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Research Article

Groundwater quality assessment by Water quality index (WQI) and Multivariate statistical analysis (MSA) for coastal zones of Srikakulam district, Andhra Pradesh

A. Ganapathi Rao
Department of Basic Sciences and Humanities (Mathematics), GMRIT, Rajam, Vizianagaram, India
V. Pavan Kumari
Department of Mathematics, Malla Reddy Engineering College, Hyderabad, India
Manoj Kumar Karnena*
Department of Environmental Science, School of Science, GITAM (Deemed to be) University, Visakhapatnam, India

*Corresponding author: Email: manojkumarenviron@gmail.com

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Abstract
Groundwater is a vital resource for the drinking water supply to the people in the areas residing in the coastal zones. Rapid industrialization increased the human population, and anthropogenic activities led to groundwater pollution. The water quality should be continuously monitored to analyse the suitability of the water, and it is only possible by the water quality index. In the current study, we attempted to determine the groundwater quality of the Mandal headquarters of the coastal zones of the Srikakulam district, Andhra Pradesh, by using the water quality index (WQi) considering the parameters pH, Electrical conductivity, Total Dissolved Solids, Total Hardness, calcium and magnesium, potassium, and sodium, human health assessment tool, and multivariate statistical analysis. The results found that the WQi of the coastal zones ranged from 49.6 to 361.7, and in the post-monsoon season, the Etcherla Mandal station water was not advisable for drinking. Human health risk assessment showed that children in these sampling stations are more prone to the non-carcinogenic health risks associated with nitrate pollution. Proper reduction measures in the sampling areas must be taken to depreciate nitrate and seepage into the groundwater. Piper plots and correlation matrices showed the anion-cation interaction, and the principal component analyzed and showed the pollution sources. The current study concluded that anthropogenic activities continuously deteriorate groundwater quality, indirect saltwater intrusion was identified, and groundwater treatment is necessary before consumption.

Keywords: Groundwater, Human health, Index, Risk, Water quality

INTRODUCTION

The rapid increase in population and urbanization amplified the demand for groundwater (GW). According to the literature available, it was estimated that 1.5 billion people worldwide rely on groundwater for drinking (Karnena *et al.,* 2022; Li *et al.,* 2021). A developing country like India has a greater need for groundwater as they act as a significant source for drinking. The quality and quantity of the GW are affected at a high rate owing to man-made activities. The GW was affected majorly due to the three main activities. Firstly, due to the overutilization of recalcitrant inorganic fertilizers in the agroindustry. Secondly, they dumped the industrial wastewater directly into the environment and nearest body streams and improper pumping and management of the aquifers (Karnena and Saritha, 2019). In addition, solid waste disposal and single-use product disposal (Vara *et al.,* 2019) in unengineered land is also considered a factor for groundwater contamination as the contaminates or leachate seeps from the soil to the groundwater aquifers (Girija *et al.,* 2007). According to the WHO, 2004 nearly eighty per cent of the diseases caused by the water-born are due to the contamination of the water, which are considered waterborne diseases. Restoration of the groundwater aquifers contaminated with the contaminants is complicated; thus, preventive measures must be followed to prevent pollution. Therefore, there is a need to monitor the groundwater aquifers to avoid contamination regularly. The groundwater quality is deciphered by the physicochemical analysis of the water (Panneerselvam *et al.,* 2020), and it also helps in measuring the health hygiene of the water used for consumption.

The reason for selecting the Mandal headquarters of the district is that these are densely populated, and more people reside near these areas. The collected samples were analyzed according to the Bureau of Indian standards and the Water Quality Index (WQi) performed. The WQi are the arithmetic mean calculation used to determine the water quality in the sampling areas. Horton (1965) was the scientist who invented the analysis, and many researchers (Karnena *et al.,* 2022; Adimalla *et al.,* 2022) adopted and performed these calculations to identify the groundwater quality. Later Karnena and Vara (2019) developed various models for the WQi based on the rating and weightage of the water quality physicochemical parameters obtained by the arithmetical mean. The WQi are dimensionless, and values range from 0 to 200. These have unique digital ratings to help express the water's quality, viz. excellent to unfit for drinking. The WQi is a critical tool for comparing the groundwater quality with the management and helps to select appropriate treatment. This method used the assessment parameters like pH, EC, TDS, TH, calcium and magnesium hardness, potassium, and sodium. The study aimed to calculate the WQi of groundwater of 11 Mandal headquarters of Srikakulam coastal zones of India and evaluate the human health risk assessment (HHR). Even though we have analyzed the nitrates, it was considered for assessing only HHR and comparing the results with statistical analysis.

MATERIALS AND METHODS

Sample collection

A total of eleven samples from coastal zones of Srikakulam district Mandal headquarters were collected from the bores of varying depths up to 100 m and analyzed the physicochemical parameters for the sample using standard APHA methods in the pre-and post-monsoon of the year 2021 (Fig. 1). All the samples were analyzed at the water and wastewater treatment laboratory of the GITAM (Deemed to be) University.

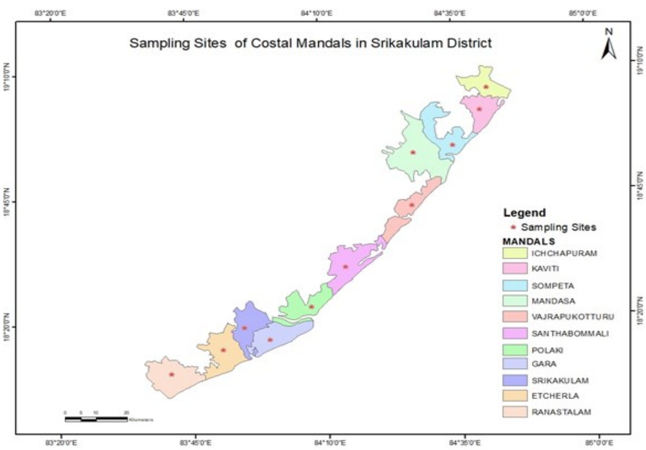

Fig. 1. *Location map of the study area of the Srikakulam district, Andhra Pradesh*

Physicochemical parameters

The parameters selected for the potable studies were pH, conductivity, total dissolved solids, calcium hardness, magnesium hardness, sulphates, sodium and potassium. The samples were compared with the Bureau of Indian standards to obtain the relationship between parameters.

Water quality index (WQi)

The WQi gives an idea on a scale rating from 0 to 300. In the present study, the WQi is evaluated by the following steps. A weight (w_i) is assigned for each chemical variable conferring to the relative weights obtained from Karnena and Vara, 2019. Further, the relative weight (W_i) was calculated from the following equations (Karnena *et al.,* 2022), and here n represents several samples (*Eq 1 to 4*).

$$W_I = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad \text{(Eq 1)}$$

The parameters' quality rating (Q_i) is obtained by dividing the concentrations by the relative standards of BIS and multiplying with 100. Cei is the parameter concentration here, and S_i is the potable water standard.

$$Q_i = \frac{Ce_i \times 100}{S_i} \quad \text{(Eq 2)}$$

The subsequent calculation obtains the Si water standard.

$$SI_i = W_i \times Q_i \quad \text{(Eq 3)}$$

$$WQI \sum_{i=1}^{n} SI_i \quad \text{(Eq 4)}$$

The calculated WQi is categorized into excellent (<50), good (50 to 100), poor (100 to 200), very poor (200 to 300) and unfit (>300).

Human health risk assessment (HHR)

HHR helps determine the groundwater quality; further, this method will evaluate the harmful impacts of contamination on newborns, kids, and adults (Adimalla *et al.,* 2019; Chen *et al.,* 2017). The primary sources of adsorption of the contaminants by human bodies are drinking and bathing in groundwater. The current study adopted the HHR assessment by considering drinking pathways as they are significant sources of groundwater entry in the study area. The contamination of nitrate exposure to humans was assumed to be ingested by taking groundwater drinking. The equation below (*Eq 6* and *Eq 7*) was obtained from the USEPA (USEPA, 2004) for analyzing the exposure of dose (Ed) via pathways and for the identification of the non-carcinogenic risk factors (hazardous Quotient) associated with the paths in the particular sampling area (Hq). Adults are represented as A_d, Children described as C_d, and Infants represented as I_f.

$$Di = \frac{\mathrm{Cng} \times \mathrm{Ir} \times \mathrm{De} \times \mathrm{Fe}}{\mathrm{Abw} \times \mathrm{Aet}} \tag{Eq 5}$$

$$Hq = \frac{Di}{\mathrm{Fst}} \tag{Eq 6}$$

Di- Daily intake, Cng- Concentration of nitrate in groundwater, Ir- Ingestion rate (A_d- 2.5; C_d- 0.3; I_f – 0.78), De- Duration of Exposure (A_d-64; C_d- 12, I_f-<1), Fe- Frequency of Exposure (1 year), Abw- Average body weight (A_d- 57.5; C_d- 18.7; I_f -6.9), Aet- Average time (A_d- 23360; C_d- 4380; I_f -365), Hq- Non-carcinogenic factor quotient, and Fst- Floride standard reference (1.6). All the units are considered as mg/kg/day.

Statistical methods

The piper plots, correlation coefficient matrix, and principal component analysis were analyzed using the Origin software (9.2) to show and distribute the ions in the sampling sites. The piper plots plot the percentage of cations and anions in milliequivalents in the base triangles and help compare the ion accumulations in the sampling sites. This method allows for providing the water quality and origin. Correlation coefficient values of the samples determine the relation matrix and help identify the interrelated parameter analyzed. The principal component analysis evaluates the water quality in the sampling site and further identifies the source of water pollution.

RESULTS AND DISCUSSION

All the Sampling areas analyzed with the physicochemical parameters using the WHO and BIS standards methods are shown in Tables 1 and 2.

pH

pH is the value explicit the groundwater concentrations for determining whether the sampling site's water is alkaline or acidic. The water pH ranges from 7.2 to 8.9 (Fig. 2) in both pre-monsoon and post-monsoon, indicating that the groundwater is slightly alkaline. The limits of the pH given by the BIS range from 6.5 to 8.5; the sampling sites in the pre-monsoon Polaki and Vajrapukothuru and the post-monsoon Etcherla and Gara exceeded the standard limits. In general, the pH alone doesn't directly affect the health of living beings (WHO, 2004).

Electrical conductivity (EC)

The EC of the water is essential for determining the water quality as the increase in these concentrations might lead to the rise in the saltiness and solids in the groundwater. The EC ranges from 520 to 4100 μS/cm (Fig. 3). EC does not have any particular standards for reference; Higher variation of the EC in the sampling areas might be attributed to agricultural and other anthropogenic activities (Subba Rao *et al.,* 2017).

Total dissolved solids (TDs)

TDs mainly consist of inorganic salts, which exist in dissolved forms in groundwater (Edition, 2011). The TDs ranged from 384 to 2624 mg/L in both seasons (Fig. 4). According to the WHO (2004) and BIS (2012), the permissible limit for the TDs is 600 mg/L. The TDs greater than 10^3 mg/L are unacceptable for drinking purposes and require treatment before consumption (Karnena *et al.,* 2022). The sampling sites in the post-monsoon, i.e., Etcherla (710 mg/L), Gara (1400 mg/L) and Polaki (1950 mg/L), exceeded the limit, and Polaki (1770 mg/L) and Kaviti (350 mg/L) exceeded the permissible limits in the pre-monsoon. This might be due to the dissolution of the natural resources during the seasons and anthropogenic agricultural activities (Karnena *et al.,* 2022; Edition, 2011) in the study area.

Total hardness (TH)

The hardness of the water is caused by the dissolution of the polyvalent metal ions, calcium and magnesium ions. TH concentration ranges from 100 to 1200 mg/L (Fig. 5). The prescribed limit for the TH is 300 mg/L suggested by WHO. The sampling areas in the post-monsoon exceeded the limits except for Polaki (410 mg/L), Sompeta (265 mg/L) and Ichchapuram (260 mg/L). In the pre-monsoon, the Gara (500 mg/L) and Polaki (300 mg/L) slightly exceeded the standard limits. Exceeding the permissible might cause the water very hard and unfit for drinking. The areas reported in this section need proper softening treatment before consumption. The hardness of the water might be due to the geographical locations or dissolution of the minerals in pre-monsoon seasons due to perceptions (Adimalla and Qian, 2019).

Cations

Sodium

Sodium is the most reactive metal and is freely available in nature. The excess sodium than the prescribed level by WHO and BIS, i.e., 200 mg/L in the groundwater, might increase the blood pressure, and further tox-

Table 1. Pre-monsoon physicochemical analysis data

Sampling Sites	p H	EC	TDS	Cl	NO_3	SO_4	Na	K	Ca	Mg	TH
Etcherla	8.03	710	454.4	120	3.28	74	60.86	1.52	56	29.17	260
Gara	8.2	1400	896	240	0.65	57	162.49	3.2	84	34	350
Ichchapuram	8.58	1340	857.6	250	25.24	84	228.2	17.5	48	34.03	260
Kaviti	8.19	2600	1664	574.4	2.04	138.7	334	219	72	30.4	304.5
Mandasa	8.5	600	384	81.55	10.21	13.44	67.9	0.78	44	9.73	150
Polaki	8.62	1950	1248	340	6.87	121	257.8	5.2	91	46	410
Ranastalam	8.33	630	403.2	90	12.91	31	116.96	1.36	40	100	100
Santhabommali	7.83	770	492.8	50	2.71	126	93.02	1.12	40	24.31	200
Sompeta	8.52	1000	640	148.93	1.27	39.98	101	8.21	64	25.5	265
Srikakulam	7.2	1320	844.8	230	2	98	220.9	17	48	29.17	240
Vajrapukothuru	8.67	1290	825.6	237.5	7.07	34.99	162	10.5	82	19.5	285

Table 2. Post-monsoon physicochemical analysis data

Sampling Sites	p H	EC	TDS	Cl	NO_3	SO_4	Na	K	Ca	Mg	TH
Etcherla	8.6	4100	2624	939.97	14.71	64	580.46	157	40	121.6	1200
Gara	8.7	2120	1356.8	419.98	5.12	69	328.16	82.16	20	48.64	500
Ichchapuram	7.4	520	332.8	110	43.6	14	56.14	18.03	32	7.29	220
Kaviti	7.7	350	224	60	12.3	12	22.16	2.3	36	7.29	360
Mandasa	7.9	1040	665.6	250	13.35	7	102.36	3.61	40	48.64	600
Polaki	8.34	1770	1132.8	159.99	2.15	44	290.38	56.8	20	24.32	300
Ranastalam	8.1	970	620.8	140	12.91	28	88.44	24.04	48	34.04	560
Santhabommali	7.9	660	422.4	110	47.24	21	54.26	8.42	40	19.45	520
Sompeta	7.8	810	518.4	190	21.47	15	54.24	51.18	52	24.32	300
Srikakulam	7.4	1140	729.6	199.99	7.79	33	74.16	20.17	56	58.36	760
Vajrapukothuru	7.8	600	384	90	19.56	11	49.19	17.47	36	19.45	340

aemia can be observed in women with pregnancy. The sodium concentrations in the pre-monsoon seasons in Ichchapuram, Kaviti (334 mg/L), Polaki (257.8 mg/L) and Srikakulam (220.9 mg/L) crossed WHO's standards; the post-monsoon season in Etcherla (580.6 mg/L), Gara (328.16 mg/L), and Polaki (290.38 mg/L) showed high concentrations of sodium. The attention of sodium in the water range from 22.16 to 580.46 mg/L (Fig. 6) and excess concentration might be attributed to saltwater intrusions as these are nearer to the sea (Basack *et al.,* 2022).

Potassium

Even though the potassium ions are vital for human health, excess concentrations in the groundwater might harm human health, resulting in hyperkalemia, kidney disease, and dietary problems (Karnena and Vara, 2019). The potassium in the sampling sites ranged from 0.78-157 mg/L (Fig. 6). The allowable limit of this cation is ten mg/L. The potassium concentration in the post-monsoon of Kaviti (2.3 mg/L), Mandasa (3.61 mg/L), and Santhabommali (8.42 mg/L) is within the standard limit and other mandals crossed the permissible limits. In contrast, Ichchapuram (17.5 mg/L), Kaviti (219 mg/L), and Vajrapukothuru (10.5 mg/L) crossed the allowable limits in the pre-monsoon. The increase in potassium concentrations is due to the seepage of the agricultural runoff consisting of potassium fertilizers (Pericherla *et al.,* 2020).

Anions

Chlorides

The excess chloride concentration in the groundwater has laxative effects and a salty taste. Thus, chloride is considered an essential parameter for measuring water pollution. Further, the excess chloride in the groundwater is due to the dumping of domestic waste and other anthropogenic activities (Subba Rao *et al.,* 2017). The chloride ranged from 50 to 939.7 mg/L in the sampling sites (Fig. 7). The permissible limit for the chlorides in the groundwater ranged from 200-to 600 mg/L. The excess concentrations of chlorides in the ground might be attributed to the saltwater intrusion in Etcherla, Polaki and Kaviti areas (Basack *et al.,* 2022).

Sulphate

The oxygenated water generally consists of sulphates as they consist of sulfur. Higher levels of sulfur in the water might affect the taste of the water and cause dehydration. The allowable limit of this ion is 400 mg/L, and significant sources of sulphate in the groundwater are due to agricultural runoff (Pericherla *et al.,* 2020). The sulphate concentrations in the water ranged from 7 to 138 mg/L, and all the samples were within the limit (Fig. 7).

Nitrates

Nitrates are considered one of the significant pollutants for water aquifers in and around the agri-land (Zhang *et al.,* 2018). The availability of nitrogenous substances in the geological system is less. These substances in the aquifers are due to the anthropogenic agricultural fertilizers, seepage of the septic tank and runoff. Nitrates in the water of sampling sites ranged from 0.65 to 47.24 mg/L (Fig. 7). The permissible limit in the drinking water suggested by the WHO and BIS is 50 mg/L. Further from the study, all the water samples were within the standards.

Water quality index (WQi)

This index helps evaluate the groundwater quality to identify whether it is suitable for drinking. The quality of the water was classified into excellent (50 and less), good (50-100), poor (100-200), very poor (200-300) and unfit (>300). The current study results ranged: In the post-monsoon season, the Etcherla mandal station (361.7) water form revealed that the water is not advisable for drinking (Fig. 8). In contrast, in the pre-monsoon season, the kaviti mandal station (282.98) water showed poor drinking quality (Tables 3 and 4). The change in the quality of the water standards is attributed to the anthropogenic agricultural and manmade activities in particular areas (Karnena *et al.,* 2022)

Human health risk assessment (HHR)

The HHR was conducted to identify the non-carcinogenic factor in this location; this parameter might vary from seasonal, geographical, and anthropogenic activities. The HHR in the sampling areas ranged from 0.01 to 4.4. As previously stated in the methodology, the Hazardous Quotient (Hq) should not exceed one. The HHR was conducted and adopted using the methods given by the USEPA. Tables 3 and 4 show the quotients and risks associated with nitrates. The values of Hq in infants, children and adults in post-monsoon ranged from 0.03 to 0.6, 0.2 to 4.3, and 0.09 to 1.3;

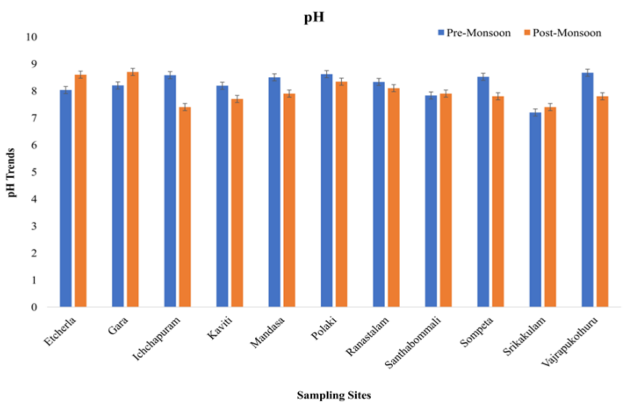

Fig. 2. *Trends of pH in the sampling sites of the district.*

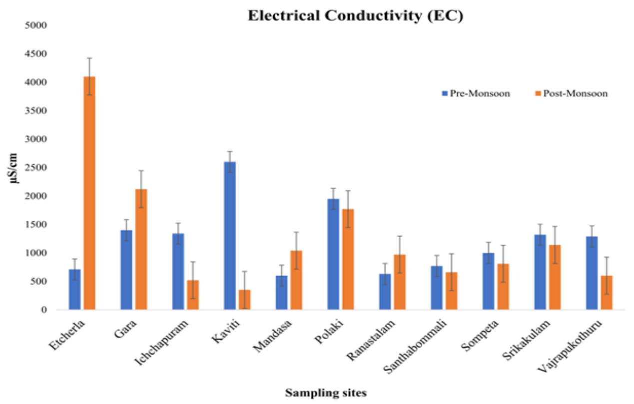

Fig. 3. *Electrical conductivity of the sampling sites of the district.*

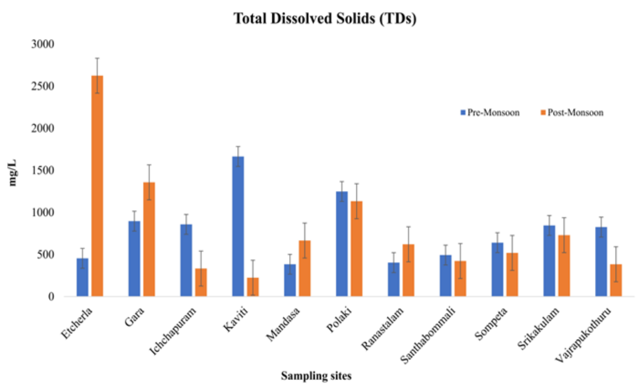

Fig. 4. *TDs in the sampling sites of the district*

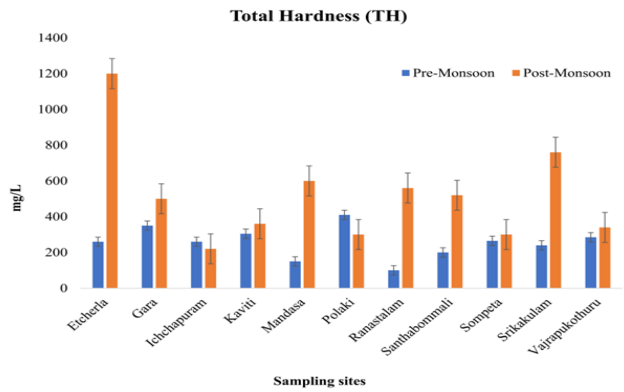

Fig. 5. *TH of the Sampling sites of the district*

whereas in pre-monsoon is 0.01 to 0.4, 0.06 to 1.3, and 0.02 to 1. In the pre-monsoon, adults in Ichchapuram and children in Ichchapuram and Ranastalam are highly prone to the risk of nitrate pollution.

In contrast, in the post-monsoon, the adults in Santhabommali and Ichchapuram, except children in Gara, Polaki, and Srikakulam and infants in all the stations, are prone to the risk of nitrate pollution. Nitrates are considered one of the most contamination sources for drinking water worldwide. The nitrate leaching into the groundwater is due to the agricultural soils (Jalali, 2011; Bawoke and Anteneh, 2020). In their studies, Chen et al. (2016) stated that the higher availability of nitrates in the water is due to the extensive use of fertilizers and irrigation. Elevated concentrations are harmful to the health of living beings. Continuous ingestion and accumulation of the nitrates might cause potential harm to humans by causing methemoglobinemia, thyroids and cancers. The current study revealed that children are more prone to this pollution than adults, and minimizing steps for preventing groundwater contamination have to be adopted in the recent sampling.

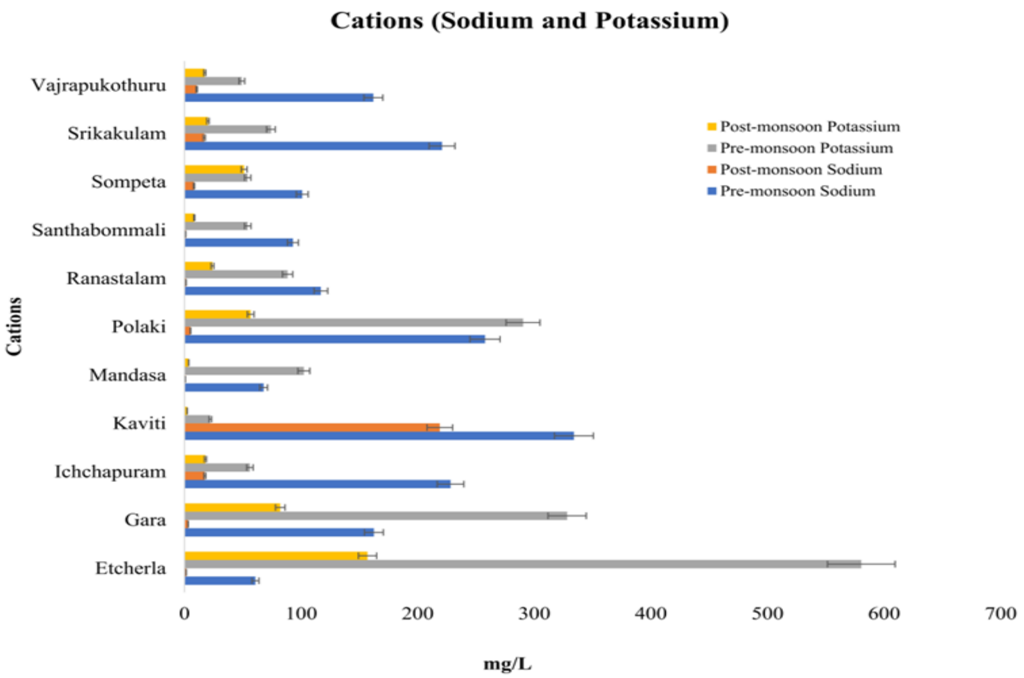

Fig. 6. *Cations in the sampling sites of the district*

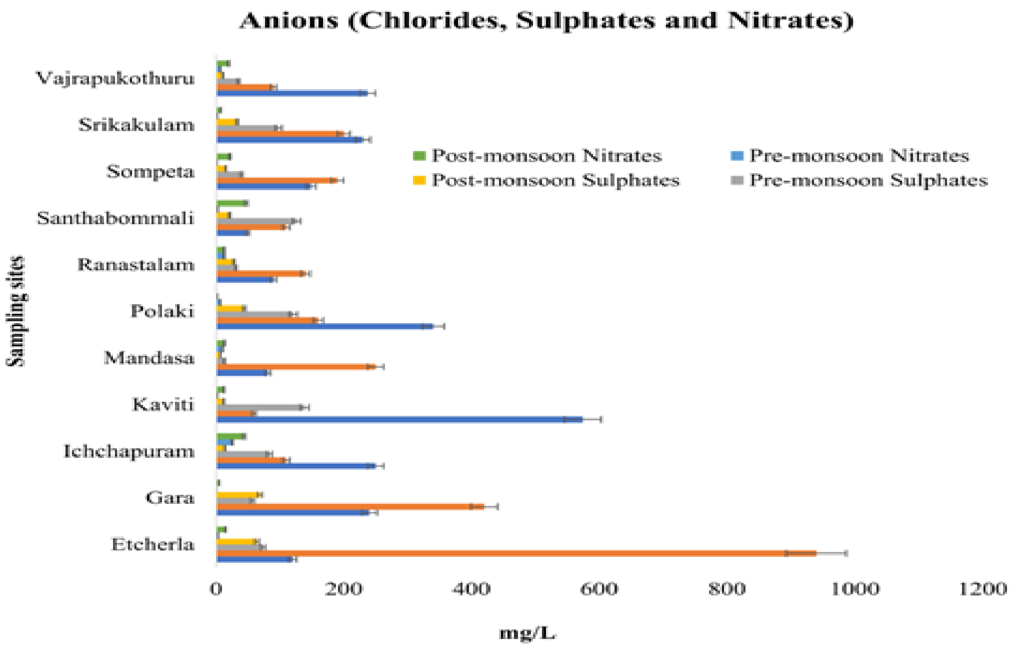

Fig. 7. *Anions in the sampling sites of the district*

Table 3. HHR and WQI of Sampling areas in pre-monsoon

Sampling Sites	HHR (Adult)	HHR (Children)	HHR (Infant)	WQI	Water Quality
Etcherla	0.14261	0.333704	0.05262	64.43	Good
Gara	0.02826	0.06613	0.01043	100.42	Good
Ichchapuram	1.09739	2.567896	0.40492	110.74	Poor
Kaviti	0.0887	0.207548	0.03273	282.98	Poor
Mandasa	0.44391	1.038757	0.1638	49.66	Excellent
Polaki	0.2987	0.698948	0.11021	139.26	Poor
Ranastalam	0.5613	1.313452	0.20711	78.02	Good
Santhabommali	0.11783	0.275713	0.04348	59.99	Good
Sompeta	0.05522	0.129209	0.02037	80.67	Good
Srikakulam	0.08696	0.203478	0.03209	94	Good
Vajrapukothuru	0.30739	0.719296	0.11342	98.79	Good

Table 4. HHR and WQI of Sampling areas in post-monsoon

Sampling Sites	HHR (Adult)	HHR (Children)	HHR (Infant)	WQI	Water Quality
Etcherla	0.63957	1.496583	0.2359893	361.7	Unfit
Gara	0.22261	0.520904	0.082139	188.69	Poor
Ichchapuram	1.89565	4.435826	0.6994652	48.37	Excellent
Kaviti	0.53478	1.251391	0.1973262	38.19	Excellent
Mandasa	0.58043	1.358217	0.2141711	90.33	Good
Polaki	0.09348	0.218739	0.034492	130.8	Poor
Ranastalam	0.5613	1.313452	0.2071123	92.54	Good
Santhabommali	2.05391	4.806157	0.757861	64.4	Good
Sompeta	0.93348	2.184339	0.3444385	91.99	Good
Srikakulam	0.3387	0.792548	0.1249733	104.04	Poor
Vajrapukothuru	0.85043	1.990017	0.3137968	59.42	Good

Statistical analysis

Piper plots

These plots helped to identify water composition and the type of water in the sampling areas. The cations/ anions and mixed concentrations can be determined in the water, depending on the geographical locations. More than 70 per cent of the samples in the sampling areas reported diverse concentrations of the ions observed in the piper triangles (Fig. 9). The pre-monsoon mixed composition is found that Ca-Mg-CO_3-HCO_3, SO_4-Cl, and Na-K-Ca. In contrast, in post-monsoon, the compositions are Cl- CO_3-HCO_3, Na-K- CO_3-HCO_3, and Na-K-Mg. The concentrations of the alkali metals are found to be within limits compared to the alkaline earth metals, which results in temporary hardness.

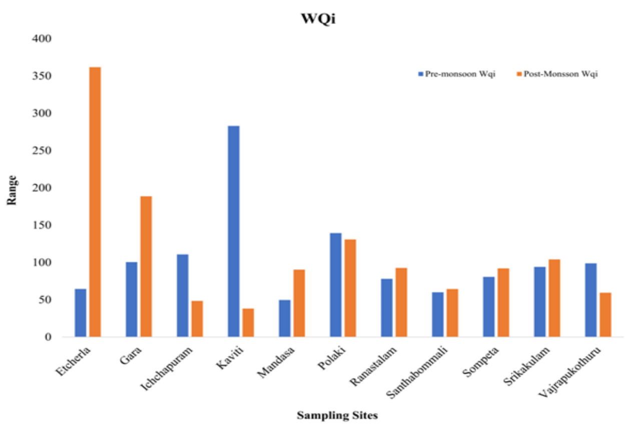

Fig. 8. *WQi of the sampling sites of the district*

Principal component analysis (PCA)

The PCA of the cations and anions of the groundwater is used to determine the relationships and identify how these ions control the overall quality of the groundwater. This analysis separates the chemical variable quantities into clusters. The PCA I is dominated by all the chemical variables in the pre-monsoon, which is observed in Fig. 10. Further from the Fig., salinity and alkalinity are the controlled factors. In contrast, the post -monsoon PCA I was influenced by Mg, sodium and potassium influenced PCA II, and Chlorides and Calcium influenced PCA III. This influence is considered a lithological or non-lithological factor of the pollution in the sampling areas.

Correlation coefficient (CC)

The CC values range from -1 to +1; zero indicates no relationship between the parameters. A strong correlation can be obtained by the positive (r) values and vice versa. The Table 5 and 6 show the importance of the

Table 5. CC of the Sampling sites in the pre-monsoon

	p H	**Conductivity**	**TDS**	**Chlorides**	**Nitrates**	**Sulphates**	**Sodium**	**Potassium**	**Calcium**	**Magnesium**	**Total hardness**
p H	1										
Conductivity	0.068820231	1									
TDS	0.068820231	1	1								
Chlorides	0.088979929	0.9811515	0.981151	1							
Nitrates	0.446712973	-0.150862	-0.15086	-0.10322	1						
Sulphates	-0.394962174	0.6442542	0.644254	0.560856	-0.20371	1					
Sodium	-0.018693979	**0.9402944**	**0.940294**	**0.925771**	0.079088	0.638611	1				
Potassium	-0.054436668	**0.7673765**	**0.767377**	**0.830241**	-0.18069	0.512991	0.692311	1			
Calcium	0.393984727	0.64494	0.64494	0.598309	-0.33749	0.15048	0.455482	0.199664	1		
Magnesium	0.056236021	-0.090742	-0.09074	-0.07384	0.269734	-0.08016	0.059411	-0.07806	-0.15659	1	
Total hardness	0.174727275	0.7108372	0.710837	0.633186	-0.28347	0.465609	0.56113	0.203601	**0.882133**	-0.29291	1

Table 6. CC of the sampling sites in the post-monsoon

	p H	**Conductivity**	**TDS**	**Chlorides**	**Nitrates**	**Sulphates**	**Sodium**	**Potassium**	**Calcium**	**Magnesium**	**Total hardness**
p H	1										
Conductivity	0.7621733	1									
TDS	0.7621733	1	1								
Chlorides	0.6597786	0.95852967	0.95853	1							
Nitrates	-0.4394402	-0.3732593	-0.37326	-0.24496	1						
Sulphates	**0.8042876**	0.8432657	0.843266	0.732121	-0.44391	1					
Sodium	**0.8242398**	**0.98207646**	**0.982076**	**0.912009**	-0.37793	0.870372	1				
Potassium	0.7482351	0.95021585	0.950216	0.921193	-0.2981	0.829229	0.943065	1			
Calcium	-0.5191452	-0.1973934	-0.19739	-0.05621	0.135531	-0.38451	-0.37361	-0.20195	1		
Magnesium	0.5328533	**0.90293392**	**0.902934**	0.936839	-0.34925	0.663193	0.812277	0.796824	0.16693687	1	
Total hardness	0.3965663	0.77891882	0.778919	0.83466	-0.22932	0.540434	0.66629	0.631492	0.31174279	0.946889154	1

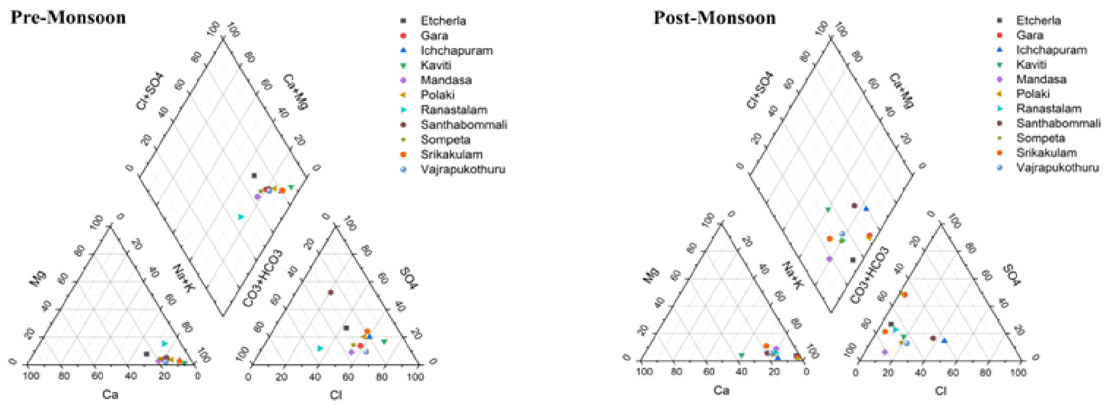

Fig. 9. *Piper plots of the sampling sites of the district.*

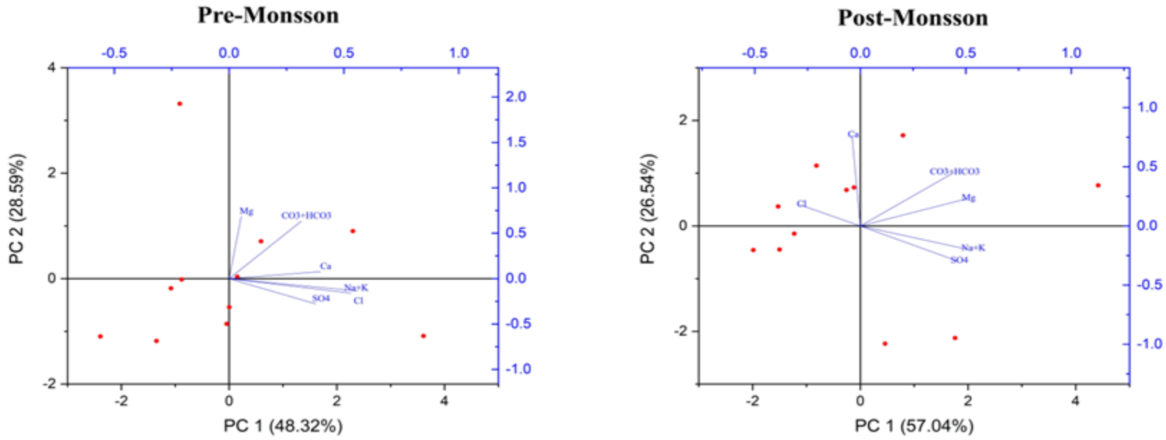

Fig. 10. *PCA of the sampling areas of the district*

CC. In the pre-monsoon, strong CC was observed with Na to Conductivity (0.94), TDS to Na (0.94), Cl to Na (0.92) and Ca to Hardness (0.83). In contrast, in post-monsoon, pH to Na and Sulphates (0.8), Sodium to Conductivity (0.98), TDS and Chlorides (0.98) showed a strong correlation and indicated that chemical parameters are interrelated.

Conclusion

The current article evaluated and highlighted the quality of the drinking water by WQi and further identified the non-carcinogenic risk factor associated with nitrate pollution using the Human Health Assessment (HHA) tool developed by the USEPA. In addition, the overall sampling station quality of the water ranged from slightly alkaline and less complicated water. The WQi of the sampling stations ranges from 49.6 to 361.7, indicating poor water quality in sampling sites Etecherla and Kaviti; According to the HHA, the children residing in these areas are more prone to nitrate pollution, which might be attributed to the excessive use of nitrate fertilizers for agriculture. The statistical data showed that the significant chemical variables identified the essential ions and their interactions responsible for the pollution. Further treatment is necessary to consume this groundwater in a few sampling areas to avoid health-related issues. Continuous evaluation of the groundwater quality by WQi every year seasonally wise is essential in these coastal zones as small indirect traces of the salt water intrusions are observed. The farmers in these areas need to be educated by the government and NGOs to minimize the usage of recalcitrant chemicals and unsustainable agricultural activities polluting the groundwater.

Conflict of interest

The authors declare that they have no conflict of interest.

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