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Assessment of Groundwater Quality Index, Suitability for Irrigation and Domestic Purposes in Krishna-Godavari Delta Region, Southern India

R. Kannan[1]*, K. Appala Naidu[1], Palika Lavanya[2], Abhrankash Kanungo[1], M.V. Ramana Murty[1], Kirti Avishek[3]

[1]Andhra Pradesh Space Applications Centre, Vijayawada, Andhra Pradesh, India -520010
[2]University of College of Engineering, JNTU, Kakinada, Andhra Pradesh, India – 533003
[3] Birla Institute of Technology, Mesra, Ranchi, Jharkhand, India – 835215

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Abstract

The water quality index (WQI) is a significant indicator for evaluating the quality of drinking water for end-users. The present work is aimed to assess the groundwater quality of the Krishna Godavari delta region in Andhra Pradesh State, for knowing its suitability for domestic, irrigation, and drinking purposes by calculating the WQI parameters and comparing it with WHO and Indian Standards. A total of 105 groundwater samples each for both Pre-monsoon and Post-monsoon periods have been collected during June 2017 and January 2018. The following 11 parameters were taken into account when calculating the WQI: pH, Electrical Conductivity (EC), Total Hardness (TH), Calcium (Ca2+), Magnesium (mg2+), Bicarbonate, Chloride(Cl-), Nitrate (Na+), Sulphate, Potassium (K+), and Total Dissolved Solids (TDS). Based on the WQI result, the samples were divided into five categories: Excellent, Good, Poor, Very Poor, and unfit for drinking purposes. In Pre-monsoon and Post monsoon season, the water quality index is 9%, 25%, 30%, 22%, 15% respectively 16%, 41%, 31%, 7%, and 5%. It can be concluded that during pre-monsoon and post-monsoon season 67% and 43% of water is not suitable for drinking purposes respectively and hence they require treatment before usage.

Keywords: Groundwater, Hydrochemical Characteristics, Water Quality Index (WQI), Krishna Godavari Delta, Correlation analysis

1 Introduction

Groundwater is used all over the world for domestic and commercial water supply and irrigation [19],[21]. Due to rapid population growth and the accelerated pace of industrialization, the demand for freshwater has risen significantly over the last few decades and hence its quality and quantity should not be compromised [18]. Most agricultural development activities endanger human health, especially in the context of excessive fertilizer use and unsanitary conditions [10] [22]. Rapid urbanization, particularly in developing countries such as India, has affected groundwater availability and quality due to over-exploitation and inappropriate disposal of waste, particularly in urban areas [12]. The quality of groundwater is still important to the environment, so it is important to maintain it is high quality at all times in order not to risk the health of the user. In theory, three main activities are influenced by groundwater supplies [13]. The first of those practices is the improper use in agricultural areas of fertilizers and pesticides. The second is environmental wastewater that is untreated / partially treated. Finally, the result is unnecessary pumping and poor aquifer management. The operation of solid waste disposal is one of the elements generating groundwater contamination in open un-engineered landfills due to a lack of pollution control interventions such as waterproof sheets, leachate treatment tanks, monitoring wells, etc [1]. Depending on the form and quantity of the dissolved salts, groundwater used for domestic and irrigation purposes will differ greatly in quality [17]. It comprises a wide range of different amounts of dissolved inorganic chemical constituents arising from chemical and biochemical reactions between water and geological materials [14]. The dissolved salts should be present in relatively small but essential quantities in irrigation water. They derive from rock and soil dissolution or weathering, including the dissolution of lime, gypsum, and other slowly dissolved minerals from the soil [15].

The objective of this study is to investigate the spatial variations in groundwater quality and to identify the source of pollution. This study is to assess the groundwater quality using geospatial analysis techniques and water quality indexing based on the availability of physicochemical parameters of the groundwater, analysis the water quality for irrigation purposes, Krishna Godavari delta region, Andhra Pradesh.

2 Study Area

The study area is Krishna - Godavari delta region its covered four districts, Andhra Pradesh, India, and lies 80° 27' 58.447" E, 15° 54' 37.888" N to 82° 32' 8.063" E 17°15'16.855"N. The area of study runs from east to west, 12km wide from the shore to the in-land and 360km long from north to south. The area is bordered on the east by the Bay of Bengal, on the north by the Krishna River, and on the south by the Godavari River (Fig. 1). The temperature ranges from 20 to

Corresponding author: R. Kannan, Andhra Pradesh Space Applications Centre, Vijayawada, Andhra Pradesh, India -520010, E-mail: maadhukanna@gmail.com

37°C in the winter and 35 to 42°C in the summer, with the highest temperatures occurring in May and June (Centre Groundwater Board) (CGWB). In June, the monthly average humidity was 65%, and in November, it was 91%. The monthly evapotranspiration varies from 4.2 to 8.2 mm/day. Precipitation is more noteworthy during the northeast monsoon (October to December) than the southwest monsoon (October to December) (June to September). From a geological standpoint, the terrain is alluvium. Alluvial deposits are the most youthful layer, comprising of sand and dirt saved by waterways. Groundwater happens in unconfined and bound springs in alluvium and dissolved translucent charnockite developments.

3 Materials and Methods

A total number of 105 samples during the Pre-monsoon and post-monsoon season periods were collected from different selected locations of the study area. The directions of the inspecting areas as far as scopes and longitudes were taken with the GPS. The examples were gathered from different sources, for example, private hand pumps, government hand pumps, and bore wells during June 2016, and January 2017. The examples were saved according to the strategy endorsed in the American Public Health Association manual [6]. The depth of fewer than 30m was considered a shallow aquifer while the depth greater than 30m is considered a deep aquifer.

The samples were analyzed for pH, EC, CO_3, HCO_3, Ca^{2+}, Mg^+, Na^+, K^+, SO_4^{2-}, and Cl^-. All of the analyses followed the American Public Health Association's established methods [6]. The pH was measured by Systronics Water Quality Analyzer 371F using a portable consort electrochemical analyzer model. A flame photometer (Systronics mk-1/mk-III) was used to quantify sodium and potassium). The Parameters Calcium, Magnesium, bicarbonate, and Chlorine were examined by the titrimetric method. Total dissolved solids (TDS) and Total Hardness (TH) of water were calculated using the formulae proposed by Lloyd and Heathcote (1985) and Sawyer and McCarty (1978), respectively.

$$\text{TDS (mg/l)} = \text{EC } (\mu\text{S/cm}) \times 0.64 \quad (1)$$

$$\text{TH (mg/l)} = 2.497\ Ca^{2+}\ \text{(mg/l)} + 4.115\ Mg^{2+}\ \text{(mg/l)} \quad (2)$$

The water quality determines by Water Quality Index (WQI) analysis, for Irrigation water quality was determined from various indices Magnesium Hazard (MH), Residual Sodium Carbonate (RSC), Sodium Percent (Na%), Sodium Adsorption Ratio (SAR), Kelly's Ratio and Permeability Index (PI).

3.1 Water Quality Index (WQI) Analysis

The Water Quality Index (WQI) system is useful for water quality deficiency analysis. WQI helps to track water quality problems and to increase the effectiveness of shielding measures [20]. The classification of water quality for suitability for drinking purposes is an important parameter. For the calculation of WQI, the criteria for drinking purposes as suggested by BIS (1998) were considered (Table 1).

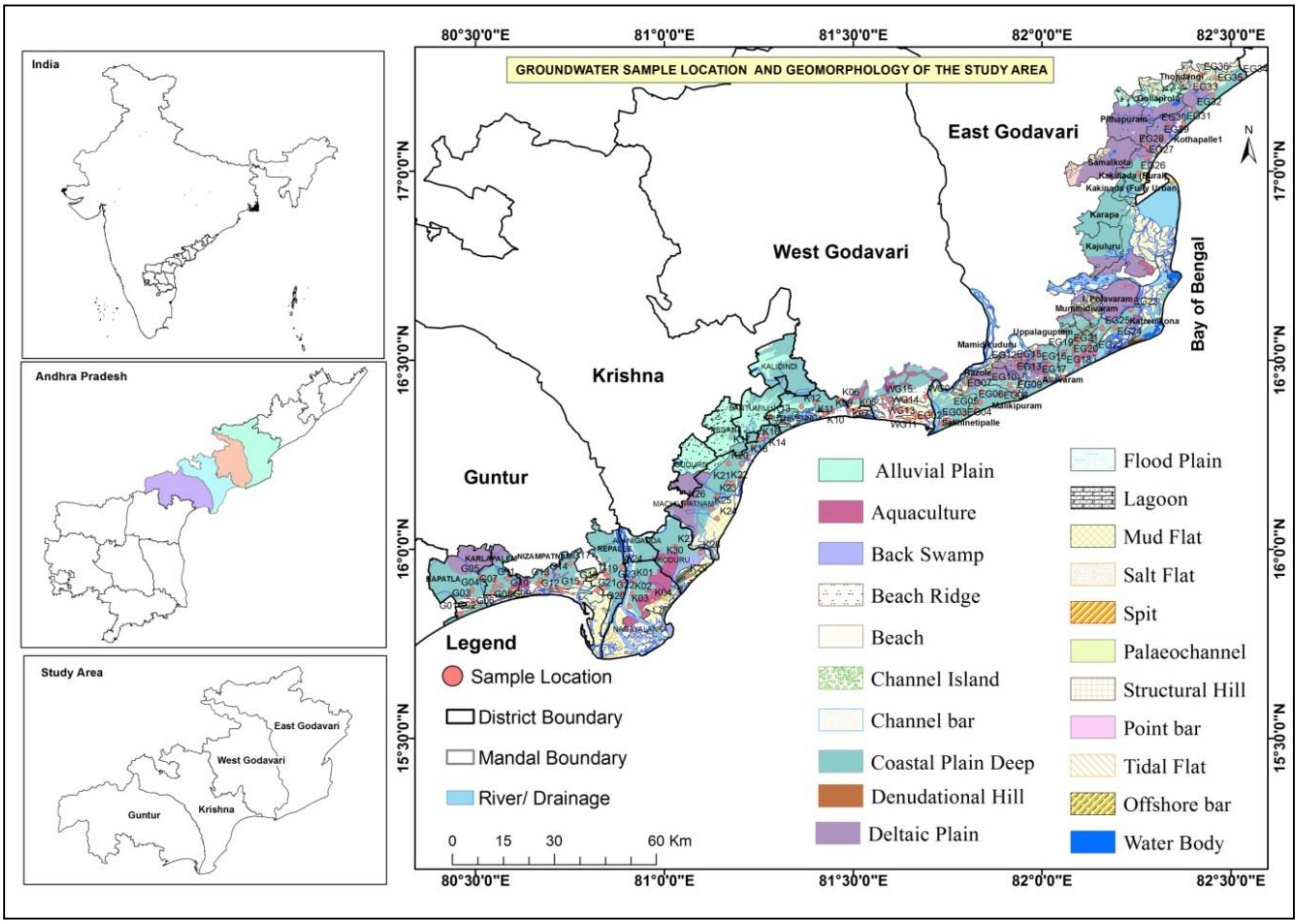


Fig. 1: Study area

The WQI measurement was carried out for drinking purposes by assigning weights (wi) according to the relative value of each chemical parameter. Due to the key importance of water quality measurement, criteria such as total dissolved solids were given the maximum weight of 5. Other parameters such as calcium, magnesium, sodium, total hardness (TH), and potassium, based on their prominence for water quality purposes, gave weight between 1 and 4. Three steps are taken for calculating the groundwater quality index. In the first step, a weight (wi) was assigned to each of the 11 parameters according to its relative significance in the overall water quality for drinking purposes. The maximum weight of 5 was allocated to the total dissolved solids parameter because of its significant significance in the evaluation of water quality. Magnesium alone may not be harmful if the minimum weight of 2 is given as magnesium. In the second step, the relative weight (Wi) is computed using the following equation:

$$\mathrm{Wi} = \mathrm{wi} / \sum_{i=1}^{n} wi \quad (3)$$

where Wi is the relative weight, wi is the weight of each parameter and 'n' is the number of parameters. Calculated relative weight (Wi) values of each parameter are given in below Table 1. In the third step, a quality rating scale (qi) 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, and the result multiplied by 100:

$$\mathrm{qi} = (\mathrm{Ci} / \mathrm{Si}) \times 100 \quad (4)$$

where qi is the quality rating, Ci is the concentration of each chemical parameter in each water sample in mg/l, and Si is the Indian drinking water standard for each chemical parameter in mg/l, according to the guidelines of the BIS 10500 (2004-2005) (Bureau of Indian Standards). 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 Eqs. (5 and 6).

$$\mathrm{SIi} = \mathrm{Wi} \times \mathrm{qi} \quad (5)$$

$$\mathrm{WQI} = \sum SIi \quad (6)$$

where SIi is the sub-index of the i^{th} parameter, qi is the rating based on the concentration of the i^{th} parameter, n is the number of parameters. An accurate rational assessment of groundwater quality is needed for determining the integrated effect of the various parameters that are relevant and significant to a particular use is proposed to express the water quality for different uses. The WQI techniques have successfully demonstrated their capability in the groundwater quality of the Krishna Godavari delta region. Water quality types were determined based on WQI. The computed WQI values range from 27.7 to 1055.8 in the pre-monsoon season and 32.2 to 1454.8 in the post-monsoon season, respectively. The WQI range and type of water can be classified in table.2. The overall groundwater quality index of the Krishna-Godavari delta region for the pre-monsoon and post-monsoon seasons has been presented in Fig. 2 and 3.

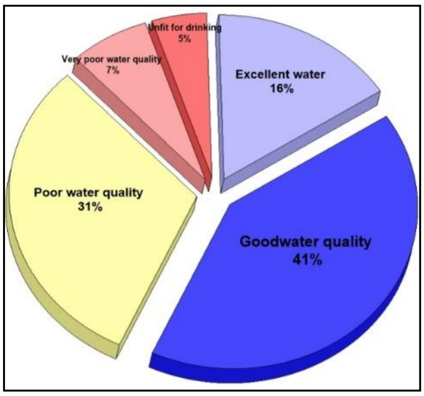
The calculation of WQI for individual samples is represented in Table 2. During the dry season, 9% of groundwater samples represent ''excellent water'', 34%indicate ''good water'', and 30% shows ''poor water'',12% indicate ''very poor water'', 15% indicate ''Unfit for drinking water' during wet season 16% of groundwater samples represent' excellent water'' and 41% indicate ''good water'', 31% indicate ''Poor water'', 7% ''Very poor water'', 5% indicate ''Unfit for drinking''. The dry season samples exhibit unfit for drinking purposes in greater percentage (15%) when compared with wet season effluents, and agricultural impact [2]. The detailed water quality maps are shown in fig: 4 and fig: 5(5%). This may be due to effective leaching of ions, overexploitation of groundwater, direct discharge of

Table: 1 Relative weight of chemical parameters

S. No	Chemical Parameter	Indian Standard	Weight (wi)	Relative weight (Wi)
1	pH	6.5-8.5	4	0.121
2	Electrical Conductivity (EC)	1500	3	0.090
3	Total dissolved solids (TDS)	1500	5	0.151
4	Bicarbonate (HCO_3^-)	500	2	0.060
5	Chloride (Cl^-)	600	5	0.151
6	SO_4^{2-}	250	3	0.090
7	Calcium (Ca^{2+})	200	2	0.060
8	Magnesium (Mg^{2+})	150	2	0.060
9	Nitrate (Na^+)	200	3	0.090
10	Potassium (K^+)	12	2	0.060
11	Total hardness (TH)	500	2	0.060
Total			∑wi = 33	∑Wi = 1

Table: 2 According to the WQI type of water

S. No	Water Quality Index (WQI)	Water Quality Status	Pre - Monsoon (%)	Post-Monsoon (%)
1	<50	Excellent water	9	16
2	50-100	Good water quality	34	41
3	100-200	Poor water quality	30	31
4	200-300	Very poor water quality	12	7
5	>300	Unfit for drinking	15	5



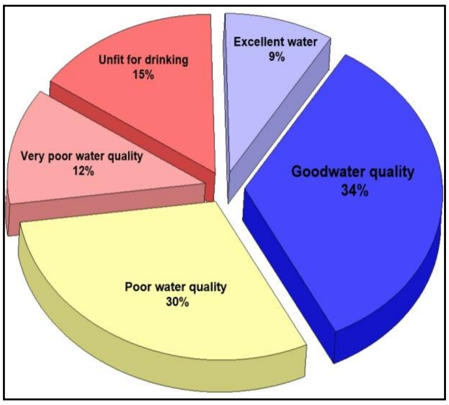


Fig. 2 & 3: Water Quality index Classification in Pre-monsoon season and Post monsoon season

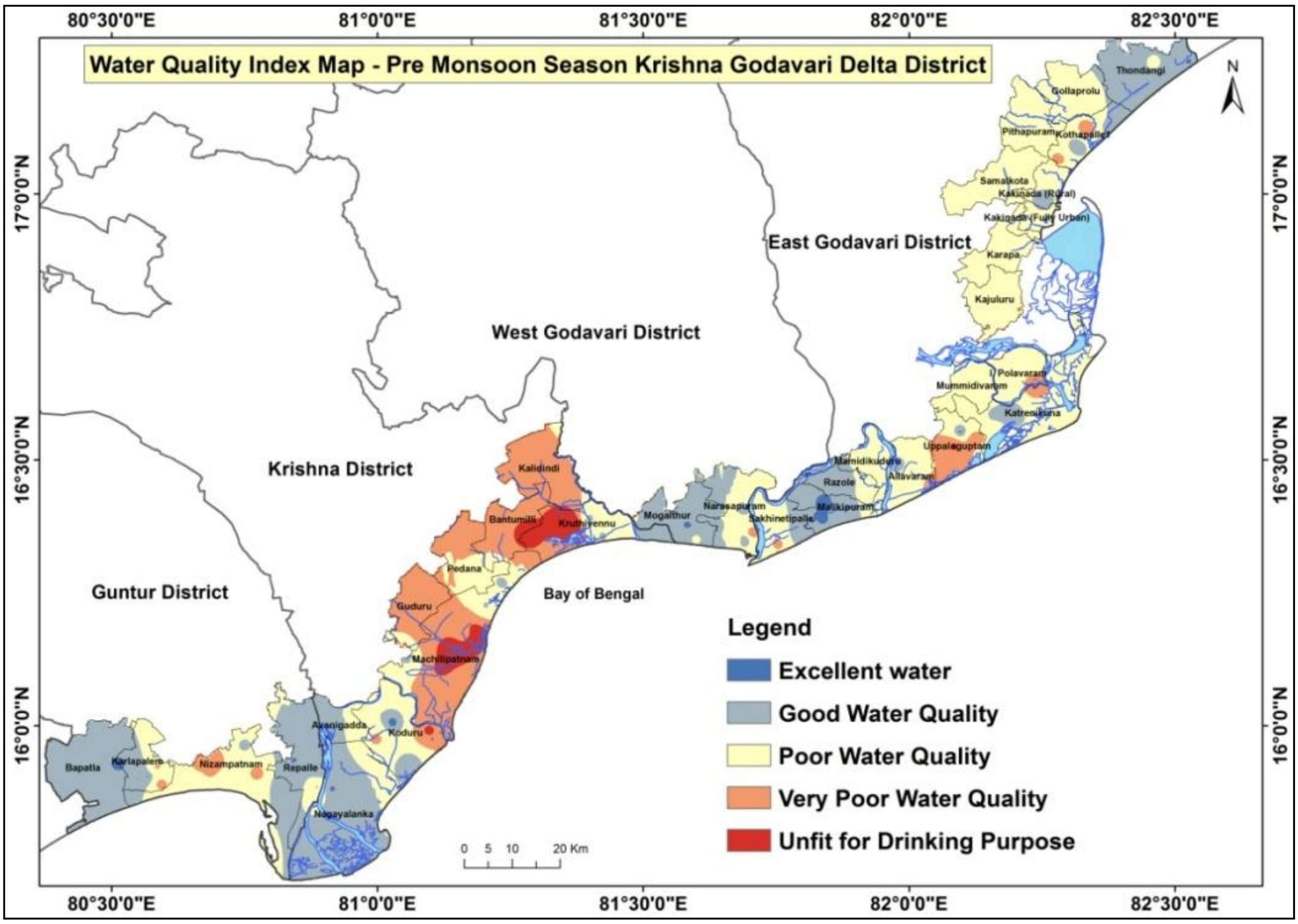


Fig. 4: Water quality index map for Pre-monsoon season in Krishna Godavari delta region

3.2 Correlation Coefficient Matrix

Statistical analysis can be applied to represent the data of the water research work and is useful in understanding the internal relations of various parameters used for the physio-chemical analysis. Correlation is a broad class of statistical relationships between two or more variables. Therefore, it can be viewed as a normalized covariance calculation. To find a predictable relationship that can be manipulated in practice, correlation analysis is beneficial. It is used to calculate the frequency and statistical significance of the relation between two or more parameters of water quality. The correlation coefficients (R) were estimated and a correlation matrix was obtained. In this case, 'R' is a dimensionless index that ranges from -1.0 to +1.0, including 0.0. A widely used measure to determine the relationship between two variables is the Correlation Coefficient. Showing how one variable predicts the other is a metric. Table: 3 mentioned displays the 'R' values from 0 to 1 and the indication of relation. The values of pre-monsoon and post-monsoon season correlation coefficients for various variables are listed in tables .4 and Table 5.

Table: 3 the relation values for a correlation coefficient

Value of 'R'	Indication of the relation
0 - 0.2	Very poor correlation
0.2 - 0 .4	Slightly significant correlation
0 .4 - 0.6	Moderate correlation
0 .6 - 0.8	High correlation
0.8 - 1	Very high correlation

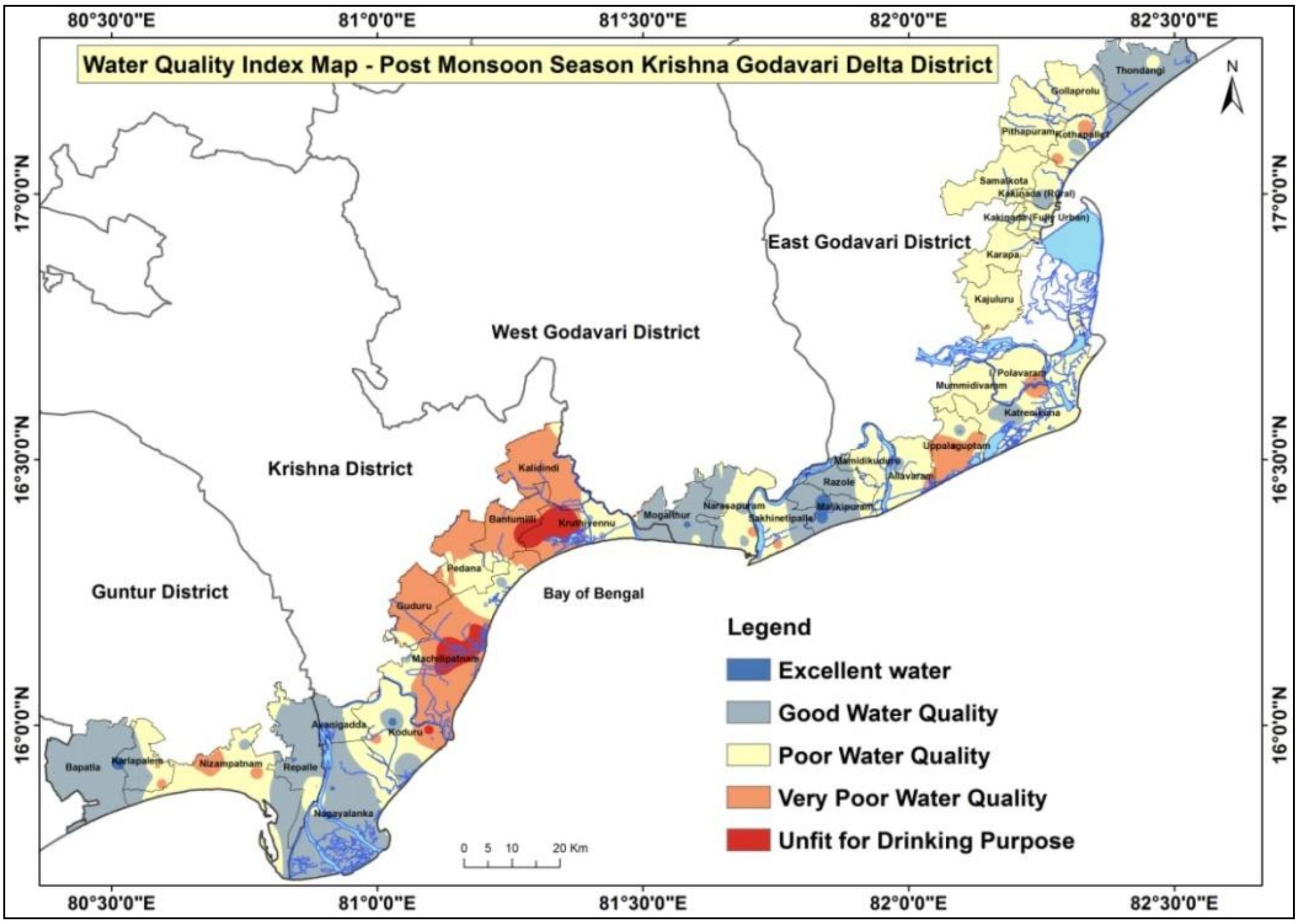


Fig. 5: Water quality index map for Post monsoon in Krishna Godavari delta region

Table 4: Correlation Coefficient Matrix (R) of Pre-monsoon season

	pH	EC	TDS	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+	TH
pH	1											
EC	0.005	1										
TDS	-0.001	**0.998**	1									
CO_3^{2-}	0.528	0.133	0.128	1								
HCO_3^-	0.306	0.522	0.514	0.378	1							
Cl^-	-0.033	**0.982**	**0.986**	0.077	0.401	1						
SO_4^{2-}	0.003	0.713	0.724	0.058	0.430	0.679	1					
Ca^{2+}	-0.073	0.682	0.687	0.021	0.121	0.711	0.525	1				
Mg^{2+}	-0.038	**0.933**	**0.933**	0.003	0.425	**0.930**	0.642	0.7181	1			
Na^+	0.002	**0.979**	**0.985**	0.121	0.492	**0.980**	0.730	0.6024	**0.883**	1		
K^+	0.135	0.547	0.539	0.197	0.591	0.449	0.512	0.4428	0.536	0.452	1	
TH	0.093	0.581	0.580	0.213	0.181	0.604	0.240	0.6304	0.546	0.527	0.152	1

Table 5: Correlation coefficient matrix (R) of Post monsoon season

	pH	EC	TDS	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+	TH
pH	1										
EC	0.198	1									
TDS	0.198	**0.990**	1								
HCO_3^-	0.250	0.191	0.191	1							
Cl^-	0.206	**0.987**	**0.987**	0.138	1						
SO_4^{2-}	0.100	0.764	0.764	0.303	0.707	1					
Ca^{2+}	-0.013	0.746	0.746	0.197	0.749	0.632	1				
Mg^{2+}	0.179	**0.959**	**0.959**	0.171	**0.962**	0.727	0.766	1			
Na^+	0.220	**0.983**	**0.983**	0.154	**0.969**	0.725	0.679	**0.923**	1		
K^+	-0.047	0.250	0.250	0.328	0.195	0.429	0.304	0.244	0.199	1	
TH	0.165	0.628	0.628	0.320	0.621	0.667	0.398	0.631	0.618	0.258	1

In the pre-monsoon season, a very high positive correlation was found between TDS and EC, High negative correlation was found between pH and Mg. A high correlation was found between Electrical Conductivity with SO_4^{2-}, Ca^{2+}, TDS with SO_4^{2-}, Ca^{2+}, Cl^- with SO_4^{2-}, Ca^{2+} with Mg^{2+}. The very poor correlations were found in pH with K^+, EC with CO_3^{2-}, CO_3^{2-} with Na and K^+, K^+ with TH.

Accordingly, in the post-monsoon season period, a high positive correlation was found between Electrical Conductivity with TDS, Cl^-, Mg^{2+}, Na^+; TDS with Cl^-, Mg^{2+}, Na^+; Cl^- with Mg^{2+}, $Na^{+,}$ and Mg^{2+} with Na^+. A very poor correlation was found between pH with EC, TDS, Mg^{2+}; TDS with HCO_3^-, Na^+ with K^+.

3.3 Water Quality for Irrigation Purposes

An assessment of groundwater suitability for irrigation is based on an assessment of the sodium content compared with the total cations. High sodium waters are not appropriate for irrigation because sodium ion participates in processes of cation trade that appear to influence soils capacity to help crop productivity. The Na^+ ion adsorbs on cation sites, which allows soil aggregates to spread and thus decreases the permeability of the soil [3] [4]. Five indices were evaluated for the irrigation suitability of groundwater used in the study area: (a) Sodium Adsorption Ratio (SAR), (b) Permeability Index (PI), (c) Sodium Percentage (Na%), (d) Magnesium Hazard (MH) and (e) Residual Sodium Carbonate (RSC) was used to assess groundwater suitability for irrigation activities.

3.4 Relation Electrical Conductivity with Sodium Adsorption Ratio (SAR)

The contents of Electrical Conductivity and sodium are critical for irrigation water classification. The Irrigation water is categorized into four categories, such as low salinity (EC <250 μS/cm), medium (250-750 μS/cm), high salinity (750-2250 μS/cm), and extremely high salinity (2,250-5,000 μS/cm). The high Electrical Conductivity in water contributes to saline soil formation, while alkaline soil is caused by elevated sodium content in water. According to EC values, in the pre-monsoon season, 4.8% of groundwater samples are medium, 50.5% of groundwater samples are high, and 44.8% of groundwater samples have very high salinity for irrigation. Furthermore, in the post-monsoon season, 8.7% of groundwater samples are medium, 40% of groundwater samples are high, and 50.5% of groundwater samples are very high salinity for irrigation in the post-monsoon season. The sodium concentration is an important parameter in groundwater geochemistry. An increase in sodium concentration affects the soil properties, which results in deterioration of soil permeability [3].

The tendency of sodium to increase is a proportion on the cation exchange sites at the expense of other types of cation estimated by the ratio of the sodium content of calcium plus magnesium in the water. High sodium ions in water affect the permeability of the soil and cause infiltration problems and replace calcium and magnesium ions adsorbed on the clays thus cause dispersion of soil particles. This, results in the breakdown of soil aggregates and becomes hard when dry, and reduces infiltration rates of water and air. The sodium adsorption ratio (SAR) was calculated using the following equation:

$$SAR = (Na^+)/ \{[(Ca^{2+}) + (Mg^{2+})]/2\}^{1/2} \quad (7)$$

Concentrations of all ions have been expressed in meq/l. SAR values less than 10 indicate excellent, 10-18 indicate good, values 18-26 indicate doubtful and greater than 26 indicate groundwater is unsuitable for irrigation purposes. In the present study the SAR values range from 1.2 - 36.5 meq/l in pre-monsoon with an average of 10.3meq/l, and 0.3-52.54 meq/l during post-monsoon with an average of 9.5meq/l respectively. According to SAR values 67.6% and 73.1% excellent for suitability in seasons, 13.3% and 11.5% for Good category, 12.4% and 9.6% for doubtful for irrigation purpose, and 6.7% and 5.8% is unsuitable for irrigation purpose in both the season.

3.5 WILCOX and USSL Classification

The SAR versus EC values for groundwater samples of the study area was plotted in the USSL graphical diagram of irrigation water. Sodium Adsorption Ratio (SAR) values are plotted against Electrical Conductivity (EC) values along Y-axis and X-axis respectively in the U.S. Salinity diagram to classify water samples (Fig: 6 and Fig:7), Also the suitability of the irrigation was classified based on the SAR values table. 6. A few of the water samples are fall in the C2-S1, C3-S1, and C3-S1 classes (post-monsoon) and C1-S1, C2-S1, C3-S1, and C4-S1 classes (pre-monsoon), and hence can be considered moderately suitable for irrigation.

Table 6: Suitability for irrigation based on SAR values

SAR (meq/l)	Suitability for irrigation	Pre Monsoon		Post Monsoon	
		No. of samples	Percentage of samples (%)	No. of samples	Percentage of samples (%)
< 10	Excellent	71	67.6	76	73.1
10 -18	Good	14	13.3	12	11.5
18-26	Doubtful	13	12.4	10	9.6
>26	Unsuitable	7	6.7	6	5.8

Table 7: Comparison of salinity classes and Electrical conductivity of Groundwater samples

Salinity classes	EC (dS m-1)	Quality	Pre Monsoon		Post monsoon	
			No. of samples	Percentage of samples	No. of samples	Percentage of samples
C1	<0.25	Low salinity	0	0	0	0
C2	0.25 - 0.75	Medium Salinity	5	4.8	9	8.7
C3	0.75 - 2.25	High Salinity	53	50.5	42	40.0
C4	>2.25	Very High Salinity	47	44.8	53	50.5

Table 8: Sodium percent (Na %) of water classes

Na%	Classification	Pre Monsoon		Post Monsoon	
		No. of samples	Percentage of samples (%)	No. of samples	Percentage of samples (%)
<20	Excellent	0	0	2	1.9
20-40	Good	1	1.0	13	12.5
40-60	Permissible	12	11.4	32	30.8
60-80	Doubtful	61	58.1	47	45.2
>80	Unsuitable	31	29.5	10	9.6

Overall, 46 % of samples fall in C3S1 and C2S1 fields, indicating medium to high salinity and low alkalinity water this can be used for irrigation. Also, 21% of samples fall in the C4S1 field, indicating very high salinity and low sodium hazard, which restrict its suitability for irrigation, 13% of samples fall in the C4S2 field, indicating very high salinity and medium sodium hazard, 12% of samples fall in C4S3 field, indicating very high salinity and high sodium hazard, which is indicating unsuitable for continues uses, 7% of samples fall in C4S4 field, indicating very high salinity and very high sodium hazard, which is indicating unsuitable for irrigation purpose in pre-monsoon season. Furthermore, in the post-monsoon season,41% of samples fall in C3S1 and 9% of C3S3 fields, indicating high to medium salinity and medium sodium hazard water, this water required amendments and leaching needed, 23 % of samples fall in C4S1 field, and 10% of samples fall inC4S2 field, indicating low salinity and low sodium hazard, this limits its use on sodium-sensitive crops such as avocados must be cautioned, 7% samples fall in C4S4 field, indicating high salinity and high sodium hazards, generally irrigation unsuitable for use.

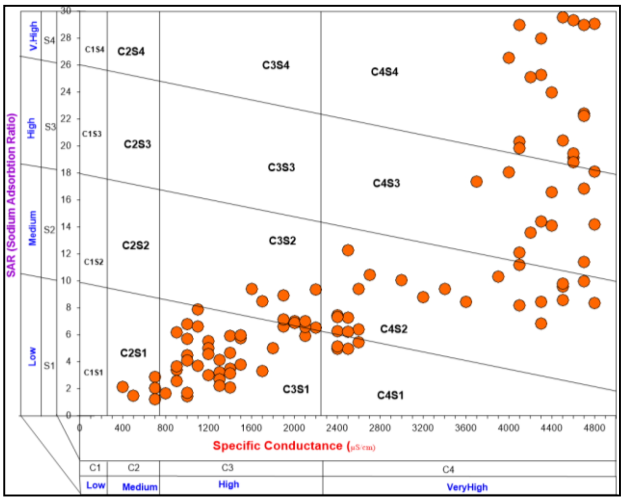


Fig. 6: USSL classifications of groundwater samples in the pre-monsoon season

3.6 Sodium Percentage (Na %)

Sodium percentage or percent sodium is very important for classifying the irrigation water because sodium by the process of Base Exchange replaces calcium in the soil thereby reduces the permeability of the soil, which eventually affects the plant growth. The percent sodium can be defined as

$$Na\% = \frac{\text{Na+K}}{Ca+Mg+Na+K} \text{ x } 100 \tag{8}$$

The suitability of water for irrigation based on Na% given in Table.8shows that pre-monsoon and post-monsoon season 58.1 % and 45.2% of the samples are doubtful while 29.5 and 9.6 % are unsuitable for pre-monsoon and post-monsoon season. The groundwater samples of the study area are plotted in Wilcox's diagram to classify the water for irrigation, wherein Electrical Conductivity is plotted against Na% (Fig. 8). The table.8explainsthat in pre-monsoon 11% of the groundwater samples are good to permissible for agriculture and 43% of samples in the post-monsoon season while the rest of them are doubtful to unsuitable.

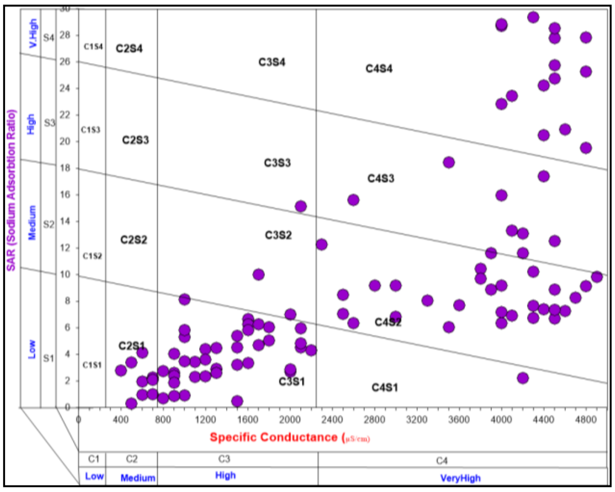


Fig. 7: USSL classifications of groundwater samples in the post-monsoon season

3.7 Residual Sodium Carbonate

Residual sodium carbonate (RSC) also influences the suitability of water for irrigation uses. RSC can be estimated by subtracting the number of alkalines (Ca^{2+} +Mg^{2+}) from the carbonates (CO_3^{2-} + HCO_3^-). When the sum of carbonates is more than calcium and magnesium, there may be a possibility of complete precipitation of Ca^{2+} and Mg^{2+}. If the carbonates are less than alkaline, it indicates that the residual sodium carbonate is zero. A high value of RSC in water leads to an increase in the adsorption of sodium in the soil. Based on RSC values, water can be classified as safe (<1.25), marginally suitable (1.25 - 2.5), and unsuitable (>2.5). In this study area, in pre-monsoon season 79% of samples area indicates suitable for irrigation, 15% sample unsuitable, accordingly post-monsoon season 82% samples are suitable and 11% samples are suitable for irrigation uses in the study area shown in the Table 9.

3.8 Permeability Index (PI)

The permeability of soil is influenced by sodium, calcium, magnesium, and bicarbonate contents in the soil which also influences the quality of irrigation water on long-term use. Doneen (1964) has evolved a criterion for assessing the suitability of water for irrigation based on PI. The soil permeability is affected by the long-term use of irrigation water as it is influenced by the Na^+, Ca^{2+}, $Mg^{2+,}$ and HCO_3^- the content of the soil [5]. WHO (1989) gave a criterion for assessing the suitability of groundwater for irrigation based on the PI, where concentrations are in meq/l [7] [9]). It is defined as:

$$PI = \frac{\mathrm{Na}+\sqrt{HCO3}}{Ca+Mg+Na} \text{ x } 100 \tag{9}$$

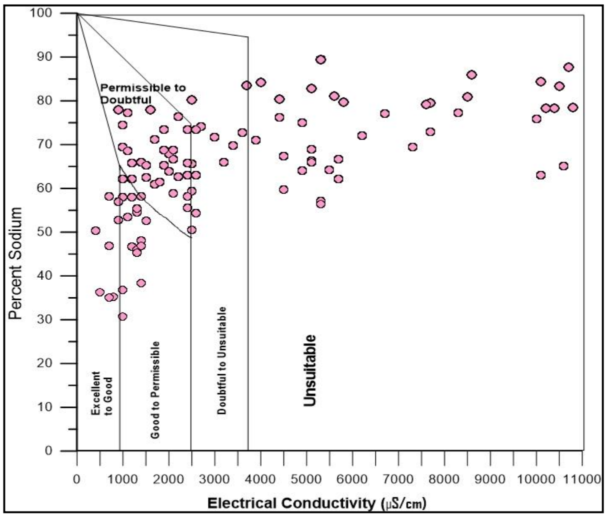


Fig. 8: Suitability of groundwater for irrigation based on Electrical Conductivity and Sodium Percent in Pre-monsoon

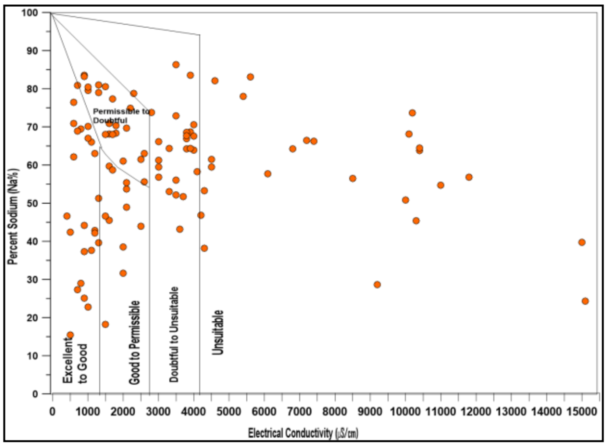


Fig. 9: Suitability of groundwater for irrigation based on Electrical Conductivity and Sodium percent in Post- monsoon

The groundwater may be classified as (a) excellent, (b) good, and (c) unsuitable based on the permeability indices. Classes 1 and 2 are suitable for irrigation, with 75% or more maximum permeability, and class 3 is unsuitable, with 25% maximum permeability. Where concentrations are in meq/l, put forth that class I and II waters are considered to be suitable for irrigation, while class III water is unsuitable for irrigation. In the pre-monsoon season, 9% of groundwater samples were not suitable for irrigation, and in the post-monsoon season, two samples were unsuitable for irrigation, whereas the rest of the samples are good for irrigation purposes shown in fig.10 and Fig. 11.

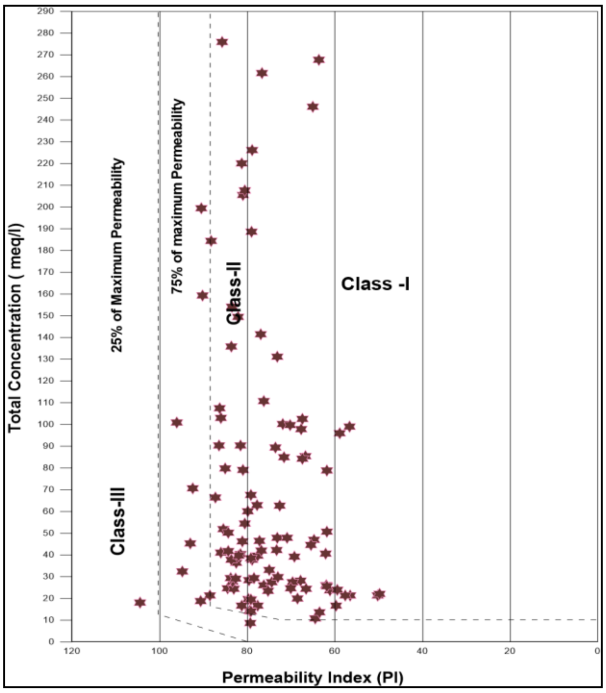


Fig. 10: Suitability of groundwater for irrigation based on PI in the Pre-monsoon season

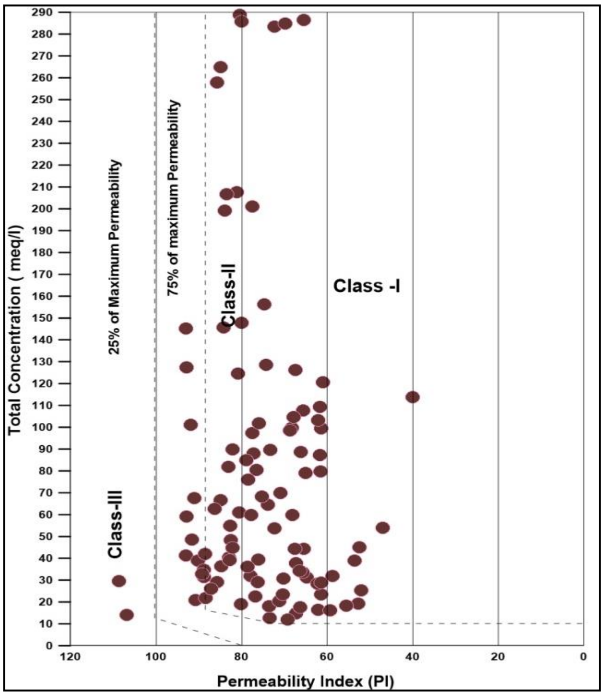


Fig. 11: Suitability of groundwater for irrigation based on PI in Post monsoon season

Table 9: Groundwater quality based on Residual Sodium Carbonate (RSC)

RSC (meq/l)	Suitability for irrigation	Pre-monsoon		Post-monsoon	
		No. of samples	Percentage of samples (%)	No. of samples	Percentage of samples (%)
<1.25	Safe	83	79.0	86	82.7
1.25–2.5	Moderate	6	5.7	6	5.8
>2.5	Unsuitable	16	15.2	12	11.5

Table 10: Irrigation water quality classification based on Kelley's Ratio

Kelly Ratio	Pre Monsoon No. Samples	Pre Monsoon Percentage (%)	Post Monsoon No. Samples	Post Monsoon Percentage (%)
<1	20	19.0	33	31.7
>1	91	86.7	71	68.3

Table 11: Irrigation water quality classification based on Magnesium Hazards

Magnesium Ratio	Pre Monsoon No. Samples	Pre Monsoon Percentage (%)	Post Monsoon No. Samples	Post Monsoon Percentage (%)
<50	100	95.2	101	97.1
>50	5	4.8	3	2.9

3.9 Kelly's Index (KI)

Sodium measured against Ca^{2+} and Mg^{2+} is used to calculate Kelley's ratio. Kelly's index of more than 1 (<1) shows an extra concentration of sodium in waters (Table.10). Hence, groundwater with Kelly's index less than 1(>1) is suitable for irrigation, while those with a ratio of more than 1 are unsuitable. The Kelly's index in the present study during pre-monsoon season 86% and 68% in the post-monsoon season period were unsuitable for irrigation, the remaining samples area was less than 1 suitable for irrigation purposes.

3.10 Magnesium Hazard (MH)

The calcium and magnesium do not behave equally in the soil system, and magnesium deteriorates soil structure particularly when waters are sodium-dominated and highly saline. A high level of Mg^{2+} is usually due to the presence of exchangeable Na^{+} in irrigated soils. [16] Introduced an important ratio called an index of magnesium hazard. Magnesium hazard value of more than 50% would adversely affect the crop yield as the soils become more alkaline:

$$\mathrm{MH} = \frac{Mg^{2+}}{(Ca^{2+} + Mg^{2+})} X\ 100 \qquad (10)$$

The MH values are reported to be in the range of 6.3% to 85.5%. Out of the 105 samples, 95.2% of the samples showed a magnesium ratio below 50%, suggesting their suitability, while only 5% fall in the unsuitable category with magnesium hazard more than 50% in the pre-monsoon season, accordingly post-monsoon season 97.1% of samples are below 50% category and 2.9% samples are unsuitable, indicating their adverse effect on crop yield.

4 Conclusion

Groundwater is an important source of drinking water for many people around the world. Groundwater pollution typically leads to low drinking water quality, water depletion, high cleaning costs, high-cost alternative water sources, and possible health issues. Based on the examination of groundwater, the geochemical condition and the many locations not appropriate for drinking and irrigating groundwater in the study region could be understandable. The study found that groundwater is slightly alkaline in the study area Water Quality Index was used to determine the groundwater quality and its suitability for drinking purposes. According to WQI, during the pre-monsoon season, 9% of groundwater samples ‘‘excellent water’’,34% indicate ‘‘good water’’, and 30% shows ‘‘poor water’’,12% indicate ‘‘very poor water’’, 15% indicate ‘‘Unfit for drinking water’’ during post-monsoon season 16% of groundwater samples ‘‘excellent water’’, 41% indicate ‘‘good water’’, 31% indicate ‘‘Poor water’’, 7% ‘‘Very poor water’’ and 5% indicate ‘‘Unfit for drinking’’. This situation was thought to be due to the effective leaching of ions, overexploitation of groundwater, direct discharge of effluents, and agricultural impact.

The different indexes extracted from the study show that in some places groundwater is sufficient for irrigation purposes in agriculture. The graphic geochemical representation of the consistency of the soil water indicates that most water samples are of high to medium salinity at low alkaline hazards. SAR, PI, Na%, and RSC are determined to provide permissible irrigation use of groundwater. The sodium threat to soils would be caused by the long-term use of such groundwater for irrigation. The effects on crop yields and soil properties would be negative. However, before irrigation, mixing low and high salinity water is advised to reduce the salinity threat in local areas. Finally, based on these studies, recommendations were made to local authorities to implement the collective use of groundwater-surface water to strictly track and regulate regions of low groundwater quality to ensure that the resource is used sustainably and securely.

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Availability of data and materials

All data generated or analyzed during this study are included in this article. The raw data are available from the corresponding author upon reasonable request.

Competing interests

The authors declare they have no competing interests.

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Competing interests

The authors declare that there are no conflicts of interest. The authors also certify that there are no ethical issues involved.

Ethical issue

Authors are aware of and comply with, best practices in publication ethics specifically about authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language. Also, all procedures performed in studies involving human participants were by the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. All procedures performed in this study involving animals were following the ethical standards of the institution or practice at which the studies were conducted.

Authors' contribution

All authors of this study have a complete contribution to data collection, data analyses, and manuscript writing.

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