	Water Classification	Number of samples	% of sample	Representing Samples
WQI	<25	Excellent water	01	1.53	S23
	26-50	Good water	39	60.00	S1-4, S7-10, S12, S14, S17-18, S20, S22, S24-26, S29, S31, S34, S37, S39, S41-45, S47, S49, S52-53, S55-58, S61-63, S65
	51-7 5	Poor water	16	24.61	S5-6, S11, S13, S16, S19, S27-28, S38, S40, S48, S51, S54, S59, S60, S64
	76-100	Very poor water	03	4.61	S15, S21, S33
	>100	Water unsuitable for drinking	06	9.23	S30, S32, S35, S36, S46, S50
Degree of Hardness	0-75	Soft	01	1.53	S31
	75-150	Medium	Nil	-	Nil
	150-300	Hard	18	27.69	S1-2, S4, S7, S17, S23-26, S34, S37, S39-40, S53, S55, S59, S62, S65
	>300	Very Hard	46	70.76	S3, S5-6, S8-16, S18-22, S27-30, S32-33, S35-36, S38, S41-52, S54, S56-58, S60-61, S63-64
TDS	<500	Desirable for drinking	6	9.23	S23, S37, S44, S56, S58, S65
	500-1000	Permissible for drinking	32	49.23	S1-4, S7-8, S14, S16-18, S20, S24-26, S29, S31, S34, S39, S42-43, S45, S47, S49, S52-53, S55, S57
	1000-3000	Useful for irrigation	20	30.76	S5-6, S9-13, S15, S19, S21-22, S27-28, S32, S40-41, S48, S51, S59, S64
	>3000	Unfit fro drinking and irrigation	7	10.76	S30, S33, S35-36, S46, S50, S54
Fluoride	<0.5	Dental caries Hazard	50	76.92	S3-7, S9-11, S13-14, S16, S18-23, S27, S29-39, S42-44, S46-47, S49-58, S60-65
	0.5-1.5	Prevents tooth decay	11	16.92	S2, S8, S12, S15, S17, S24, S26, S28, S41, S45, S48
	1.5-4.0	Dental fluorosis	4	6.15	S1, S25, S40, S59
	>4.0	Skeletal fluorosis	-	-	-



(a) pH (b) Electrical Conductivity (c) Total Dissolved soilds

(d) Total Alkalnity (e) Total hardness (f) Calcium

(g) Magnesium (h) Chloride (i) Sulphate

(j) Fluoride (k) Nitrate (l) Phosphate

(m) Sodium (n) Potassium (o) Water Quality Index

Fig. 2. Spatial distribution of physicochemical parameters and water quality index of groundwater for drinking purpose

According to WHO (2011), the suggested sodium limit is 200 mg/l. In the present study, sodium content is well within the suggested level. The spatial variability map of sodium in the study area illustrated in Fig. 2(m).

Potassium (K^+)

The potassium concentration is always lower than the calcium, magnesium and sodium in nature (Gouri Sankar Bhunia, 2018). The concentration of potassium varied between 0.31 and 106.45 mg/l with a mean concentration of 42.89 mg/L. As per the WHO standards, potassium concentration must be less than 12 mg/l in the drinking water. In the present study, 73.85 % of the collected samples were found above the permissible limit. It was observed due to the effect of fertilizer applied to crop fields. The spatial distribution map of the potassium illustrated in Fig. 2(n).

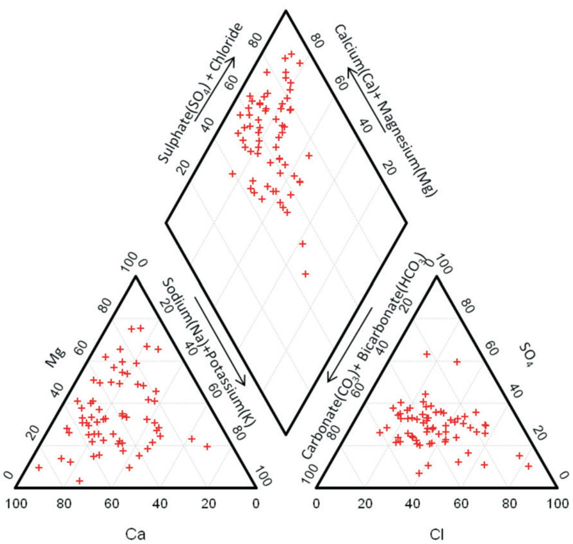


Fig. 3. Trilinear piper diagram for graphical analysis

Groundwater quality index (GWQI)

Groundwater quality index fluctuated between 21.40 and 200.85. As per the index, 1% and 39% of the samples belongs to excellent to good water category respectively, and 16% and 03% belong to a poor and very poor category. The remaining 6% of the samples belong to an unsuitable category. In the study area wherever poor WQI is there, it suggested that simple water quality treatment techniques such as heating and/or filtration at a household level should be adopted (Felistas *et al*., 2019). The spatial variability of WQI in the study area shown in Fig. 2(O).

Geochemical classification and hydrogeochemical facies

Pipers trilinear diagram for graphical analysis (Fig. 3). used to examine water composition and the chemical relationship between dissolved ions, the concept of hydrochemical facies in the studied area. This reveals similarities and differences among water samples (Todd, 1980). The results suggested that mixed cation-HCO_3 is the dominant hydrochemical facies for the surveyed groundwater.

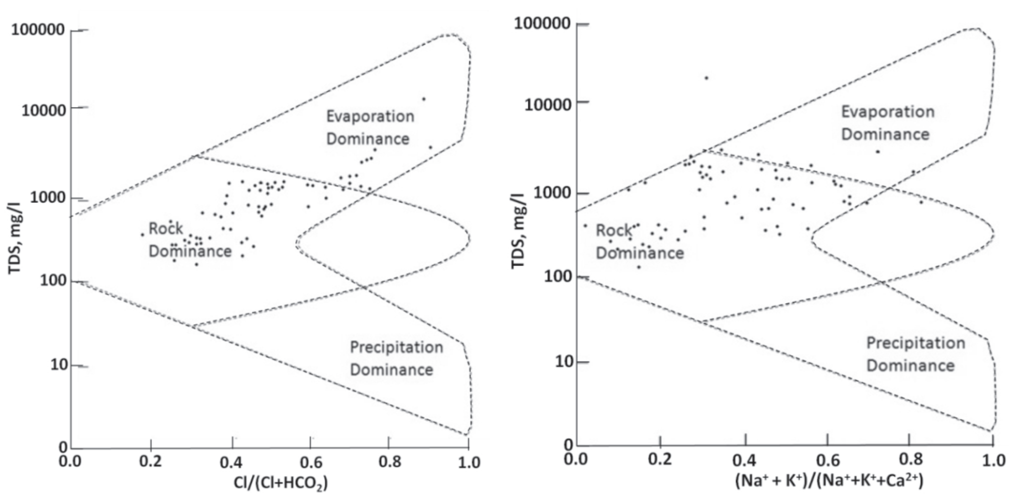


Fig. 4(a) Gibss I **Fig. 4(b)** Gibss II

Fig. 4. Gibbs plot showing hydro-geochemical processes in groundwater

Gibbs' ratio

In the present study, the chemical properties of water are controlled by the interaction between aquifer rocks and groundwater, and to some extent by evapotranspiration etc. Gibbs ratio for major anions and cations of the groundwater samples were plotted separately against respective values of total dissolved solids (Fig. 4). Fig.4(a) shows that Gibbs ratio I for anions 81.53% by rock dominance and 18.46% by evaporation dominance. Similarly, Fig. 4(b) shows that Gibbs ratio II for cations 84.61% by rock dominance and 9.23% by evaporation dominance. The overall evaluation substantiated mineral composition in the groundwater from rock origin.

Conclusion

Groundwater Quality Index reveals that 61.53% of the samples in the study area exhibited excellent to good category and were suitable for drinking purpose. The degree of hardness confirmed that 70.76% of the samples belong to the very hard category. Most of the concentration of the physicochemical parameter is permissible according to WHO and BIS standards. The Gibbs ratio on minerals confirmed more than 80% by rock dominance and less than 20% by evaporation dominance. The spatial variability map shows a variation in the concentrations of physico-chemical parameters in the study area.

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