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Assessment of Groundeater Quality using the Pollution Index in the Narketpally Mandal, Nalgonda District, Telangana State, India

Bolleddu Roja *[1] and Kunsothu Sreenu[1]

[1]Department of Geology, Osmania University, Hyderabad, Telangana State, India.

* Email: rojabolleddu34@gmail

ABSTRACT

A total of thirty-five groundwater samples were collected in the western part of Nizamabad district, Telangana State, India. The results obtained compared with IS 10500 standards, which shows more than 80% of the samples are unfit for drinking purposes. The results were also analyzed to know the irrigation suitability; where about 80% of the samples are fit for agricultural use. The major ions in groundwater quality for irrigation and drinking, contradictory locations exist which are majorly caused by geogenic (silicate weathering minerals) and anthropogenic (fertilizers and manure). The spatial distribution diagrams of the major ions were high concentration in Northern areas followed by Northeast, South, Northwest and Southeast portions. As per the groundwater quality of pollution index (PIG), most of the study region (62 percent) comes under the low contamination zone and the rest (38 percent) under the moderate to unacceptable zone.

Keywords: Groundwater quality, Agricultural and Drinking and Pollution Index of Groundwater (PIG)

Introduction

Groundwater is one of the most important freshwater resources, as it helps to sustain various aspects of human and agricultural ecosystems (Satyanarayana et al. 2016; Etikala et al. 2020). On a regional and local scale, it is also a key source of fresh water supply in hard rock terrains (Chaudhary and Satheeshkumar 2018). The hard rock terrains have limited infiltration capacity and the water potential is restricted to weathered/fractured zones (Etikala et al. 2019). The quality of water is of utmost concern as its quantity due to its prominent role in evaluating water for drinking, agricultural and industrial purposes (Subramani et al. 2005; Kaur et al. 2017). Normally, the surface water is more vulnerable to pollution, whereas the groundwater is free from pollutants due to their removal and dissolution in the unsaturated zone. Groundwater chemistry is influenced by aquifer geology, geochemical processes in aquifers, human activities, rainfall, and the type of water that infiltrates the earth's subsurface (Laxman et al. 2015; 2022). Groundwater is the major vital freshwater resource for drinking and irrigation purposes worldwide. As per UNESCO 2012 and WHO 2004 a total of 2.5 billion people depending on groundwater for basic needs and 3.4 million people suffer from water-related diseases.

Irrigation based agriculture occupies 20% of the overall cultivated land which accounts for about 40% of the global food production. The latest forecast shows that the irrigated land rises at a rate of 0.6 percent per year during 1998-2030 which raises food production to 36% with 13% more water requirement (UNESCO 2009). The increased dependence on groundwater for drinking, agriculture, and industrial purposes has created further stress on this limited resource and posing a big challenge to mankind. Hence, proper hydrogeochemical studies are required to know the suitability of groundwater for domestic, agricultural and other allied sectors (Ratnakar Dhakate et al. 2020). India uses 80% of its water for irrigation needs, and 65% of this is sourced from groundwater. Groundwater availability therefore is a primary metric in determining the overall availability of water. The State of Telangana holds 3.6% of national groundwater resources and 2.89% of the country’s population. A number of factors determine the groundwater levels of a region, including the amount of rainfall, usage of groundwater for irrigation, dependence on groundwater, incentives to use/misuse groundwater, and degree of groundwater development.

The Narketpally region is dominantly occupied by hard rock where as these wells yield in low quantities of water. Furthermore, agricultural land is the most common land use type in the research area where groundwater is being exploited. As a result, it is an effort to learn about the water for drinking and agricultural uses. According to Groundwater provinces classification by **(**Taylor 1995**)** the present area falls in the Precambrian crystalline province. The rocks of this province lack primary inter-granular porosity and are therefore poor receptacles of groundwater. With weathering, fracturing and jointing/shearing they develop secondary porosity and become water bearing water yielding. This province supports dependable, though limited, water supplies.

Study area and its geology

The Narketpally mandal, Nalgonda district of Telangana State, India and falls in Survey of India Toposheet No. 56 O/3, 56 O/4, 56 O/7 and 56 O/8; lies between Longitude 79° 9' 48" to 79° 15' 51" and latitudes 17° 9' 28" to 17° 19' 41". It has an extent of 240 sq. kms and the altitudinal range is 255 meters above mean sea level (MSL) (Fig. 1). The climate in the area is tropical. The area is hot for most of the year. The maximum and minimum temperature in the summer is 32°C - 46°C and 21°C - 26°C. May is the hottest month. The maximum and minimum temperature in the winter is 28°C and 14°C. December is the coldest month. The mean rainfall in the past ten years is 846 mm shows that the rainfall has been below the average. The geology consists of granites and gneisses of Archaean rocks are of Peninsular gneissic complex.

Methodology

To evaluate the groundwater quality 35 sampling sites spread over the area were selected water samples were collected in pre and post-monsoon seasons. The analysis was carried out for pH, EC, TDS, TH, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, NO_3^- and F^- were analyzed by standard method (APHA 2005). The pH values were determined using (Hachsens ION) and Conductivity Meter (Model 304, Systronics) was used to measure Electrical Conductivity. Total Dissolved Solids were calculated from electrical conductivity values. Na^+ and K^+ were determined by a flame photometer (Model Systronics, 128). The TH (as $CaCO_3$) and Ca^{2+} were measured using the standard EDTA titration method. The concentration of Mg^{2+} was estimated using the difference between TH and Ca^{2+}, whereas the CO_3^- and HCO_3^- were obtained by using the titration method with standard HCl. The Cl^- concentrations were measured using $AgNO_3$ titration. SO_4^{2-} and NO_3^- were estimated by spectrophotometer (BAUSCH & LOMB 21D Vis), whereas, the F^- was obtained from an ion-selective electrode (Orion 2109XP) (Laxman et al. 2019). For the calculated of major ions mass balance error, the total cations (Ca^{2+}+Mg^{2+}+Na^++K^+) and the total anions (HCO_3^-+Cl^-+SO_4^{2-}+NO_3^-+F^-) were expressed in milliequivalent per liter (meq/l) of each sample (Eq. 1), The ionic mass balance error (IMBE) was observed to be within the permissible limit of ±5% (Laxman et al. 2021).

$$IMBE = \frac{(TC - TA)}{(TC + TA)} \times 100 - - - - - - - - - (1)$$

Besides, various widely accepted criteria for drinking and irrigation were used to assess the groundwater suitability for various purposes and also Pollution Index of groundwater quality (PIG) was carried out to find out suitability of groundwater for drinking and irrigation purposes.

Groundwater for Irrigation uses

The analysed parameters were then evaluated using Kelly's ratio, Magnesium hazard, Permeability index and conventional diagram such as USSL for the suitability of groundwater for irrigation activities.

Kelly's Ratio

Kelly (1963) proposed a method based on which irrigation water can be rated. Usually, Kelly's ratio <1 is ideal for agricultural practices, Kelly' ratio 1-2 is marginal irrigation uses and Kelly's ratio >1 is not suitable for agricultural practices. It can be measured with the formula given below (Eq. 2).

$$KR = \frac{Na^{+}}{Ca^{+2} + Mg^{+2}} - - - - - - - - - - - - (2)$$

(Ionic concentrations were in meq/L)

Permeability Index (PI)

In general, the long-term use of water with excess ions such as Na^+, Ca^{2+}, Mg^{2+} and HCO_3^- for irrigation can affect the soil permeability which necessitates calculating the permeability index values. The values can be obtained by the given formula (Eq. 3).

$$PI = \frac{(Na^{+} + K^{+}) + \sqrt{HCO_3^-}}{Ca^{+2} + Mg^{+2} + Na^{+} + K^{+}} x100 - - - - - - - - - - (3)$$

(all concentrations are reported in meq/L)

USSL diagram

The U.S. salinity laboratory (1954) developed a SAR based model to analyse groundwater suitability irrigation uses.

Sodium Adsorption Ratio (SAR)

Richards (1954) established a method for the evaluation of water for agricultural uses. The values can be obtained by the given formula (Eq. 4).

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}} ---------------- (4)$$

Pollution index of groundwater (PIG)

The Pollution Index of groundwater quality (PIG) is used to quantify pollution activities caused by geogenic and anthropogenic sources (Subba Rao 2020). The status of the relative impact of individual variables, for example, pH, TDS, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, SO_4^{2-} and NO_3^{-}, on total groundwater quality (Table 1). In this strategy, there were five stages required to calculate the groundwater quality pollution index. In the initial step, the Relative weight (Rw) from 1 to 5 was allotted for each variable, contingent upon its overall effect upon individuals. Minimum weight (1) was given to K^{+} and maximum weight (5) to pH, TDS, SO_4^{2-} and NO_3^{-} (Table 2). The weight variable (Wv) was determined for each component in the second stage to determine its proportionate contribution to the overall compound of groundwater quality [Eq. (5)]. The concentration status (Sc) was determined in the third phase by dividing the concentration (C) of each chemical in each groundwater sample by the relevant drinking water standard limit [Ds; (Eq. 6)] (pH value has taken in ideal value average). The total groundwater quality (Ow) was computed in the fourth stage by multiplying Wp with Sc [Eq. (7)]. The Pollution Index of groundwater quality (PIG) was calculated by all values of Ow [Ow; Eq. (8)].

$$WP = \frac{Rw}{\sum Rw} ---------------- (5)$$

$$Sc = \frac{C}{Ds} ------------------ (6)$$

$$Ow = Wp \times Sc ---------------- (7)$$

$$WQPI = \sum Ow --------------(8)$$

Results and discussion

Groundwater quality for drinking

To know the suitability of water for potable uses, a total of thirty-five groundwater samples were taken and evaluated for different parameters Table 1. The chemical analysis data of pre and post monsoon samples collected during 2023 were compared with IS 10500 (BIS 2012). The pH values of the region of groundwater samples are slightly alkaline. The TDS values of the region are about 83% of water samples in pre monsoon and 80% in post monsoon are exceeding the limits. Mean value of TDS in pre and post monsoon are 722 mg/l and 678 mg/l, the high concentration of TDS values are due to soil contamination, household wastewater and agricultural activities (Subba Rao 2017). The hardness has mean values of 347 mg/l and 446 mg/l, 100% and 97% of the samples are exceeding the acceptable limits of 200 mg/l recommended for drinking water specifications (BIS 2012). The major ions of cations and anions, Na^{+} ranges from 26 to 310 mg/l and 25 to 280 mg/l. K^{+} is a mean value of 8 mg/l and 8 mg/l, Ca^{2+} is a mean of 79 mg/l and 77 mg/l, 63% and 65% of samples are have been exceeded the acceptable limits of 75 mg/l (BIS 2012). Mg^{2+} has a mean value of 38 mg/l and 36 mg/l, 71% of samples are have been exceeded the acceptable limits of 30 mg/l (BIS 2012). Apart from potassium feldspars, the main source of potassium is the application of chemical fertilisers (Karunanidhi et al. 2020). Calcium feldspars are the primary calcium source in groundwater (Laxman et al. 2019). The presence of magnesium in groundwater is expected as a result of ferromagnesium minerals (biotite and hornblende) and domestic wastes (Subba Rao et al. 2017).

The Cl^{-} values ranges from 85 to 380 mg/l and 76 to 365 mg/l, around 49% and 31% of samples are have been exceeded the acceptable limits of 250 mg/l (BIS 2012). A high concentration of chloride in groundwater is due to the weathering of phosphate mineral apatite in granites of the study region (Karanth 1987). SO_4^{2-} values ranges from 22 to 168 mg/l and 20 to 140 mg/l, all the samples are acceptable limits for the drinking water is 200 mg/l (BIS 2012). NO_3^{-} has a mean value of 43 mg/l and 40 mg/l, 49% and 34% of samples are have been exceeded the acceptable limits of 45 mg/l (BIS 2012) drinking water specifications. The nitrate is a consequence of influence of sewage wastes, spillage of septic tanks, and chemical fertilizers on groundwater system (Zhang et al. 2018; He et al. 2019).

Groundwater for Irrigation uses

Kelly's Ratio

The results reveal that 63% of samples from pre-monsoon, 66% of samples from post-monsoon seasons are suitable. Whereas 31% of samples in the pre-monsoon and 34% of samples post-monsoon seasons are marginal for irrigation uses (Table 3).

Permeability Index (PI)

Doneen 1964 introduced method of evaluating for irrigation water based on PI values, where waters can be grouped into I, II, and III. The results revealed that most of the wells fall in class I is 54% and 74%, II is 44% and 26% in pre and post-monsoon seasons, III is 2% in pre-monsoon season only (Fig. 3 and Table 3). As per the PI values of the study region class I, class II is suitable for irrigation and except class III is one sample for pre-monsoon season unsuitable.

USSL diagram

Figure 3 demonstrates that in the pre- and post-monsoon seasons most of the samples are plotted in C3S1 (69% and 74%) high salinity hazard to low sodium hazard, C3S2 (17% and 12%) high salinity hazard to medium sodium hazard and C2S1 (14%) medium salinity hazard to low sodium hazard water quality types respectively (Fig. 3). Furthermore, the classification indicates the hazard risk caused primarily by salinity in groundwater, which has a negative impact on soil characteristics, plant growth, and yields (Rajmohan et al. 2020). Thus, the salinity hazard can be reduced through artificial recharge, which is the simplest and most effective method among others for reducing plant salt ingestion via the roots (Aravinthasamy et al. 2020).

Sodium Adsorption Ratio (SAR)

This condition is promoted by waters of high SAR and reversed by waters containing a high proportion of calcium and magnesium (Hem 1985). The unfavourable condition created by high SAR can be turned favourable by adding proper proportion of gypsum or lime to the soil. As water with low SAR is desirable for agriculture, studies on the suitability of groundwater of the investigated area have been carried out. The table for evaluation of irrigation waters on the basis of their specific conductance and SAR ratios is used purpose. From the results, all the samples are excellent for irrigation purposes in pre and post-monsoon (Table 3).

Groundwater contamination

In evaluating the quantification of groundwater quality pollution index (PIG), the chemical parameters from each groundwater sample are taken into consideration. According to the grouping of PIG, it is delegated irrelevant contamination, on the off chance that it is underneath 1.0; low contamination, on the off chance that it is from 1.0 to 1.5; moderate contamination, if it fluctuates from 1.5 to 2.0; high contamination, on the off chance that it is in the middle of 2.0 and 2.5; Unacceptable, on the off chance that it is more than 2.5.

The estimations of PIG fluctuate from 0.49 to 1.36 and 0.50 to 1.23, with a mean of 0.92 and 0.87 in pre and post-monsoon seasons (Table 4). As per the arrangement of PIG, 71% of the all-out groundwater samples PIG under 1.0, which go under the Insignificant zone and 29% of the groundwater samples fall in low contamination zone in pre-monsoon season. Post-monsoon seasons 83% of the groundwater sample under 1.0 and 17% of the groundwater samples are under 1.0 to 1.5 low contamination zone (Table 5).

Conclusions

The study area most of the samples are unfit for drinking purposes in the Narketpally. Based on the irrigation classifications are like Kelly's ratio, Permeability index, Wilcox and SAR, most of the samples are suitable for agricultural purposes. The spatio-temporal maps of the study area are high concentrations in parts of Northeast, South, Northwest and Southeast. The groundwater quality pollution index (PIG) result from the study region one third-of the area is moderate to the unacceptable. The study reveals that there may be a further chance of water degradation water due to intense agricultural activities. It suggests that regular monitoring of water resources is needed in the study area for sustainable development. The study is useful for decision-makers for managing the resource for various purposes.

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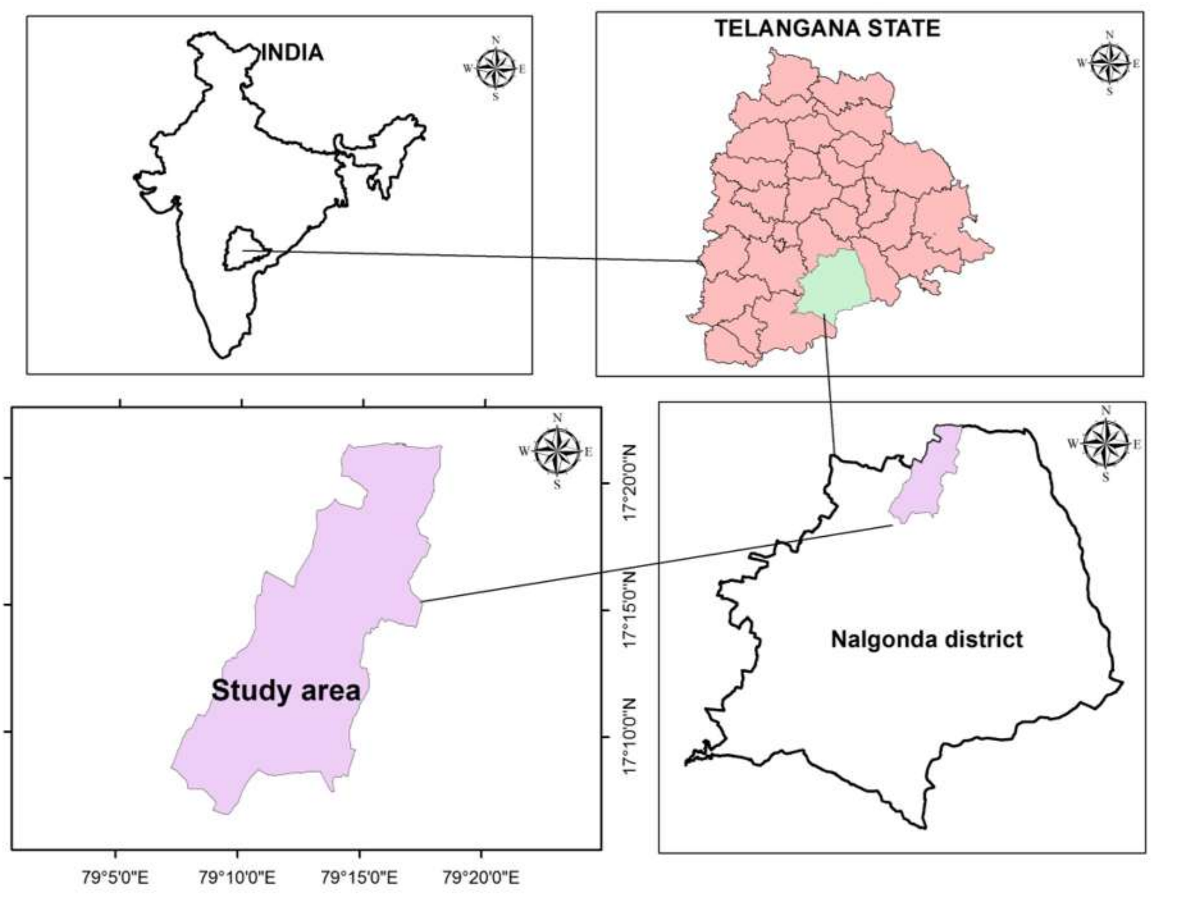

Fig. Location map of the study area

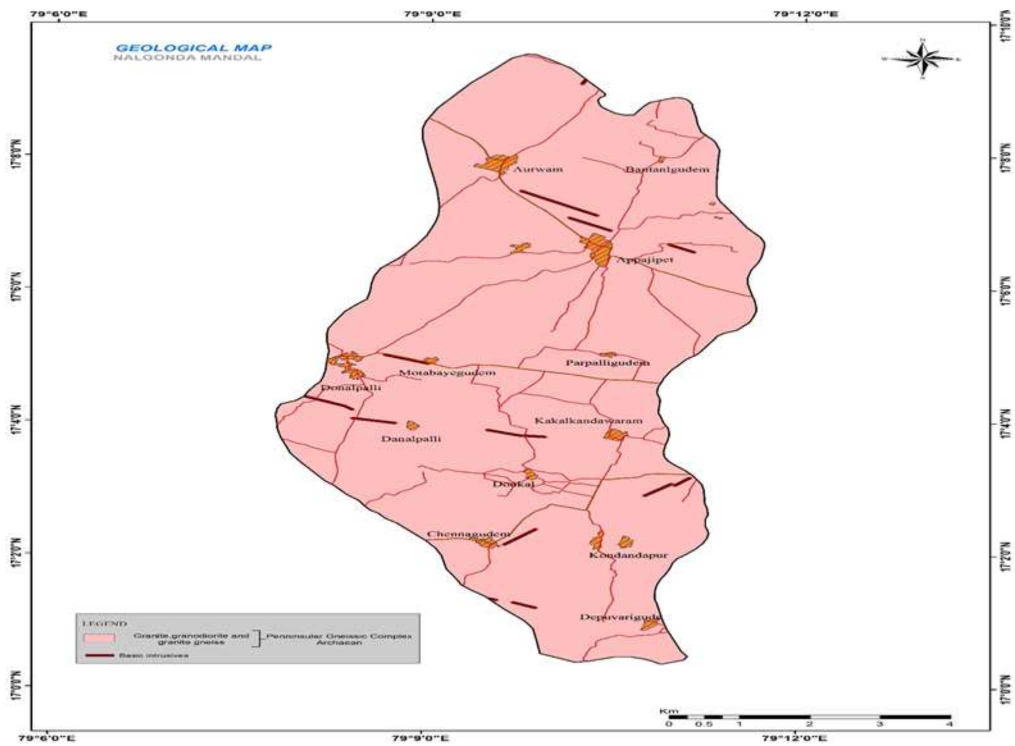

Fig. 2 Geology map of the study area

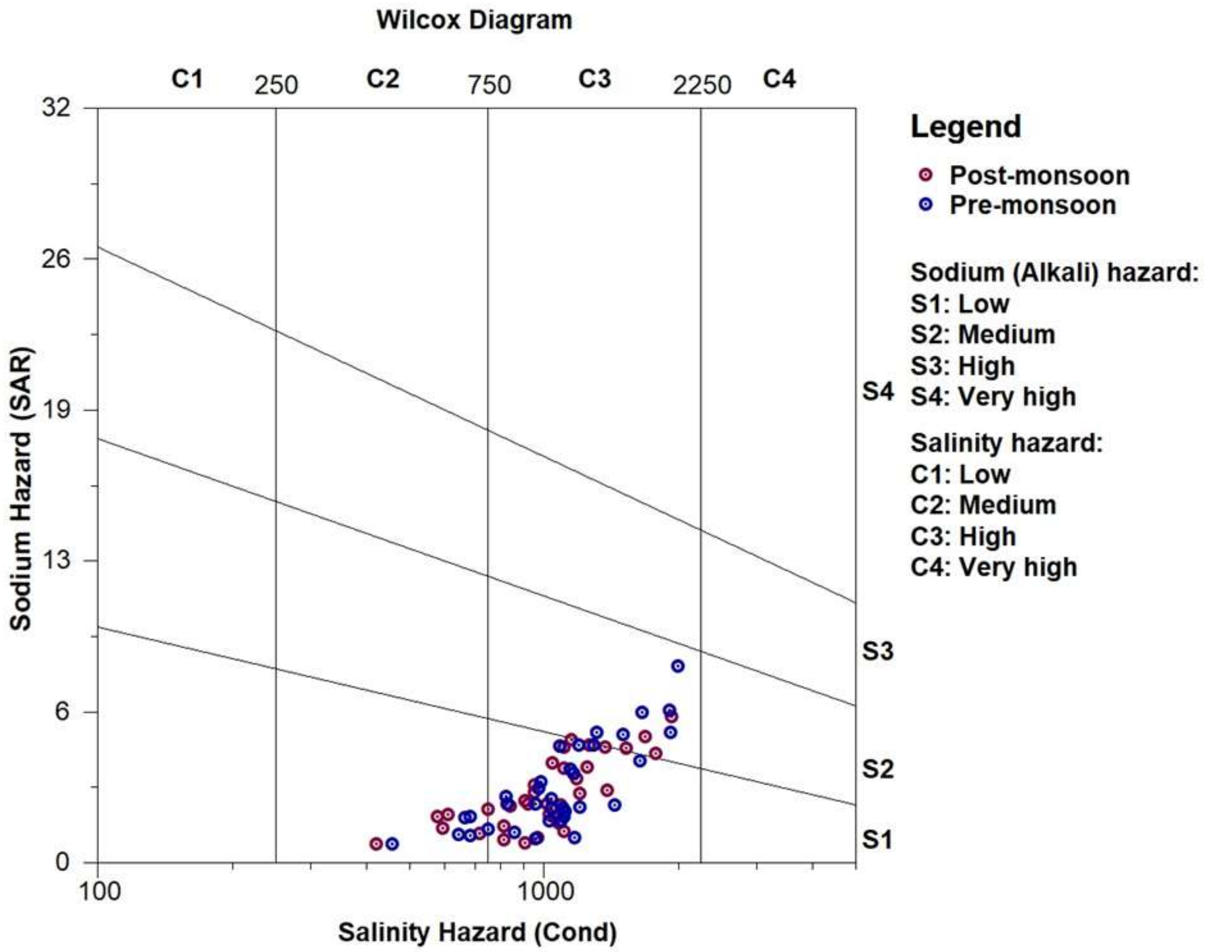

Fig.3 USSL diagram of the study area

Table 1 Statistics of major ions of water samples in pre- and post-monsoon seasons

Variables	Pre-monsoon season				Post-monsoon season				BIS (2012)
	Minimum	Maximum	Mean	% of samples exceeded the limits	Minimum	Maximum	Mean	% of samples exceeded the limits	
pH	6.90	8.80	7.89		7.10	8.60	7.88		**6.5 - 8.5**
EC (µS/cm)	456	2002	1129	-	406	1844	1059		-
TDS (mg/l)	292	1281	722	83	260	1180	678	80	**500**
TH as CaCO3	208	549	347	100	198	446	33	97	**500**
Ca^{2+} (mg/l)	55	112	79	63	48	96	77	66	**75**
Mg^{2+} (mg/l)	18	68	38	71	20	56	36	71	**30**
Na^{+} (mg/l)	26	310	132	-	25	280	124		-

K^+ (mg/l)	2	36	8	-	2	12	5		-
Cl^- (mg/l)	85	380	242	49	76	365	221	31	**250**
CO_3^- (mg/l)	0	36	9	-	0	30	11		
HCO_3^- (mg/l)	28	350	111	-	30	320	111		-
SO_4^{2-} (mg/l)	22	168	86	-	20	140	78		**200**
F^- (mg/l)	0.18	5.25	1.41	51	0.12	3.80	1.15	43	**1.5**
NO_3^- (mg/l)	16	88	43	49	18	85	40	34	**45**

Table 3 Groundwater classifications on the basis of TDS (Freeze and Cherry 1979); Davis and Dewiest and TH (Sawyer and McCarthy 1967)

Parameters	**Range**	**Water type/Classification**	**% of groundwater samples pre-monsoon**	**% of groundwater samples post-monsoon**
TDS (mg/L)	<1000	Fresh	86	91
	1000-10000	Brackish	14	9
	10000-100000	Saline	-	-
	>100000	Brine	-	-
TH (mg/L)	<75	Soft	-	-
	75-150	Moderately hard	-	-
	150-300	Hard	31	23
	>300	Very hard	69	77

Table 2 Classification of groundwater for irrigation suitability and % of samples falling in various categories

Kelley's Ratio (Kelley 1951)	**Range**	**Pre-monsoon (%)**	**Post-monsoon (%)**
Suitable	<1	63	66
Marginal	1-2	31	34
Unsuitable	>2	6	-
Permeability Index (PI)	**Range**	**Pre-monsoon (%)**	**Post-monsoon (%)**
100 % permeability	Class I		
75 % permeability	Class II		
25 % permeability	Class III		
Sodium Adsorption Ratio (Richards, 1954)	**Range**	**Pre-monsoon (%)**	**Post-monsoon (%)**
Excellent	<10	100	100
Good	10-18	Nil	Nil
Doubtful	18-26	Nil	Nil
Unsuitable	>26	Nil	Nil

Table 3 Relative weight, weight variable and drinking water quality standards limits

Chemical Variable	Relative weight (Rw)	Weight variable (Wv)	Drinking water standard limit
pH	5	0.128	7.5
TDS (mg/L)	5	0.128	500
TH (mg/L)	3	0.077	200
Ca^{2+} (mg/L)	2	0.051	75
Mg^{2+} (mg/L)	2	0.051	30
Na^{+} (mg/L)	4	0.103	200
K^{+} (mg/L)	1	0.026	12
HCO_3^- (mg/L)	3	0.077	200
Cl^- (mg/L)	4	0.103	250
SO_4^{2-} (mg/L)	5	0.128	200
NO_3^- (mg/L)	5	0.128	45
$\sum$ Sum	39	1.000	-

Table 4 Results for Ow, PIG and major ions of groundwater samples in pre and post-monsoon season

Parameter	Pre-monsoon season			Post-monsoon season		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
pH	0.12	0.15	0.13	0.12	0.15	0.13
TDS	0.07	0.33	0.18	0.07	0.3	0.17
Na^{+}	0.01	0.16	0.07	0.01	0.14	0.06
K^{+}	0	0.08	0.02	0	0.03	0.01
Ca^{2+}	0.04	0.08	0.05	0.03	0.07	0.05
Mg^{2+}	0.03	0.12	0.06	0.03	0.1	0.06
TH	0.05	0.14	0.09	0.05	0.11	0.09
HCO_3^-	0.01	0.1	0.03	0.01	0.09	0.03
Cl^-	0.04	0.16	0.1	0.03	0.15	0.09
SO_4^{2-}	0.01	0.11	0.05	0.01	0.09	0.05
NO_3^-	0.05	0.25	0.12	0.05	0.24	0.11
PIG	0.49	1.36	0.92	0.5	1.23	0.87

Table 5 The pollution index of Groundwater quality (PIG) in pre and post-monsoon seasons

Sl. No.	Pre-monsoon		Post-monsoon	
	GQPI	Range	GWPI	Range
1	0.97	Insignificant	0.87	Low
2	0.84	Insignificant	0.88	Insignificant

3	1.02	Low	0.87	Insignificant
4	0.91	Insignificant	0.85	Insignificant
5	0.64	Insignificant	0.80	Insignificant
6	0.49	Insignificant	0.50	Insignificant
7	0.82	Insignificant	0.79	Insignificant
8	0.89	Unacceptable	0.84	Insignificant
9	1.21	Low	0.89	Insignificant
10	1.05	Low	0.86	Insignificant
11	1.00	Insignificant	0.98	Insignificant
12	1.09	Low	0.93	Insignificant
13	1.24	Low	1.12	Insignificant
14	0.98	Insignificant	0.87	Insignificant
15	1.07	Low	1.00	Insignificant
16	1.20	Low	1.04	Low
17	0.84	Insignificant	0.76	Insignificant
18	1.13	Low	1.03	Low
19	0.62	Insignificant	0.60	Insignificant
20	0.77	Insignificant	0.71	Insignificant
21	0.84	Insignificant	0.81	Insignificant
22	0.87	Insignificant	0.83	Insignificant
23	0.91	Insignificant	0.86	Insignificant
24	1.26	Low	1.13	Low
25	0.75	Insignificant	0.80	Insignificant
26	0.93	Insignificant	0.88	Insignificant
27	0.89	Insignificant	0.80	Insignificant
28	1.36	Low	1.23	Low
29	0.79	Insignificant	0.77	Insignificant
30	0.64	Insignificant	0.70	Insignificant
31	0.66	Insignificant	0.72	Insignificant
32	0.70	Insignificant	0.71	Insignificant
33	0.99	Insignificant	1.02	Low
34	0.92	Insignificant	0.92	Insignificant
35	0.99	Insignificant	0.98	Insignificant