

Evaluating Groundwater Suitability for Both Domestic and Agricultural Uses in Shaligowraram Mandal, Nalgonda District, Telangana State

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Abstract

Groundwater is the primary source of drinking and irrigation water in semi-arid regions of India, making its quality assessment essential for sustainable water resource management. This study evaluates the hydrogeochemical characteristics and suitability of groundwater in Shaligowraram Mandal, Nalgonda District, Telangana, India. A total of 42 groundwater samples were collected during the pre- and post-monsoon seasons to assess seasonal variations in groundwater chemistry. The samples were analyzed for major physico-chemical parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), major cations (Ca^{2+} , Mg^{2+} , Na^+ , and K^+), and major anions (HCO_3^- , CO_3^{2-} , Cl^- , SO_4^{2-} , NO_3^- , and F^-), following standard analytical procedures. The results were compared with the Indian Standard for Drinking Water Specification (IS 10500) to evaluate their suitability for domestic use. Irrigation suitability was assessed using the Sodium Adsorption Ratio (SAR), Kelly's Ratio (KR), Residual Sodium Carbonate (RSC), and Permeability Index (PI). Most groundwater samples belong to the high salinity–low sodium (C3S1) and high salinity–medium sodium (C3S2) classes, indicating elevated salinity but moderate sodium hazard. Water Quality Index (WQI) analysis showed that 43% of the samples were of excellent to good quality, whereas 19% were classified as poor. Approximately 80% of the samples exceeded the permissible limits for drinking water quality, primarily due to elevated salinity and dissolved constituents. In contrast, nearly 80% of the samples were suitable for irrigation based on hydrochemical indices. These findings demonstrate the influence of seasonal hydrogeochemical processes on groundwater quality and highlight the need for continuous monitoring and effective groundwater management to ensure its sustainable use for domestic and agricultural purposes.

Keywords: Hydrogeochemistry, water quality index, drinking water, irrigation water quality, groundwater assessment

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INTRODUCTION

Groundwater constitutes a vital component of the globe's freshwater repository, serving as critical sustenance for various human and agricultural ecosystems [1–3]. In regions characterized by hard rock terrains, it plays a pivotal role as a primary source of fresh water supply [4]. Notably, the infiltration capacity in such terrains is severely limited, and the water potential is predominantly confined to fractured and weathered zones [5]. Consequently, the quality of groundwater is of paramount importance, alongside its quantity, owing to its multifaceted applications in the

drinking, agricultural, and industrial sectors [6, 7]. In contrast to surface water, groundwater is less susceptible to pollution, primarily because of the attenuation of pollutants in the unsaturated zone. The geochemistry of groundwater is influenced by a complex array of factors, including aquifer geology, geochemical processes within aquifers, anthropogenic activities, precipitation, and the type of water infiltrating the subsurface [5, 8]. Groundwater is a vital freshwater resource and a primary source of potable water and irrigation for millions of people worldwide, with an estimated 2.5 billion individuals reliant on it for basic needs and 3.4 million people suffering from water-related health issues [9–11].

Global food production predominantly relies on irrigated agriculture, which covers approximately 20% of the cultivated land and accounts for approximately 40% of the global production levels. Forecasts indicate that the area under irrigation will experience a compound annual growth rate of 0.6% between 1998 and 2030, resulting in a 36% increase in food production and a 13% increase in water usage requirements. The heightened reliance on groundwater for human consumption, agricultural purposes, and industrial use has intensified the strain on this limited resource, thereby posing significant challenges to human populations. Consequently, comprehensive hydrogeochemical investigations are essential to evaluate the suitability of groundwater for domestic, agricultural, and related applications [4,12–17].

The northern part of the region comprises predominantly hard-rock formations, resulting in low-yielding wells. The main land use in the study area is agriculture, with groundwater being heavily exploited. There is a need for information on water that is suitable for both drinking and agricultural purposes [1,2,5,7,18–20].

STUDY AREA AND ITS GEOLOGY

The Study Region and General Geology

The Shaligowraram region spans a range of 17.2308 °to 17.3522 °north latitude and 79.3036 °to 79.4706 °east longitude. This area encompasses approximately 220 square kilometers of rocky terrain, featuring large monolithic rocks on its periphery. The dominant granitic geology shapes the semi-arid landscape of the study region. However, the area is plagued by groundwater overexploitation, which has led to declining water quality. The primary objectives of this study were to identify the spatiotemporal patterns and incidence of nitrate and fluoride contamination, as well as the underlying hydrogeochemical processes driving their enrichment Figures 1-3 Tables 1-2 [3,8,21–23].

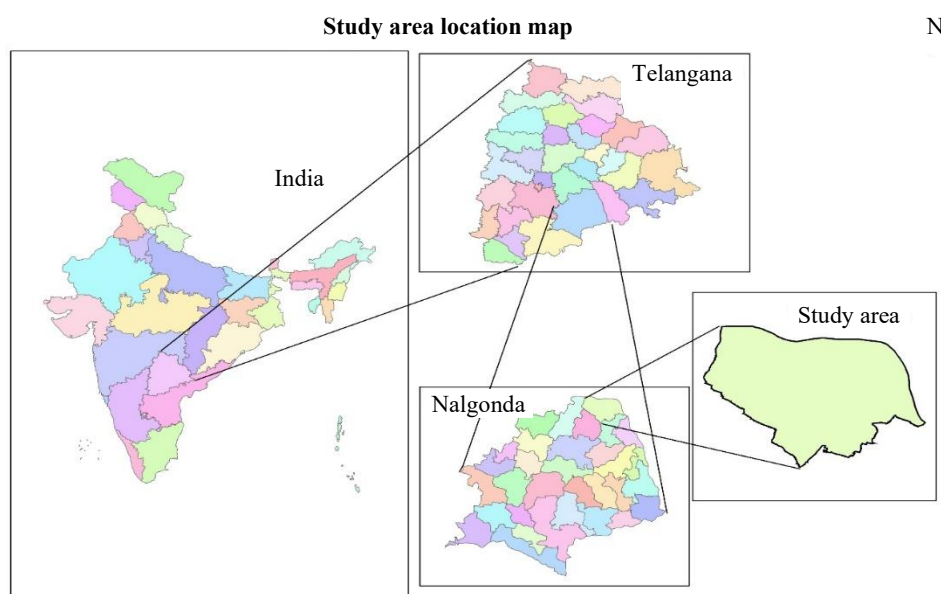


Figure 1. Location map of the study area.

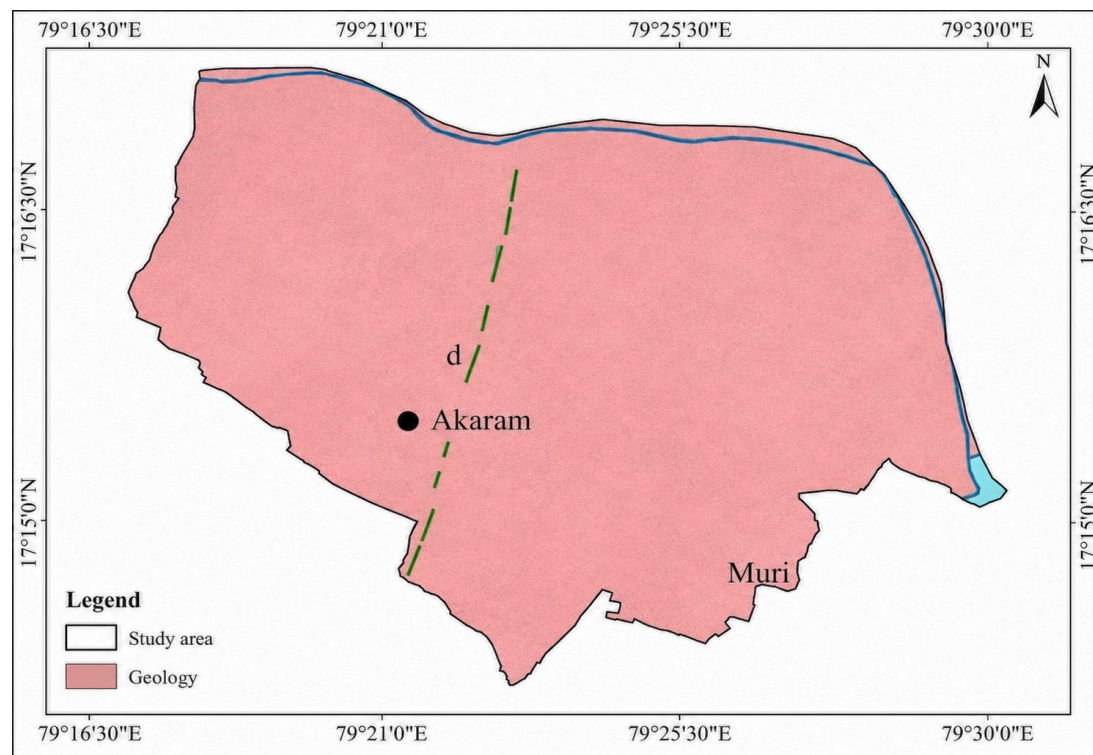


Figure 2. Geology map of the study area.

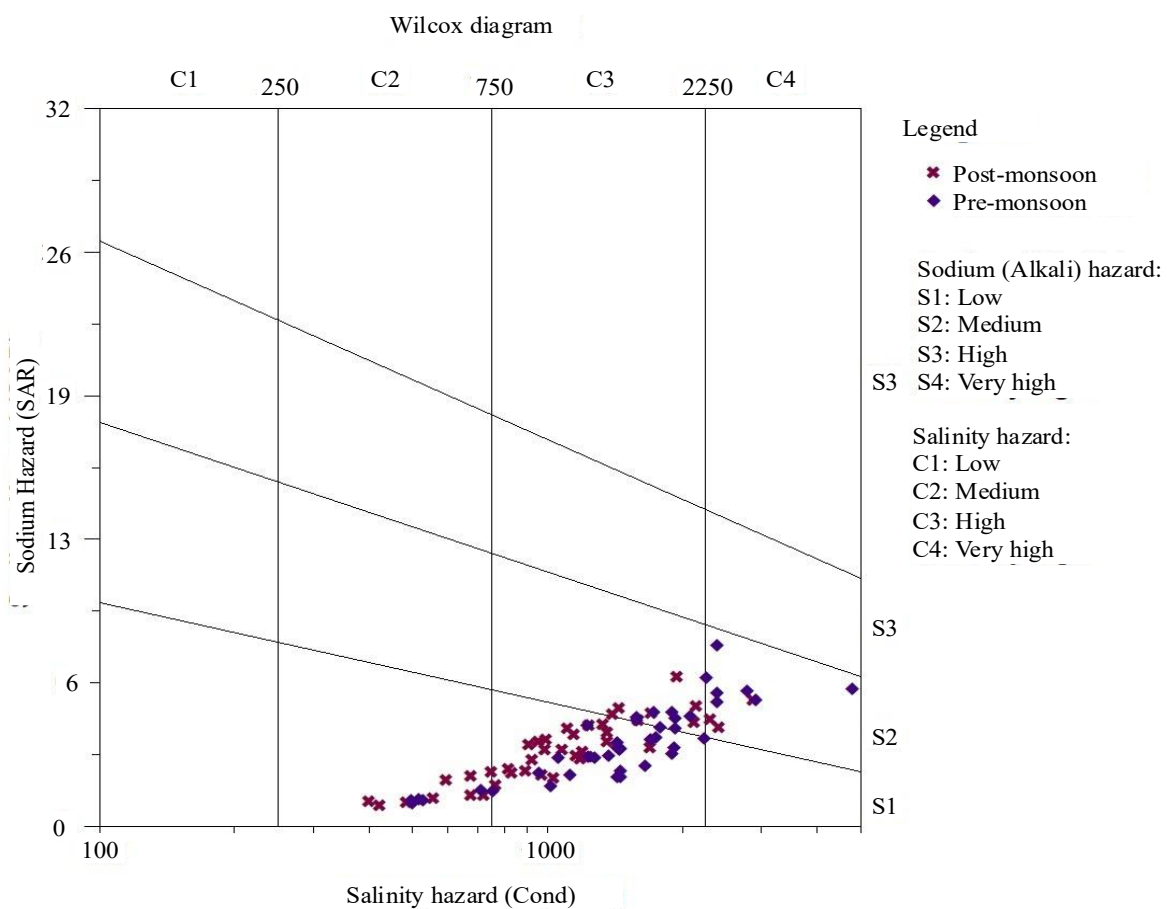


Figure 3. Wilcox diagram in the pre and post-monsoon seasons.

Table 1. Statistics of groundwater chemistry of the study area.

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	7.80	9.40	8.26	12	7.56	9.22	8.28	21	6.5 - 8.5
EC ($\mu\text{S}/\text{cm}$)	495	4766	1623	-	400	2867	1197	-	-
TDS (mg/l)	317	3050	1038	86	232	1835	784	81	500
TH as CaCO_3	230	876	420	100	188	720	354	98	500
Ca^{2+} (mg/l)	48	156	88	62	44	132	76	43	75
Mg^{2+} (mg/l)	28	122	51	91	20	98	41	71	30
Na^+ (mg/l)	38	420	179	-	30	350	150	-	-
K^+ (mg/l)	2	32	9	-	2	24	8	-	-
Cl^- (mg/l)	86	770	306	57	56	520	238	36	250
CO_3^{2-} (mg/l)	0	48	14	-	0	36	14	-	-
HCO_3^- (mg/l)	50	410	131	-	42	350	140	-	-
SO_4^{2-} (mg/l)	24	330	154	24	18	280	111	10	200
F^- (mg/l)	0.24	2.70	1.30	67	0.15	2.11	1.08	64	1.5
NO_3^- (mg/l)	18	188	53	50	12	140	50	41	45
SAR (meq/l)	0.98	8.06	3.68	-	0.90	6.63	3.35	-	-
%Na (meq/l)	25	68	46	-	26	65	46	-	-
KR (meq/l)	0.29	2.10	0.89	-	0.31	1.80	0.88	-	-
RSC (meq/l)	-11.10	-2.74	-5.95	-	-9.51	-2.11	-4.44	-	-
PI (meq/l)	39	74	56	-	37	74	58	-	-

NOTE: SAR (Sodium adsorption ratio), KR-kelley's ratio, RSC (Residual sodium carbonate) and PI-permeability index

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

Category	Ranges	Pre-monsoon (%)	Post-monsoon (%)
Based on TDS (mg/L)			
Fresh water	0 – 1,000	50	76
Brackish water	1,000 – 10,000	50	24
Saline water	10,000 – 100,000	00	00
Brine	>1,00,000	00	00
Based on Hardness (mg/L)			
Soft	0 - 75	Nil	Nil
Moderate to Hard	75 – 150	Nil	Nil
Hard	150 – 300	19	31
Very Hard	>300	81	69
Sodium Adsorption Ratio (meq/L)			
Excellent	<10	100	100
Good	10-18	Nil	Nil
Doubtful	18-26	Nil	Nil
Unsuitable	>26	Nil	Nil
Residual Sodium Carbonate (RSC) (meq/L)			
Suitable	<1.25	100	100
Marginal	1.25-2.5	Nil	Nil
Unsuitable	>2.5	Nil	Nil
Kelley's Ratio (Kelley 1951)			
Suitable	<1	62	67
Marginal	1-2	36	33
Unsuitable	>2	2	Nil

Table 3. Assigned weights, relative weights and respective (WHO 2011) standards of IPs.

Parameter	pH	TDS	Na ⁺	K ⁺	Ca ⁺²	Mg ⁺²	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁻²	NO ₃ ⁻	F ⁻
S _i	8.5	500	200	12	75	50	500	250	200	45	1.5
w _i	4	5	2	2	2	1	3	3	4	5	5
W _i	0.111	0.139	0.056	0.056	0.056	0.028	0.083	0.083	0.111	0.139	0.139

Table 4. Estimated WQI and respective classification of drinking water.

Sample ID	Owner name	Village name	Pre-monsoon		Post-monsoon	
			WQI	Class	WQI	Class
1	Nagesh	Thakkalapadu	58	Good water	51	Good water
2	Rambabu	Bhaironi Banda	101	Poor water	84	Good water
3	Narayana	Bhaironi Banda	57	Good water	51	Good water
4	Sri Umamaheshwara swamy temple	Bhaironi Banda	49	Excellent water	52	Good water
5	Stream water	Ramanjapuram	72	Good water	70	Good water
6	Grampanchayath	Uppalancha	117	Poor water	98	Good water
7	Paramesh Poultry farm	Ramanjapuram	98	Good water	88	Good water
8	Cheruvu	Kothapally	131	Poor water	119	Poor water
9	Temple	Kothapally	104	Poor water	89	Good water
10	Harish, Agricultural land	Kothapally	84	Good water	75	Good water
11	Eddamma temple	Manimidde	80	Good water	69	Good water
12	Agricultural land	Manimidde	122	Poor water	103	Poor water
13	Grampanchayath	Gurujala	114	Poor water	88	Good water
14	Shivalayam	Gurujala	139	Poor water	115	Poor water
15	Krishnamurthy, agricultural land	Ramgiri	96	Good water	79	Good water
16	Cheruvu	Ramgiri	76	Good water	66	Good water
17	Lingaiah	Shalilingotam	72	Good water	57	Good water
18	Grampanchayath	Ambaripeta	163	Poor water	138	Poor water
19		Ambaripeta	116	Poor water	97	Good water
20	Gangaiah	Chittalore	85	Good water	73	Good water
21	Maszid	Chittalore	156	Poor water	140	Poor water
22	Grampanchayath	Tudimidi	60	Good water	49	Excellent water
23	Grampanchayath	Vaddipalem	59	Good water	45	Excellent water
24	Ch Simhadri	Jalanigudem	108	Poor water	82	Good water
25	Cheruvu	Magammagudem	78	Good water	68	Good water
26	S. Ramesh	Thirumalagudem	92	Good water	81	Good water
27		Shaligowraram	93	Good water	76	Good water
28	ZPHS	Shaligowraram	100	Good water	83	Good water
29	R. Ayodhya	Uttkur	177	Poor water	145	Poor water
30	Grampanchayath	Uttkur	241	Very Poor water	177	Poor water
31	Agricultural land	Madaram	127	Poor water	105	Poor water
32	Grampanchayath	Madaram	114	Poor water	95	Good water
33	Bharath Petrol Bunk	Vangamarthy	103	Poor water	78	Good water
34	Church	Vangamarthy	79	Good water	63	Good water
35	Lingaiah, Agricultural land	Perka Kondaram	92	Good water	82	Good water
36	Grampanchayath	Perka Kondaram	107	Poor water	95	Good water
37	R. Bixam	Vallala	53	Good water	43	Excellent water
38	Domestic	Vallala	69	Good water	66	Good water
39	Sarswathi temple	Adlur	107	Poor water	83	Good water
40	JCM Church	Adlur	98	Good water	82	Good water
41	Rukkamma, house	Akaram	93	Good water	75	Good water
42	Shasirekha, house	Akaram	76	Good water	67	Good water

Methodology

To assess groundwater quality, 42 sampling sites were selected across the study area, and water samples were collected during the pre- and post-monsoon seasons. A comprehensive chemical analysis was conducted for the following parameters: pH, Electrical Conductivity, Total Dissolved Solids, and concentrations of major ions, including Calcium, Magnesium, Sodium, Potassium, Carbonate, Bicarbonate, Chloride, Sulfate, Nitrate, and Fluoride. The analysis was performed using standardized methods outlined in the APHA 2005 guidelines. Specific equipment was utilized to measure each parameter, including Hachsens ION for pH and Conductivity Meters for Electrical Conductivity. The concentrations of the major ions were determined using a variety of techniques, including flame photometry, EDTA titration, titration with standard HCl, AgNO₃ titration, spectrophotometry, and ion-selective electrodes. The total cations and anions were expressed in milliequivalents per liter for each sample (Eq. 1) [6,9,10, 24–27].

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

Several common criteria were applied to evaluate groundwater's suitability for various uses, such as drinking and irrigation, including the Water Quality Index (WQI), which helped determine its safety for both drinking and irrigation purposes.

Groundwater for Irrigation uses

The parameters were assessed using multiple criteria, including Kelly's ratio, magnesium hazard, and USSL diagrams, to evaluate their suitability for irrigation.

Sodium Adsorption Ratio (SAR)

Richards' water evaluation method for agricultural purposes was initially conceptualized by Richards (1954), whereby parameters can be computed using a mathematical formula (Eq. 2).

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

Kelly's Ratio

Kelly (1963) developed an irrigation water rating method, wherein a ratio less than unity is deemed ideal for agricultural applications, a ratio exceeding unity is considered unsuitable, and a ratio ranging between one and two encompasses marginally adequate irrigation practices. The ratio can be quantified using the following formula (Eq. 3) [1].

$$KR = \frac{Na^+}{Ca^{+2}+Mg^{+2}} \quad (3)$$

Permeability Index (PI)

Prolonged irrigation with water containing high levels of certain ions, such as sodium, calcium, magnesium, and bicarbonate, can impact soil conductivity, requiring an assessment of its permeability. The permeability index values were determined using a specific equation (Eq. 4).

$$PI = \frac{(Na^++K^+)+\sqrt{HCO_3^-}}{Ca^{+2}+Mg^{+2}+Na^++K^+} \times 100 \quad (4)$$

USSL diagram

In 1954, a U.S. laboratory developed a water analysis model to assess the suitability of groundwater for irrigation.

Drinking Water Quality

Groundwater quality was compared with the standard guidelines stipulated by IS 10500 (BIS 2012) for drinking and public health. A comparison of parameters revealed that the concentrations of cations (Na⁺, Ca²⁺, Mg²⁺, and K⁺) and anions (HCO₃⁻, CO₃²⁻, Cl⁻, and SO₄²⁻) fell within the established maximum allowable limits.

RESULTS AND DISCUSSION

General Characteristic of Groundwater Chemistry

Analysis of groundwater chemistry in the study area revealed conformity with standard drinking water specifications (BIS, 2012). The pH values recorded a mean range of 7.80 to 9.40 during the pre- and post-monsoon seasons (Table 1), suggesting predominantly basic/alkaline conditions. These findings align with the stipulated pH limit of 6.5–8.5 (BIS 2012) for potable water in the region. Additionally, the EC mean values of 1623 $\mu\text{S}/\text{cm}$ during the pre-monsoon and post-monsoon seasons (Table 1) were 1197 $\mu\text{S}/\text{cm}$.

Cations

Variations in calcium concentrations within the pre- and post-monsoon periods ranged from 48 to 156 mg/L and 44 to 132 mg/L, respectively, with 62% and 43% of samples exceeding the non-acceptable limit of 75 mg/L as per BIS 2012. This phenomenon is attributed to the predominance of plagioclase feldspars in the host rock [21,22]. Magnesium values fluctuated between 28 and 122 mg/L and 20 and 98 mg/L, with 91% and 71% of groundwater samples surpassing the prescribed limit of 30 mg/L for drinking water (BIS 2012). The magnesium concentrations originate from the dissolution and ion exchange of plagioclase feldspars, which are characteristic of granitic terrain. Sodium and potassium values exhibited ranges of 38–420 mg/L and 2–32 mg/L in the pre-monsoon period and 30–350 mg/L and 2–24 mg/L in the post-monsoon period, respectively.

Anions

Analysis of groundwater quality revealed significant variations in total alkalinity and chloride concentrations between the pre-monsoon and post-monsoon seasons. The total alkalinity levels ranged from 0 to 498 mg/L and 0 to 350 mg/L, whereas the chloride concentrations varied from 86 to 770 mg/L and 56 to 520 mg/L, respectively. Notably, approximately 57% and 36% of the groundwater samples surpassed the acceptable chloride limit of 250 mg/L, as specified by the Indian Standards (BIS 2012). This elevated chloride content is attributed to the weathering of granitic rock, apatite, municipal waste, and industrial effluents. The sulfate concentrations also exhibited considerable fluctuations, with ranges of 24–330 mg/L and 18–280 mg/L, respectively. Interestingly, 24% and 10% of groundwater samples exceeded the acceptable sulfate limit of 200 mg/L, as stipulated by the BIS standards. Geochemical analysis indicated that the groundwater in the study region was predominantly characterized by the cationic sequence $\text{Na} > \text{Ca} > \text{Mg} > \text{K}$ and anionic sequence $\text{Cl} > \text{TA} > \text{SO}_4 > \text{NO}_3 > \text{F}$ in both seasons.

The total dissolved solids (TDS) concentrations in the study area exhibited considerable variability, ranging from 317 to 3050 mg/L and 232 to 1835 mg/L during both monsoon seasons. Approximately 86% and 81% of the sampled groundwater exceeded the permissible TDS limit of 500 mg/L, as specified by the Bureau of Indian Standards (BIS) in 2012. Water quality classification, as per established criteria, categorized approximately 50% of pre-monsoon samples as fresh and 50% as brackish, whereas the post-monsoon season displayed a contrasting ratio of 76% fresh to 24% brackish, as shown in Table 2. Elevated TDS levels in the study region are indicative of an increased risk of gastrointestinal disturbances, including laxative and stomach problems.

The TH as CaCO_3 concentrations varied from 230 to 876 mg/L and 188 to 720 mg/L (Table 1). For the pre- and post-monsoon periods, approximately 100% and 98% of water samples were examined, with a non-permitted level of 200 mg/L (BIS 2012). The classified water samples were 19% hard and 81% very hard in the pre-monsoon and post-monsoon seasons, respectively 31% and 69% (Sawyer et al. 2003).

GROUNDWATER FOR IRRIGATION USES

Sodium Adsorption Ratio (SAR)

High SAR waters induce this state, whereas fluids high in calcium and magnesium reverse it (Hem 1985). The unfavorable conditions generated by a high SAR can be improved by adding an appropriate quantity of gypsum or lime to the soil. Because water with a low SAR is desirable for agriculture, research on the appropriateness of groundwater in the investigated area has been conducted. The goal

of this table is to evaluate irrigation water based on its specific conductance and SAR ratios. According to the findings, all samples were ideal for irrigation both before and after the monsoon (Table 2).

Kelly's Ratio

The findings showed that 62% of the samples from the pre-monsoon and 67% of the samples from the post-monsoon seasons were appropriate. In the pre-monsoon and post-monsoon seasons, 36 % and 33% of the samples were marginal for irrigation, respectively. Only 2% of the pre-monsoon samples were found to be inappropriate for irrigation (Table 2).

Permeability Index (PI)

Doneen (1964) proposed a technique for rating irrigation water based on PI values, with water classified as I, II, or III. The results revealed that the majority of the wells fell into class I at 54% and 74%, class II at 44% and 26% in the pre- and post-monsoon seasons, and class III at 2% in the pre-monsoon season only (Figure 3 and Table 2). According to the study region's PI values, classes I and II are suitable for irrigation, with the exception of class III, which is unsuitable for the pre-monsoon season.

USSL diagram

A graphical representation (Figure 3) indicates that during the pre-monsoon season, a significant proportion of wells (75%) were classified into three water quality categories: high salinity-low sodium (C3S1, 50%), medium salinity-medium sodium (C2S3, 19%), and very high salinity-medium sodium (C4S2, 17%), with medium salinity-low sodium wells accounting for 14%. Conversely, in the post-monsoon season, the majority of wells (81%) were categorized into four classes: high salinity-low sodium (C3S1, 55%), medium salinity-low sodium (C2S1, 21%), high salinity-medium sodium (C3S2, 17%), and very high salinity-medium sodium (C4S2, 7%).

The classification of these water quality types corresponds to the USSSL diagram ratings, suggesting that these wells possess good, poor, and very poor water quality. This classification further suggests that groundwater salinity poses a significant hazard risk, exerting adverse effects on soil properties, plant growth, and agricultural productivity. Consequently, mitigation strategies can be implemented to reduce this hazard, and artificial groundwater recharge has been identified as a simple and effective method for minimizing plant salt uptake via root system infiltration, thereby promoting more favorable soil characteristics and increasing agricultural yields.

Water Quality Index (WQI)

To assess the general suitability of groundwater for drinking purposes, a water quality index (WQI) was employed, as advocated by Sahu and Sikdar (2008) to provide a comprehensive evaluation of groundwater quality for domestic use. The estimation of the WQI necessitates the incorporation of relevant water quality parameters, which are contingent on the intended utilization of the water. For this study, cations, anions, and heavy metals were considered, as they can have detrimental effects on human health. The chosen parameters included pH, total dissolved solids (TDS), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), bicarbonate (HCO_3^-), chloride (Cl^-), sulfate (SO_4^{2-}), nitrate (NO_3^-), and fluoride (F^-). Considering their health implications, weights of five were assigned to pH, TDS, NO_3^- , and F^- . The WQI for each groundwater sample was calculated using designated equations and compared with the criteria outlined by Sahu and Sikdar (2008).

$$W_i = \frac{w_i}{\sum_{n=1}^n w_i} \quad (6)$$

where, W_i is the relative weight, w_i is the weight assigned to an influential parameter relative to its impact on the overall quality of drinking water for human health. The water quality rating (q_i), according to Sahu and Sikdar, 2008, is given by:

$$q_i + \frac{C_i}{S_i} \times 100 \quad (7)$$

where q_i is the water quality rating, C_i and S_i represent the measured concentration in the sampled groundwater and the respective standard of the i th influential parameter. The water quality sub-index for each influential parameter (SI_i) is estimated as follows:

$$SI_i = q_i \times W_i \quad (8)$$

where, the symbols have their usual meanings.

$$WQI = \sum_{i=1}^n SI_i \quad (9)$$

In determining the overall water quality of groundwater in the study area, the results for w_i , W_i , SI_i and WQI using the selected IPs for each of the forty-two selected point sources are shown in Tables 3 and 4, respectively.

Notably, the Water Quality Index (WQI) values for the region fell within the range of 49 to 241 throughout the pre- and post-monsoon seasons, with mean values of 100 and 84, respectively. According to the established WQI criteria, excellent water quality corresponds to values of 50 or below, whereas values between 50 and 100 indicate good water quality. Conversely, poor water quality is denoted by values ranging from 100 to 200, values between 200 and 300 signify very poor quality, and values exceeding 300 are deemed unsuitable for human consumption. During the pre-monsoon season, 2% of the groundwater samples exhibited excellent water quality, 55% possessed good water quality, 41% demonstrated poor water quality, and 2% showed very poor water quality. In contrast, during the post-monsoon period, 7% of the groundwater samples had excellent water quality, 74% had good water quality, and 19% had poor water quality.

CONCLUSION

The study site exhibited predominantly unsuitable conditions for potable water. In terms of irrigation classifications, most samples demonstrated suitability for irrigation purposes, as evidenced by the Sodium Adsorption Ratio, Kelly's ratio, Residual Sodium Carbonate, Permeability index, and USSL categorizations. The Water Quality Index (WQI) results revealed a disparate trend, with 43% of samples indicating poor water quality during the pre-monsoon season and 19% in the post-monsoon period, contrasting with excellent to good water quality in the remaining samples. Physico-chemical parameter analysis indicated conflicting groundwater quality conditions for drinking and irrigation at various locations, primarily caused by geogenic and anthropogenic factors such as pesticide use, poultry, and dairy farming activities. Consequently, this study advocates the implementation of appropriate remedial measures to mitigate degraded groundwater quality conditions.

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