International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor 2025: 7.089

Hydrochemical Characterization and Water Quality Evaluation for Drinking and Irrigation in Shaligouraram, Nalgonda District

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Abstract: ***Forty-two groundwater samples were collected from the vicinity of Shaligowraram Mandal, Nalgonda District, in the Indian state of Telangana, spanning both pre- and post-monsoon seasons. These samples were subjected to physico-chemical characterization, encompassing parameters such as pH, electrical conductivity, total dissolved solids, and major ion composition. In accordance with established criteria, the irrigation water quality of the study area was evaluated through indices including the sodium adsorption ratio, kelly ratio, residual sodium carbonate, and permeability index. The salinity classification of the groundwater samples falls within the 'high salinity-low sodium' and 'high salinity-medium sodium' categories. Notably, the Water Quality Index for the study area exhibits a relatively low value of 43%, with 19% of the samples identified as being of poor quality, while the remaining categories exhibit excellent to good physico-chemical characteristics. Comparison with the Indian Standard IS 10500 reveals that approximately 80% of the samples fail to meet drinking water quality standards. Conversely, approximately 80% of the samples are deemed suitable for agricultural use, indicating a potentially promising prospect for irrigation purposes.***

Keywords: Hydrogeochemistry, Water quality Index, Drinking and Irrigation

1. Introduction

Groundwater is a vital freshwater resource that supports drinking water supply, agriculture, and industrial activities, particularly in hard rock regions where groundwater is mainly stored in weathered and fractured zones due to limited infiltration (Satyanarayana et al. 2017; Chaudhary and Satheeshkumar 2018). Groundwater quality is governed by aquifer geology, water–rock interactions, climatic conditions, and anthropogenic activities, making hydrogeochemical evaluation essential for sustainable resource management (Kaur et al. 2017; Laxman et al. 2022). Globally, nearly 2.5 billion people depend on groundwater for drinking and irrigation, while increasing agricultural and industrial demand continues to intensify pressure on this finite resource (UNESCO 2012; WHO 2004).

Irrigated agriculture occupies about 20% of cultivated land but contributes nearly 40% of global food production, leading to a steady increase in groundwater abstraction. Therefore, assessing groundwater quality for drinking and irrigation is essential for sustainable water resource management. In the present study area, the northern region is characterized by hard rock formations with low-yielding aquifers, where agriculture is the dominant land use and groundwater is extensively exploited. Hence, a comprehensive hydrogeochemical assessment is necessary to determine its suitability for domestic and agricultural use.

2. 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 (Fig. 1). This area encompasses approximately 220 square kilometers of rocky terrain, featuring large monolithic rocks on its periphery. Dominant granitic geology shapes the semi-arid landscape of the study region. However, the area is plagued by groundwater over-exploitation, which has led to declining water quality. The primary objectives for this study are to identify the spatiotemporal patterns and incidence of nitrate and fluoride contamination, as well as the underlying hydrogeochemical processes driving their enrichment.

3. Methodology

A total of 42 groundwater samples were collected during the pre- and post-monsoon seasons to assess groundwater quality in the study area. The samples were analyzed for pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), and major ions, including Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{-}, Cl^{-}, SO_4^{2-}, NO_3^{-}, and F^{-}, following standard procedures prescribed by APHA (2005). Physicochemical parameters were measured using calibrated instruments, while major ions were determined using flame photometry, titrimetric methods, spectrophotometry, and ion-selective electrodes.

4. Results and Discussion

Groundwater chemistry

Groundwater chemistry was evaluated against the drinking water standards prescribed by BIS (2012). The pH ranged from 7.8–9.4 during both seasons, indicating slightly alkaline conditions. Electrical conductivity (EC) averaged 1623 µS/cm in the pre-monsoon and 1197 µS/cm in the post-monsoon period (Table 1), reflecting seasonal dilution after rainfall.

Calcium concentrations ranged from 48–156 mg/L (pre-monsoon) and 44–132 mg/L (post-monsoon), with 62% and 43% of samples exceeding the desirable limit of 75 mg/L

(BIS 2012). Magnesium varied between 28–122 mg/L and 20–98 mg/L, exceeding the desirable limit of 30 mg/L in 91% and 71% of samples, respectively. Elevated Ca^{2+} and Mg^{2+} concentrations are mainly associated with the weathering and ion exchange of plagioclase feldspars in the granitic aquifer (Laxman et al. 2019). Sodium and potassium ranged from 38–420 mg/L and 2–32 mg/L during pre-monsoon, and 30–350 mg/L and 2–24 mg/L during post-monsoon.

Total alkalinity ranged from 0–498 mg/L (pre-monsoon) and 0–350 mg/L (post-monsoon), while chloride concentrations varied from 86–770 mg/L and 56–520 mg/L, respectively. About 57% and 36% of samples exceeded the desirable chloride limit of 250 mg/L (BIS 2012), likely due to rock weathering and anthropogenic inputs such as municipal and industrial wastes (Kaur et al. 2017). Sulphate concentrations ranged from 24–330 mg/L and 18–280 mg/L, with 24% and 10% of samples exceeding the desirable limit of 200 mg/L.

Total dissolved solids (TDS) ranged from 317–3050 mg/L in the pre-monsoon and 232–1835 mg/L in the post-monsoon season. Approximately 86% and 81% of samples exceeded the desirable BIS limit of 500 mg/L. Based on the classification of Davis and DeWiest (1966) and Freeze and Cherry (1979), groundwater was classified as 50% fresh and 50% brackish during pre-monsoon, whereas post-monsoon samples comprised 76% fresh and 24% brackish (Table 2).

Total hardness (as $CaCO_3$) ranged from 230–876 mg/L and 188–720 mg/L during the pre- and post-monsoon seasons, respectively. Nearly all samples (100% in pre-monsoon and 98% in post-monsoon) exceeded the desirable limit of 200 mg/L (BIS 2012). According to Sawyer et al. (2003), groundwater was classified as hard (19% and 31%) and very hard (81% and 69%) during the pre- and post-monsoon seasons, respectively.

Groundwater for Irrigation uses

The parameters were assessed using multiple criteria including Sodium Adsorption ratio, Kelly's ratio, and Permeability Index and USSL diagrams to evaluate their suitability for irrigation.

Sodium Adsorption Ratio (SAR)

Richards' water evaluation method for agricultural purposes was initially conceptualised by Richards (1954), whereby parameters can be computed using a mathematical formula (Eq. 1).

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}} ------ (1)$$

In the present study, all groundwater samples were classified as suitable for irrigation based on SAR values during both the pre- and post-monsoon seasons (Table 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, while a ratio ranging between one and two encompasses marginally adequate irrigation practices. The ratio can be quantified using the following formula (Eq. 2).

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

Kelly's Ratio indicated that 62% (pre-monsoon) and 67% (post-monsoon) of groundwater samples were suitable for irrigation. Marginal-quality water accounted for 36% and 33% of samples during the respective seasons, while only 2% of pre-monsoon samples were unsuitable for irrigation (Table 2).

Permeability Index (PI)

Prolonged irrigation with water containing high levels of certain ions like sodium, calcium, magnesium and bicarbonate can impact soil conductivity requiring an assessment of its permeability. Permeability index values need to be determined using a specific equation (Eq. 3).

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

Based on the classification proposed by Doneen (1964), groundwater samples were grouped into Classes I, II, and III. Class I comprised 54% and 74% of samples, while Class II accounted for 44% and 26% during the pre- and post-monsoon seasons, respectively. Only 2% of pre-monsoon samples belonged to Class III (Table 2).

USSL diagram

A U.S. laboratory developed a water analysis model in 1954 to assess whether groundwater is suitable for irrigation.
The USSL classification (Fig. 3) showed that pre-monsoon groundwater was dominated by C3S1 (50%), followed by C2S3 (19%), C4S2 (17%), and C2S1 (14%). During the post-monsoon season, most samples belonged to C3S1 (55%), C2S1 (21%), C3S2 (17%), and C4S2 (7%). These classes indicate predominantly moderate to high salinity with low to medium sodium hazards.

Water Quality Index (WQI)

The Water Quality Index (WQI) ranged from 49 to 241, with mean values of 100 during the pre-monsoon and 84 during the post-monsoon season. Based on standard WQI classification, groundwater quality improved after the monsoon. During the pre-monsoon season, 2% of samples were classified as excellent, 55% as good, 41% as poor, and 2% as very poor. In the post-monsoon season, 7% of samples were excellent, 74% were good, and 19% were poor, indicating an overall improvement in groundwater quality following rainfall.

5. Conclusions

Groundwater quality in the study area is generally unsuitable for drinking at several locations due to elevated concentrations of major ions and dissolved solids. However, most samples are suitable for irrigation based on SAR, Kelly's Ratio, Permeability Index (PI), and USSL classification. The WQI indicated that 43% of pre-monsoon samples and 19% of post-monsoon samples were of poor quality, while the remaining samples ranged from excellent to good. The observed groundwater quality is controlled by both geogenic processes and anthropogenic activities, including intensive agriculture, pesticide application, poultry, and dairy farming. Therefore, appropriate groundwater management and pollution control measures are recommended to improve water quality and ensure its sustainable use.

Acknowledgments

We are thanks to the Department of Geology, University College of Science, Osmania University, Hyderabad, Telangana State, India for providing laboratory facilities.

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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 (µS/cm)	495	4766	1623	-		400	2867	1197	-	-
TDS (mg/l)	317	3050	1038	86		232	1835	784	81	500
TH as CaCO3	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^{-} (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 – 100000	00	00
Brine	>1,00,000	00	00
Based on Hardness (mg/L)	Ranges	Pre-monsoon (%)	Post-monsoon (%)
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)	Ranges	Pre-monsoon (%)	Post-monsoon (%)
Excellent	<10	100	100
Good	10-18	Nil	Nil
Doubtful	18-26	Nil	Nil
Unsuitable	>26	Nil	Nil
Residual Sodium Carbonate (RSC) (meq/L)	Range	Pre-monsoon (%)	Post-monsoon (%)
Suitable	<1.25	100	100
Marginal	1.25-2.5	Nil	Nil
Unsuitable	>2.5	Nil	Nil
Kelley's Ratio (Kelley 1951)	Range	Pre-monsoon (%)	Post-monsoon (%)
Suitable	<1	62	67
Marginal	1-2	36	33
Unsuitable	>2	2	Nil

Table 3: 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

Paper ID: SR26701145915 DOI: https://dx.doi.org/10.21275/SR26701145915

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

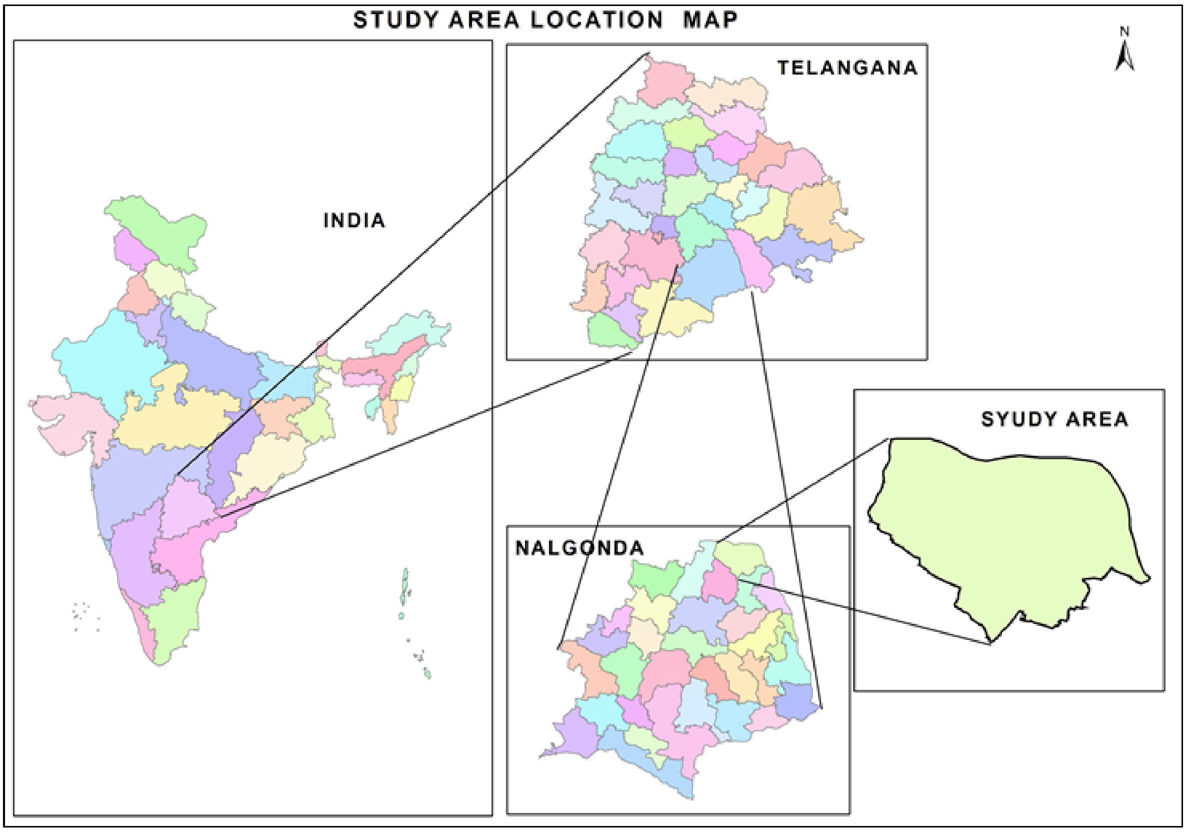

Figure 1: Location map of the study area

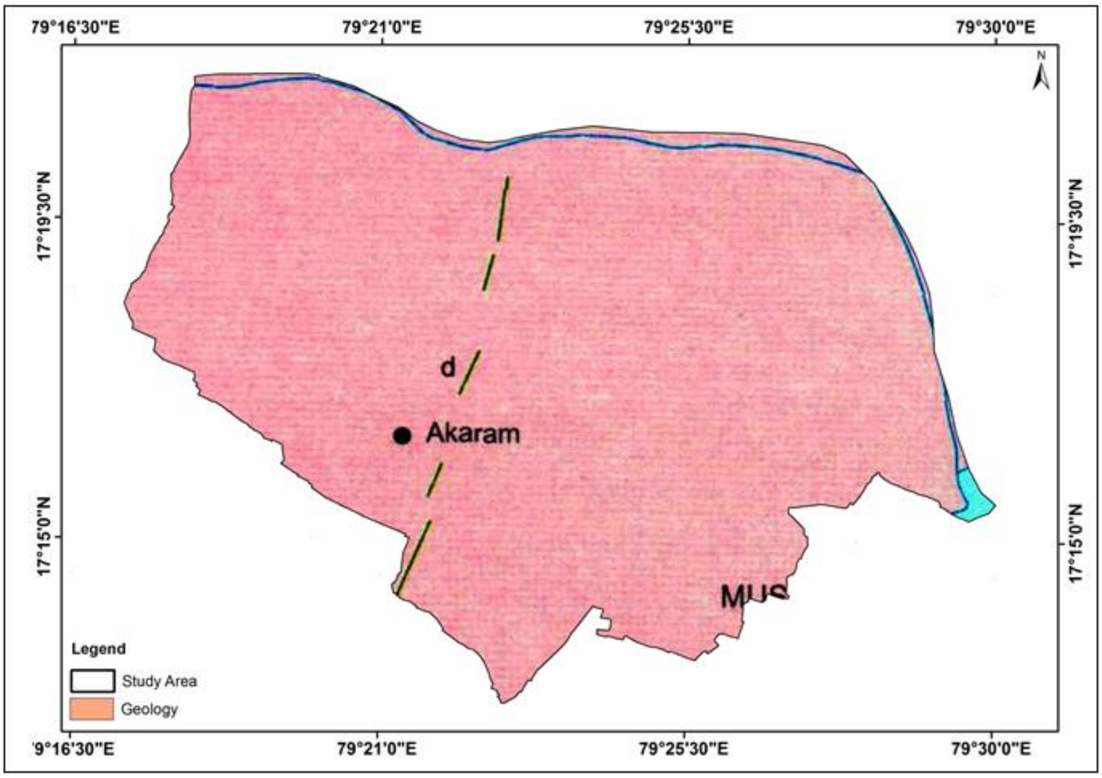

Figure 2: Geology map of the study area

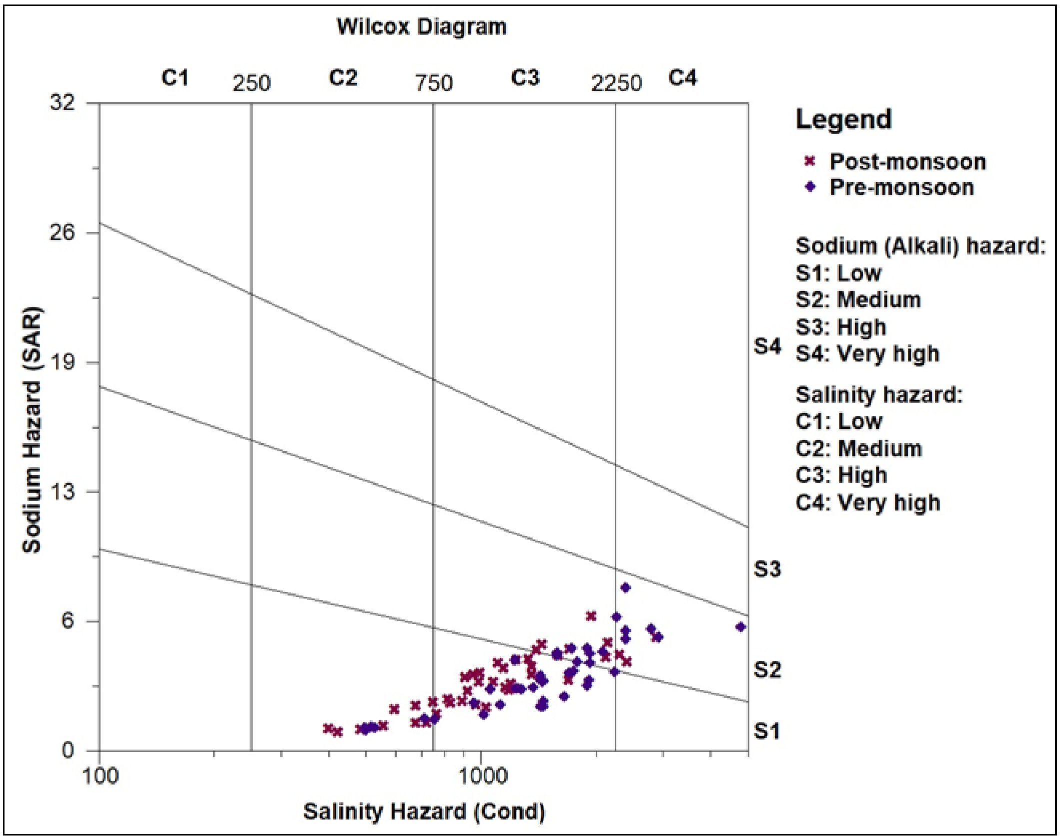

Figure 3: Wilcox diagram in the pre and post-monsoon seasons