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Seasonal Variation of Groundwater Quality in Erode District, Tamil Nadu, India

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In recent years, the recurring environmental issues regarding hazardous waste, global climate change, stratospheric ozone depletion, groundwater contamination, disaster mitigation and removal of pollutant have become the focus of environmental attention. In the management of water resources, quality of water is just as important as its quantity. In order to assess the quality and/or suitability of groundwater for drinking and irrigation in Erode District, 144 water samples each in post-monsoon and pre-monsoon during the year 2007 were collected and analyzed for various parameters. These parameters were compared with IS: 10500-1991 drinking water standards. Out of 144 samples, 29 samples exceeded the permissible limit for both the monsoons, 71 samples were within the permissible limit for both the monsoons and the remaining samples exceeded the permissible limit for any one of the monsoon. During both monsoons, except some samples, most of the samples were suitable for drinking and irrigation.

Key words : *Groundwater, drinking, irrigation, water quality, permissible limit*

Introduction

Fresh water is the most precious material for the survival on earth, not only for human life but also for flora and fauna. Major water sources on the earth are saline water sources (seas and oceans), which consists 99% of total water resource and remaining 1% of water sources include the fresh water bodies on the earth and the groundwater sources. The groundwater is an important source of water for agriculture, domestic and industrial purposes. The groundwater scenario in India, which receives a substantial amount of annual rainfall, is not very encouraging primarily due to the imbalance between recharge and groundwater exploitation. Variation of groundwater quality in an area is a function of physical and chemical parameters that are greatly influenced by geological formations and anthropogenic activities.

Sreedevi[1] assessed the groundwater quality in both pre and post monsoon of Pageru river basin, Cuddapah District, Andhra Pradesh. Janardhana Raju[2] studied hydro-geochemical parameters for assessment of groundwater quality in the upper Gunjanaeru river basin, Cuddapah district, Andhra Pradesh, India, for both pre-monsoon and post-monsoon. Sinha and Saxena[3] calculated the statistical assessment of underground drinking water contamination and effect of monsoon at Hasanpur, J.P.Nagar, Uttar Pradesh, India.

The study of variations of the groundwater quality in Erode district is necessitated since this area has many dyeing industries, with some tanneries and sugar industries along with intense agricultural activities. The samples from this area were analysed for different geochemical constituents using standard methods of analysis. An attempt has been made in this paper to evaluate the seasonal variation of groundwater quality based on IS: 10500-1991 for its suitability for drinking and irrigation purposes.

Study area

The study area is located between $10^{0}35'$ and $12^{0}0'$ North latitude and $76^{0}50'$ and $77^{0}50'$ East longitude. It is positioned North Western part of Tamil Nadu in India. The average rainfall in Erode region is 660.10 mm and total area is 8161.21 sq. km. The area has a tropical climate with the highest and lowest temperature recorded in May and January respectively. The precipitation in this area mainly depends upon North East monsoon. Cultivation in this area mainly depends on Cauvery river basin. Paddy, Groundnut, Sugarcane, Cotton, Turmeric, Cumbu, Pulses, Ragi and Flowers are the common crops cultivated here. The important soil types are red calcareous soil, black soil, alluvial soil, forest soil, red non-calcareous soil and brown soil. The important rock types encountered in this area are Granitic Gneiss, Mica Gneiss, Hornblende Gneiss, Charnockite and Pink Granite. The northern part of Erode district is completely covered by hilly areas with reserved forest. In the hilly areas, plateau are identified which are distributed in the entire hilly areas. Generally the entire district area is covered by pediments, shallow pediments and deep pediments.

Materials and methods

In this study, 144 water samples (**Fig. 1**) at various locations were collected from bore wells. Samples were

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analysed in the laboratory for the Cajor ions using standard methodologies prescribed by American Public Health Association (APHA)[4]. Hydrogen ion concentration (pH) and Electrical Conductivity (EC) were measured using pH and EC meters. Total Dissolved Solids (TDS) were calculated by gravimetric method. Total hardness (TH) as $CaCO_3$ and Calcium (Ca^{2+}) were analysed titrimerically, using standard EDTA solution. Sodium (Na^+) and Potassium (K^+) were measured by a flame photometer. Chloride (Cl) was estimated by standard $AgNO_3$ titration. Sulphate (SO_4^{2-}) and Nitrate (NO_3) were analysed using a colorimeter. The quality parameters like turbidity, pH, TH, Cl, TDS, Ca^{2+}, SO_4^{2-}, NO_3^- and F^- are compared with drinking water quality standards given by the Indian Standards. And also some parameters like Salinity (EC), toxicity due to sodium (SAR), sodium percentage (Na %) and residual sodium carbonate (RSC) were determined to assess the irrigational suitability of the groundwater.

Results and discussion

The classical use of water analysis in groundwater hydrology is to produce information concerning the water quality. The statistical parameters of different chemical compositions of pre-monsoon and post-monsoon samples are shown in **Table 1**.

Groundwater quality for drinking water

Groundwater quality for drinking water purpose was analysed by considering the Indian Standard (IS) 10500 – 1991[5] (**Table 2**). It has been found that some samples show TH (14%), TDS (9%), Ca^{2+} (5%) and Cl^- (4%) values above permissible limit during both the monsoon.

Turbidity

Turbidity is due to the presence of suspended solids in the water. The character and amount of turbidity depends on the types of soil over which the water has flown. Out of 144 samples, 18% and 6% of samples were above the permissible limit for pre-monsoon and post-monsoon respectively. The turbidity of groundwater samples varied from 1 to 230 NTU and 1 to 30 NTU for pre-monsoon and post-monsoon respectively.

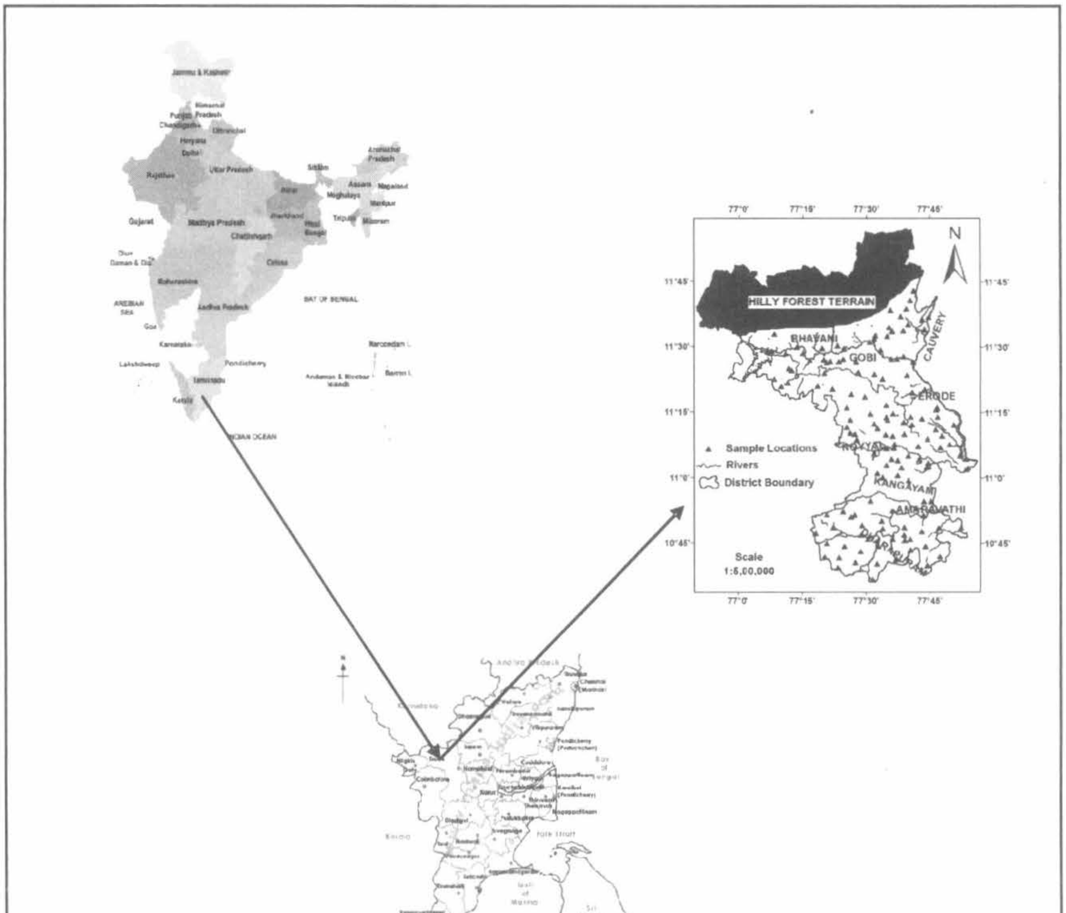

Fig. 1: Study area and sampling locations

Table 1: Statistical parameters of groundwater samples for both pre-monsoon (PRM) and post-monsoon (POM)

Water quality parameters	Unit	Maximum value		Minimum value		Average		Median		Mode		Standard deviation	
		PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM
Turbidity	NTU	230	30	1	1	9.04	6.44	5	6	1	5	21.26	3.39
pH		9.10	9.90	7.22	7.28	7.88	7.92	7.88	7.90	7.69	8.00	0.34	0.32
TDS	mg/L	4720.94	5969.30	189.74	226.07	1147.34	1244.06	913.28	816.55	456.00	456.00	875.42	1119.00
TH	mg/L	1226.83	1422.94	33.91	91.37	419.10	483.22	339.88	412.70	342.64	337.91	273.01	291.08
EC	µs/cm	7376.46	9327.03	296.47	353.24	1792.72	1943.85	1427.00	1275.86	712.00	712.00	1367.85	1748.44
Na^+	mg/L	1188.00	1410.00	7.00	8.00	191.58	194.19	131.50	88.00	146.00	12.00	191.02	274.46
K^+	mg/L	252.00	291.00	1.00	1.00	47.52	52.35	35.00	29.50	12.00	12.00	43.84	59.12
Ca^{2+}	mg/L	378.00	398.00	7.00	30.00	104.56	111.23	81.30	91.90	109.00	76.00	78.46	71.51
Mg^{2+}	mg/L	126.00	168.00	3.00	4.00	38.48	49.94	32.00	43.00	25.00	23.00	25.40	31.64
HCO_3^-	mg/L	1238.00	1432.00	84.00	92.00	445.56	448.38	398.00	398.00	232.00	336.00	239.41	257.57
NO_3^-	mg/L	124.00	305.00	2.00	5.00	40.33	53.15	42.22	49.50	58.83	55.00	26.11	49.81
SO_4^{2-}	mg/L	852.00	916.00	6.42	6.00	104.66	123.12	56.48	59.00	13.00	32.00	137.53	166.46
Cl^-	mg/L	1656.00	1860.00	10.00	12.00	289.42	313.67	173.00	148.00	76.00	72.00	319.22	386.64
F	mg/L	2.00	2.00	0.10	0.10	0.50	0.62	0.40	0.60	0.10	0.60	0.40	0.35
Na	%	86.16	85.73	12.75	4.42	49.83	40.60	53.01	36.31		0.00	14.92	20.75
SAR		17.15	18.15	0.27	0.18	3.88	3.58	3.21	1.97		5.78	2.68	3.96
RSC	meq/l	4.45	1.51	-11.08	-16.69	-1.03	-2.31	-0.47	-1.42	-0.35	-0.93	2.53	2.62

pH

pH is the measure of hydrogen ion concentration in the water. Lower the pH value of water will be more acidic and higher the pH value will be more alkaline in nature. In both the monsoons all the samples were found within the permissible limit. pH exceeded the value of 7 and varied from 7.22 to 9.1 and 7.28 to 9.9 for pre-monsoon and post-monsoon respectively, which indicate that the groundwater samples were slightly alkaline in nature.

Total dissolved solids

Total dissolved solids denote the various types of minerals present in the water in dissolved form. Concentrations of TDS are an important parameter in drinking water and other water quality standards. Caroll[6] and Davis & Dewiest[7] have proposed four classes of water based on TDS values (**Table 3** and **Table 4**). According to Caroll classifications, 46% of groundwater samples in the study area come under the fresh water type and remaining 29% come under the brackish water type for both the monsoon. From Davis and Dewiest classification, 9% of groundwater samples were desirable for drinking purposes and 24% were permissible for drinking. In the remaining, 22% were useful only for irrigation and 3% were unfit for both drinking and irrigation purposes for both monsoon. The values of TDS in post-monsoon groundwater samples varied from 226.07 to 5969.30 mg/L with an average of 1244.06 mg/L and in the pre-monsoon groundwater samples varied from 189.74 to 5969.30 mg/L with an average of 1147.34 mg/L.

Electrical conductivity

The analysis has shown that 55% and 58% of samples fall under the "safe category" (< 1500 µs/cm) whereas 28%, 17% and 24%, 18% of samples come under "marginal category" (1500 – 3000 µs/cm), "unsuitable category" (> 3000 µs/cm) of pre-monsoon and post-monsoon respectively. The higher concentration of EC might be due to domestic pollution caused in rural areas associated with limited use of the bore wells.

Calcium

Calcium is an important constituent of water which is contributed by various rocks and minerals into the aquifer. Permissible limit of calcium content in the drinking water is 100 mg/L. Water with low calcium if used for long time by the inhabitants of the area can cause the cardiovascular disease, especially for men and hence increase the mortality rate in the area. Out of 144 groundwater samples, 14% of groundwater samples were above the permissible limit for pre-monsoon and post-monsoon respectively. The calcium of groundwater

Table 2 : Comparison of groundwater samples with drinking water standards for both pre-monsoon and post-monsoon (IS: 10500-1991)

Parameter	IS: 10500-1991		Sample numbers exceeding permissible limit		Sample locations exceeding the permissible limits in both the seasons
	Desirable	Permissible	Pre- monsoon	Post-monsoon	
Turbidity	5	10	2,12,13,26,32,38, 39,40,41,44,50,54, 55,56,59,85,89,97, 102,107,108,116, 121,122,123, 127	84,88,99,102,116, 121,123,127,140	102,116,121,123,127
pH	6.5 to 8.5	-	Nil	Nil	Nil
Total Hardness	300	600	1,5,8,11,12,15,16, 18,20,21,22,30,32, 33,34,37,43,60,78, 81,84,88,95,96,100, 107,109,112,116, 121,122,123,131, 132	16,20,21,22,32,41, 43,60,62,74,78, 81,84,86,88,89,93, 94,95,96,97,99, 100,104,106,112, 113,121,122,123, 125,127,131,132, 138,140,141	16,20,21,22,32,43,60,78,81, 84,88,95,96,100,112,121, 122,123,131,132
Total Dissolved Solids, mg/L	500	2000	1,5,11,12,15,20,32, 60,78,81,84,88,95, 96,100,104,107,109 ,112,116,122,123, 131,132	20,78,81,84,86,88, 89,93,94,95,96, 99,100,104,109, 112,113,114,116, 123,140	20,78,81,84,88,95,96,100, 104,109,112,116,123
Calcium, mg/L	75	200	1,5,8,11,12,15,16, 20-22,32,60,78, 84,88,95,107, 121-123	16,20,22,32, 74,78, 81,84, 86,88,93-97, 106,113,121,125, 140	20,22,32,78,84, 88,95
Chlorides, mg/L	250	1000	78,81,84,88,95,96	78,81,84,88,94,95, 96,100,109,112, 113	78,81,84,88,95,96
Nitrate, mg/L	45	100	84,127,129,139	4,8,10,16,20,21, 22,60,84,86,95,97, 127,129,139	84,127,129,139
Sulphate, mg/L	200	400	20,32,84,95,96, 100,107,109	84,88,94- 96,99, 100, 104,109, 113,114	95,96, 100,109
Fluoride, mg/L	1	1.5	62, 141	8, 62, 141	62,141

samples varied from 7 to 278 mg/L and 30 to 398 mg/L for pre-monsoon and post-monsoon respectively.

Chloride

The analysis of chloride indicates that 4% and 8% of samples exceeded the permissible limit in pre-monsoon and post monsoon respectively. 4% of samples in both pre and post monsoon exceeded the permissible limit. The abnormal concentration of chloride is the result of contamination by sewage wastes and from saline residues in the soil (Subrahmanyam and Yadaiah)[8].

Table 3 : Groundwater quality classification based on TDS (Caroll 1962)

Category	TDS (mg/L)	Sample numbers		
		Pre-monsoon	Post-monsoon	Both the monsoons
Fresh water type	<1000	3,4,6,7,9,10,13,14,17,19,23,24, 25,26,28,29,31,35,36,38, 39,41, 42,45,46,48-59,61,63-65,67-70, 73,75-77,79, 83,85-87,89-93,97, 98,99, 102-103,106,108,111, 117-120,124,126-128,130, 133,135-139,142,144	1-3,5-7,11-15,17-19, 23-31,34-37, 39,40,42,45-59, 61, 63-65,67-70,73,75-77, 79,83,85,87,90-92,98, 101, 105,108,110,111, 117-120,124, 26, 28,130, 133,134,136, 137, 39,142, 144	3,6,13,14,17,19,23,24, 25,26,28,29,31,35, 36,42,45,46,48, 49,50,51,52,53, 54,55,56,57,58, 59,61,63,64,65,67,68,69,70,73, 75,76,77,79,83,85,87,90, 91,92,98,106,111,117,118,119, 120,124,126,128,130,133, 136,137,139,142,144
Brackish water type	1000-10,000	1,2,5,8,11,12,15,16,18,20-22, 27,30,32-34,37, 40,43,44,47,55, 57,60,62,66,71,72,74, 78, 80-82,84,86,88,94-96, 100,104, 105, 107, 109, 110,112-116, 121-123, 125, 129,131,132, 134, 140, 141,143	4,8-10,16,20-22,33,38, 41,43, 44,60,62,66,71,72, 74, 78, 80-82,84,86,88,89, 93-97,99, 100,102-104, 106,107,109, 112-116,121-123,125,127,129, 131, 132, 135,138,140,141,143	8,16,20,21,22,33,43,44,60, 62,66,71,72,74,78,80,81,82,84, 86,88,94,96,100,104,107, 109,113,114,115,116,121, 122,123,125,129,131, 132,140,141,143
Saline water type	10,000 - 100,000	– –	– –	– –
Brine water type	>100,000	–		

Table 4 : Groundwater quality classification based on TDS (Davis and Dewiest 1966)

Category	TDS (mg/L)	Sample numbers		
		Pre-monsoon	Post-monsoon	Both the monsoons
Desirable for drinking	<500	4,9,10,13,14,17,23,28,31,42, 45,49,58,63,68,83,85,87,89, 90, 91,93,101,106,108, 111,119,128	1,2,5,11,13,14,17,23,24, 28,29,131,36,42,45,46,51, 52,54,69,87,90, 91,111, 119,133	13,14,17,23,28,31, 42,45,87,90,91,111,119
Permissible for drinking	500-1000	3,6,7,19,24-26,29,35,36, 38,39, 41, 46,48,50-54, 56,59,61,64,65, 67,69, 70, 73,75-77,79,86, 92,97-99, 102, 103, 117, 118,120,124, 126,127, 130,133, 135-139, 142,144	3,6,7,12,15,18,19,25,27,30,34,3 5,37,39,40,47,48-50,53,55-59, 61, 63-65,67,68, 70,73,75-77, 79,83, 85, 92, 98,101,105,108,110, 117, 118,120,124,126,128, 130, 134, 136,137,139,142,144	3,6,7,19,25,35,39,48,50,53, 56,59,61,64,65,67,70,73,75, 76,77,79,92,98,117,118, 120,124,126,130,136,137, 139,142,144
Useful for irrigation	1000-3000	1,2,5,8,11,12,15,16,18,21,22, 27,30, 32-34,37,40,43, 44, 47,55,57,60, 62, 66,71, 72, 74,80-82,94,100,104, 105, 107, 109,110,112-116, 121-123,125,129, 131,132, 134,140, 141, 143	4,8-10,16,20-22,32, 33,38, 41, 43,44,60,62,66, 71,72, 74,80-82, 86, 89,93,97,99, 102,103,106, 107, 114-116, 121-123,125,127, 129,131, 132,135,138,140,141,143	8,16,21,22,32,33,43, 44,60,62,66,71,72,74,80,81, 82, 107, 114,115,116,121, 122, 123,125,129,131,132, 140,141,143
Unfit for drinking and irrigation	>3000	20,78,84,88,95,96	78,84,88,94-96,100,104, 109, 112,113	78,84,88,95,96

Hardness

Water hardness is caused primarily by the presence of cations such as calcium and magnesium and anions such as carbonate, bicarbonate, chloride and sulphate in water. These ions react with soap to form precipitates. Hard water is unsuitable for household cleaning purposes, hence water softening processes for removal of hardness are needed (Todd)[9]. In the study area, the total hardness varied from 33.94 to 1228.00 mg/L and 91.37 to 1422.94 mg/L during pre-monsoon and post-monsoon respectively. According to Sawyer and McCarty's[10] classification (**Table 5**) 10% of samples fall under the moderately hard class and 28% samples fall under the hard class in the pre-monsoon. 6% of samples fall under the moderately hard class and 25% samples fall under the hard class in the post-monsoon.

Nitrate

The high nitrate concentration is due to the intensive urbanization and industrialization. Permissible limit of nitrate is 100 mg/L as per IS: 10500 – 1991. In the study area 3% and 10% of samples exceeded the permissible limit in the pre-monsoon and post-monsoon respectively. The high concentration of nitrate in drinking water is toxic and causes blue baby disease/ methaemoglobianemia in children and gastric carcinomas. Nitrate encourages growth of algae and other organisms which produce undesirable tastes and odors.

Sulphate

According to IS: 10500 – 1991, the permissible limit of sulphate is 400 mg/L. 6% of pre-monsoon and 8% of post-monsoon samples in the study area exceeded the permissible limit. The excess concentration of sulphate causes laxative effect on human system. As per Scofield's classification[11] 86% of samples fall under excellent category for both the monsoon (sulphate < 4 meq/l). Water containing high concentration of sulphate caused by the leaching of natural deposits of magnesium sulphate or sodium sulphate may be undesirable because of their laxative effects.

Fluoride

From IS: 10500 – 1991, the permissible limit of fluoride is 1.5 mg/L. Only 1% and 2% of samples exceeded the permissible limit in the pre-monsoon and post-monsoon respectively. Bedrock containing fluoride is generally responsible for high concentration of this ion in groundwater (Asgeir Bardsen)[12]. When consumed during the period of enamel calcification, fluoride in drinking water reduces the incidence of tooth decay in children. But fluoride may cause mottling of the teeth, depending on the concentration of fluoride, the age of the child, the amount of drinking water consumed and the susceptibility of the individual.

Groundwater quality analysis for irrigation

Water quality, soil types and cropping practices play an important role in irrigation. Agriculture is found to be one of the major land use practices in the study area. Therefore it is necessary to perform the analysis of chemical quality of groundwater for irrigation purposes. If the proportion of sodium is high, the alkali hazard is high and conversely, if calcium and magnesium predominates, the hazard is less. If water used for irrigation is high in sodium and low in calcium, the cation exchange complex may become saturated with sodium. This can destroy the soil structure owing to

Table 5 : Classification of groundwater based on hardness (Sawyer and McCarty 1967)

Category	Hardness (mg/L)	Sample numbers		
		Premonsoon	Postmonsoon	Both the monsoons
Soft	<75	49,106,108	—	—
Moderately hard	75-150	14,31,58,68,83,85,87,89, 90,91,93,98,101,111,119	23,54,83,85,87,98,101,108	83,85,87,98,101
Hard	150-300	4,7,10,13,17,23,28,35,36,42, 45,46,49,51-53,63,64,69,70,76, 77,79,92,99,102,103,110,117, 118,120,128,133,135-139,144	2,5,6,11-14,17,24,28,29, 31,36, 42,45,46,49, 51-53,63,64,69,71,75, 77,80,82,90,91,102,103, 110,111,133,136,139	13,17,28,36,42,45,46,49, 51-53,63,64,69,102, 103,110,133,136,139
Very hard	>300	1-3,5,6,8,9,11,12,15,16,18-22, 24,25-27,29,30,32-34,37-41,43,44, 47,48,50,51,53,55-57,59,60,62,66, 71-75,78, 80-82,84,86,88,94-97,100, 104,105,107,109,112-116, 121-127,129-132,134,140-143	1,3,4,7-10,15,16,18-22, 25-27,30,32-35,37-41, 43,44,47,48,50,55-62, 65-68,70,73,74,76,78, 79, 81,84,86,88,89,92-97, 99,100,104-107,109,112-132, 134,135,137,138,140-144	1,3,8,9,15,16,18-22,25-27, 30,32-34,37-41,43,44,47, 48,50,55-57,59,60,62,66, 73,74,78,81,84,86,88, 94-97,100,104,105,107,109, 112-116,121-127,129-132, 134,140-143

dispersion of the clay particles. A simple method of evaluating the danger of high-sodium is the sodium adsorption ratio (SAR) and the sodium percentage (soluble sodium percentage, SSP) is calculated as follows.

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

and

$$Na\% = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} * 100$$

The values of SAR varied from 0.38 to 17.15 and the values of sodium percentage varied from 12.75 to 86.16% with average values of 4.00 and 50.11% in the pre-monsoon respectively. The values of SAR varied from 0.18 to 18.15 and the values of sodium percentage varied from 4.42 to 85.73% with average values of 3.58 and 40.60% in the post-monsoon respectively. As per the Richards[13] classification, based on SAR values (**Table 6**) 94% and 90% of samples fall below 10.0, therefore, groundwater in the study area could be classified under 'excellent' category of water for irrigation in the pre and post monsoon respectively.

Sodium content is expressed in terms of sodium percentage or soluble sodium percentage (Todd)[9]. Sodium concentration is important in classifying irrigation water because sodium reacts with soil to reduce its permeability. Sodium percentage up to 60% (**Table 7**) is acceptable for the irrigational use. Above 60% sodium, alkalization steadily increases and soil will support little or no plant growth[14]. In the present study 107 and 110 samples (74% & 76%) of pre and post monsoon were found useful for irrigation. 36 samples and 33 samples (25% & 23%) were doubtful for irrigation and one sample each in pre and post monsoon is (1%) not suitable for irrigation.

Residual Sodium Carbonate (RSC)

Irrigation water with high RSC[15] is considered to be deleterious to the physical properties of the soils. If irrigation water contained carbonate and bicarbonate ions, in excess of Magnesium and Calcium ions, then there is a tendency for calcium and magnesium ions to precipitate as carbonates. As a consequence, the relative proportion of sodium ion increases and gets fixed in the soil by the process of Base Exchange and thereby decreasing the soil permeability. The RSC is calculated using the following equation:

$$\text{RSC (meq/l)} = (HCO_3^- + CO_3^-) - (Ca^{2+} + Mg^{2+})$$

In the study area, 86% and 99% of RSC[7] values of pre and post monsoon fall under "safe category" (RSC <1.25 meq/l) and 10% and 1% were observed under "marginal" (1.25-2.5 meq/l) category of pre and post monsoon respectively. 4% of pre monsoon samples come under "unsuitable" (RSC >2.5 meq/l) category. More RSC may reduce permeability of soils and tendency of fixing the sodium in soils.

Conclusion

The geochemical analysis reveals that the groundwater in Erode district is fresh to brackish and alkaline in nature for both pre and post monsoons. Based on TDS, out of 144 samples collected in the study area, 28 and 26 samples are desirable (TDS <500 mg/L) for drinking, 55 and 59 samples are permissible (500-1000 mg/L) for drinking, 55 and 48 samples are suitable for irrigation (1000-3000 mg/L) purposes and 6 and 11 samples are unfit (>3000 mg/l) for drinking and irrigation purposes for pre and post-monsoon respectively. Concentration of fluoride (141 samples each) is within the permissible limit (<1.5 mg/L) for drinking in pre and post-monsoon. 60% and 69% of the groundwater samples in the study area come under very hard (TH >300 mg/L) in pre and post-monsoon respectively. The classification based on EC of groundwater under "marginal category (1500 – 3000 μs/cm)" zone and "unsuitable category (> 3000 μs/cm)" zone at 28%

Table 6 : Water quality classifications based on SAR (Richards 1954)

Category	SAR	Sample numbers		
		Pre-monsoon	Post-monsoon	Both the monsoon
Excellent	<10	1-19,21-77,79-83,85-87,89-94, 96-99,101-108,110-144	1-77,79-81,83,85-87,89-93,97-98, 101-103,105-108, 110, 111,115-144	1-19,21-77,79,80,81, 85,86,87, 89,90,91, 93,97,98,101,102,103, 105,106,107, 108,110,111,115-144
Good	10-18	20,78,84,88,95,100,109	78,82,88,94-96, 99,100, 104, 109, 112-114	78,88,95,100,109
Doubtful	18-26	—	84	—
Unsuitable	>26	—	—	—

Table 7: Irrigation quality of groundwater based on sodium percentage

Category	Na %	Sample numbers		
		Pre-monsoon	Post-monsoon	Both the monsoons
Excellent	<20	14,23,45	1,2,13,14,39,42,45,47,58,68-70,86,105, 106,19,120, 125,128,142	14,45
Good	20-40	3,5,6-10,12,13,1 8,19, 21,24, 26,28-31,36-39,41-44,46,48, 50-53 56, 57,59,97,111	3,5,7,11,15-21,23-37,40,41, 43,44,46, 48,50,57,59,61,62 , 64,65,67,73,74,76, 77,79,97,117,118,121,124,126,127,129, 133,134,137,138,140,141,144	3,5,18,19,21,24,25,26,28, 29,30,31,36,37,41,43,44,46, 48,50,97
Permissible	40-60	1,2,4,11,15- 17,22,27,32-34,40, 47,5 4,55,58,60-63, 65,67-70, 73-76, 79,80,83,85-87,91-93, 112,117-137, 140-144	6,12,22,38,49,51-56,60, 63,72, 75,87, 90-93,107, 111,122,123, 130-132,135, 136,143	22,60,63,75,87,91,92,93, 122,123,130,131,132,135, 136,143
Doubtful	60-80	20,35,64,66,71,72,77,78,81, 82,84,88-90,94-96,98-110, 113-116,138,139	4,8-10,66,71,78,80,81,83-85, 88,89, 94-96,98-104, 108-110, 112-116,139	66,71,78,81,84,88,89,94,95,96, 98,99,100,101,102,103,104,108, 109,110,113,114,115,116,139
Unsuitable	>80	49	82	—

and 17% in pre-monsoon, 24% and 17% in post-monsoon respectively. In the study area 3% and 10% of samples exceed the permissible limit (nitrate <100 mg/L) for nitrate concentration in pre and post-monsoon respectively and also 86% (Sulphate <4 meq/L) of samples fall under excellent category for sulphate concentration in both pre and post-monsoon. Irrigation waters classified based on SAR indicated 94% and 90% of samples are excellent (SAR <10) in pre and post-monsoon respectively. 4% and 1% (RSC >2.5 meq/l) water sample showed residual sodium carbonate values in groundwater are unsuitable in pre and post-monsoon respectively.

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