International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Assessment of Groundwater Quality and Suitability Analysis for Irrigation Purpose, Cuddalore District, Tamilnadu

Dr. B. Kumaravel
Assistant Professor, Department of Civil Engineering, Annamalai University, Annamalainagar, India–608002

***Abstract*— *The suitability of groundwater quality was assessed for agricultural purposes along the coastal area of Cuddalore District. A total of 21 groundwater samples were collected and analyzed for 14 different chemical parameters during the period of 2012-13. Standard methods were followed and the concentrations of physicochemical parameters of pH, Total Dissolved Solids (TDS), electrical conductivity (EC), Ca^{++}, Mg^{++}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-} and , SO_4^{-} analyzed. The results of the concentrations were interpreted and measured with different irrigation indexes like EC, sodium percent (SP), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), permeability index (PI) and Kelly's ratio (KR). The interpreted results were indicated that the groundwater quality stands on EC values; 62 and 38% of the samples fall under medium to high salinity and very high salinity category in pre and post-monsoon seasons was 75 and 20% respectively and stands on sodium percent (SP) values, 43 and 29% of the samples fall under doubtful to unsuitable category in both seasons. The remaining indexes SAR and PI values stands on 100% of the samples and fall under the excellent and excellent to good category in both seasons. Hence, the indexes results were concluded that the quality of groundwater in general 60% of sample was suitable for irrigation without any practices.*

***Keywords*— *Groundwater quality, cuddalore district, irrigation water, sodium adsorption ratio, high salinity*.

I. INTRODUCTION

Groundwater is one of the most important and alternative source for domestic, industrial and agricultural water supply in the world. Exploitation of groundwater has been increased, ensuring an increasing reliance on groundwater quality due to increasing pollution with the concomitant rise (Kortatsi, 2007). Where the available soil moisture derived from rain is deficient, this lack can be made up by irrigation (P.R. George, 2004). Particular in arid and semi-arid areas their natural groundwater sources are declining in quantity and quality of water for irrigation. It is estimated that about 45 to 60% of irrigation water requirement is met from groundwater sources. The quality of ground water varies from place to place along with the depth of water table. Practically, water quality refers to the characteristic of a water supply which influences its suitability for a specific use to meets their needs. To evaluate the suitability of water supply for irrigation, Irrigation water quality is a key requirement as well as it is very important for every agricultural use improvement before it is acceptable for a given use (R.S. Ayers, 1977; Anikwe et al, 2002). A major concern for water use for irrigation is decreased crop yields and land degradation as a result of excess salts being present in water and soils.

In the study area most of the population, however, (49%) obtain drinking water from wells, and 1% from rain (Prasanna, 2008). Groundwater from the shallow aquifer is mostly used as potable water, domestic purposes and also used for irrigation. The pollution of surface and coastal waters is also an emerging problem in Cuddalore district, which can lead to an increased demand for cleaner groundwater. In India unfortunately, salinity hazards is extensive irrigation regions problem. In addition, different crops require different irrigation water qualities (K. Srinivasa Reddy, 2013). Therefore, testing the irrigation water quality is prior to contribute to effective management and utilization of the groundwater resources by clarifying relations among many hydrogeological considerations. In the present study, the physiochemical quality of groundwater has assessed with respect to pH, Electrical Conductivity (ECw), Total Dissolve Solids (TDS), Sodium Adsorption Ratio (SAR) and specific ions such as Sodium (Na^{+}), Magnesium (Mg^{++}), Calcium (Ca^{++}), Potassium (K^{+}), Bicarbonate (HCO_3^{-}), Chloride (Cl^{-}) and Sulphate (SO_4^{-}) to ascertain their suitability for irrigation purpose.

II. STUDY AREA

In Tamilnadu, Cuddalore district is located on the east coast and is bounded by four district in three sides and by Bay of Bengal in the East. (Gazette of India, 1991). The study area is lies between latitudes 11˚60' and 11˚40' N and longitudes 79˚80' and 78˚00' E. It falls in Survey of India map 56 M/10 and 14, with a total area of the study is 37 sq. km. The predominant occupation is agriculture followed by agricultural labor and fishing.

The district is benefited by the influence of the southwest monsoon stretching from June to September and the north east monsoon from October to December. The winter and hot seasons i.e., from January to May from the transition period and the rainfall is scanty. Long term average rainfall of the district is 1160.36 mm. A perusal of the data revealed that the northeast monsoon is more effective contributing 53.01% and is usually associated with storms from the Bay of Bengal, while the southeast monsoon is moderate contributing 32.66% of district total rainfall. The rest falls during the hot and winter seasons.

The mean maximum temperature ranges between 27.9^{o} and 36.9^{o} C and the mean minimum temperature ranges between 20.8^{o} and 27.1° C at Cuddalore. The depth to water table was in the range of 5 to 20 m below ground level (bgl)

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during pre-monsoon whereas during post-monsoon period ranged between 2 to 10 m bgl.

III. GEOLOGY

The district is underline by the various geological formations ranging in age from the Oldest Achaean rocks to recent sediments. The most common outcrops in the area are Limestone, Sandstone and Clays. These are covered in places by Lateritic, Kankar and Alluviam. Along the coast in the district, windblown sands of 1.5 to 3 km width are common occurring in the form of low and flat topped sand dunes expecting at the confluence of the river with sea. The gravimetric and seismic surveys carried out by the ONGC and the GSI in the coastal sedimentary tract have identified two major faults in the district, one running along the crystalline sedimentary contact in the west and the other running almost parallel to it at a distances of 1.5 km west of Parangipettai, merely suggesting the existence of a graben like structural through in the sedimentary tract of the district. The GSI has concluded progressive deepings of the basin along these faults which account for huge thickness of sediments of more than 3000 m in this basin.

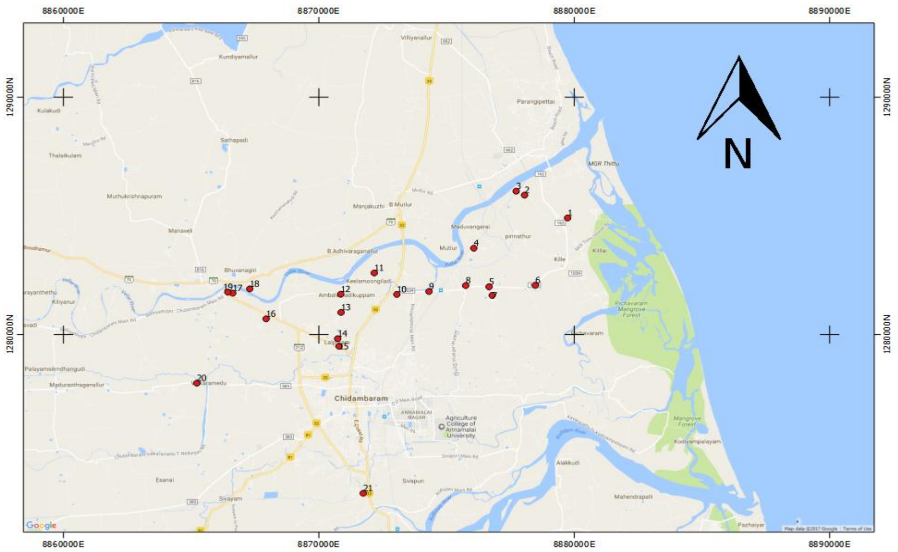

Fig. 1. Map showing the study area and location of groundwater sampling point.

IV. MATERIALS AND METHODS

Water Sampling

About 21 bore wells were selected to collect water sample in the study region (Fig. 1). The well locations was observed and noted with the help of Global Positioning System (GPS). The sampling of groundwater was carried out in the study area between the months of January to May, 2012. Groundwater samples were collected in one litre PVC bottle and preserved by adding an appropriate reagent (Jain and Bhatia, 1988; APHA, 1992). The hand pumps and tube wells were continuously pumped prior to the sampling, to ensure that ground water to be sampled was representative of ground water aquifer. They were then carefully sealed, labeled and taken for analyses. All the samples were stored in sampling kits maintained at 4^o C and brought to the laboratory for chemical analysis. The details of sampling locations and source distribution are given in table I.

Analytical Procedure

Collected samples were analyzed in the laboratory to measure the concentration of the water quality parameters using American Public Health Association standard methods (APHA, 1995). pH value of the water samples were analyzed for using electrometric pH meter according to procedure described. EC, Ca^{++}, Mg^{++}, Na^{+}, K^{+}, CO_3^{--}, HCO_3^{-}, SO_4^{--}, and Cl^{-} were the major ions in groundwater of the study area. Calcium and Magnesium concentrations were determined by Ethylenediaminetetraacetic acid (EDTA) titration using Eriochrome black-T as indicator. Sodium and potassium concentrations were determined by using a flame photometer. Chloride concentration was measured by silver nitrate titration. Carbonate and bicarbonate concentrations were measured by acid-base titration. Sulphate concentrations were measured by using colorimetric spectrophotometer. The accuracy of the analysis for major ions was cross checked from the ionic balance was within 7% for all the samples, ions were converted from milligram per litre to milliequivalent per litre. Correlation of geochemical data has been attempted as presented in tables I, II and III. The concentrations were interpreted and calculated with irrigation indexes using the following formula of SP, SAR, RSC, PI and KR as follows:

Sodium Percentage (SP)

This was calculated employing the equation (Todd, 1995) as:

$$Na\% = \frac{(Na^{+} + K^{+})}{(Ca^{++} + Mg^{++} + Na^{+} + K^{+})} x100$$

(Concentrations are in meq/L).

Sodium Absorption Ratio (SAR)

This was calculated employing the equation (Raghunath, 1987) as:

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

(Concentrations are in meq/L)

Residual Sodium Carbonate (RSC)

This was calculated employing the equation (Eaton, 1950) as:

$$RSC = \left[(CO_3^{--} + HCO_3^{-}) - (Ca^{++} + Mg^{++}) \right]$$

(Concentrations are in meq/L)

Permeability Index (PI)

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

This was calculated employing the equation (Domenico, 1990) as:

(Concentrations are in meq/L)

Kelly's Ratio (KR)

This was calculated employing the equation (Kelly, 1963) as:

$$KR = \frac{Na^{+}}{(Ca^{++} + Mg^{++})} x100$$

(Concentrations are in meq/L)

TABLE I. Summary Statistics of the analytical for both pre-monsoon and Postmonsoon.

Characteristics	Premonsoon				Postmonsoon			
	Mean	Min	Max	SD	Mean	Min	Max	SD
pH	7	6.74	8.43	0	7	6.4	8.26	0
EC (µs/cm)	2092	405	6014	1370	1671	312	4007	938
TDS (ppm)	1320	238	3430	806	1050	217	2350	586
Ca^{++}	54	24	108	26	39	12	92	22
Mg^{++}	36	9.6	148	31	3	0.5	8.5	2
Na^{+}	144	45.1	318	67	44	0	208	49
K^{+}	18	0.9	38.3	10	3	0	14.8	4
Cl^{-}	244	94.98	704	147	136	48.15	269.9	67
HCO_3^{-}	237	17.5	760.1	167	183	17.5	616.1	142
SO_4^{-}	6	3.5	14	3	4	0.30	12.50	3

TABLE II. Calculated irrigation quality characteristics.

S. No	Well Locations		Premonsoon						Postmonsoon					
	Latitude	Longitude	EC (µs/cm)	SP (%)	SAR	RSC (meq /l)	KR (%)	PI (%)	EC (µs/ cm)	SP (%)	SAR	RSC (meq/l)	KR (%)	PI (%)
1	11^{0}27'54.9"	79^{0}46'4.8"	4065	43	3.69	-7.30	0.71	52	3070	86	10.56	4.76	6.17	110
2	11^{0}28'25.4"	79^{0}45'10.2"	1190	40	2.07	-2.38	0.55	55	1167	11	0.38	-0.49	0.12	50
3	11^{0}28'35.8"	79^{0}44'55.8"	1261	47	2.84	-2.64	0.79	61	1092	66	4.03	1.57	1.92	96
4	11^{0}27'14.4"	79^{0}44'05.8"	1162	53	3.12	-0.09	0.95	71	1061	59	3.17	2.77	1.41	96
5	11^{0}26'22.8"	79^{0}44'25.2"	838	86	12.0	2.82	6.02	101	747	79	5.43	3.71	3.65	121
6	11^{0}26'24.8"	79^{0}45'24"	6014	41	2.41	-6.51	0.65	44	1261	54	2.09	-1.62	1.07	65
7	11^{0}26'11.3"	79^{0}44'29.1"	2086	65	5.48	2.66	1.70	83	1847	26	0.74	1.13	0.31	78
8	11^{0}26'24.5"	79^{0}43'55.5"	3095	71	8.12	6.66	2.38	88	3069	53	2.02	8.39	1.09	141
9	11^{0}26'15.9"	79^{0}43'5.4"	1626	65	4.15	-1.29	1.75	80	1498	33	0.75	-0.34	0.43	80
10	11^{0}26'12.6"	79^{0}42'27.9"	1194	65	4.05	-0.36	1.85	86	919	27	0.64	0.14	0.36	88
11	11^{0}26'41.4"	79^{0}41'59.6"	2138	39	2.39	-3.80	0.56	52	1920	14	0.39	-1.99	0.14	43
12	11^{0}26'12.8"	79^{0}41'17.0"	1092	64	4.93	0.45	1.75	83	967	62	1.84	0.48	1.63	125
13	11^{0}25'48.4"	79^{0}41'17.5"	405	64	4.33	-2.38	1.71	74	312	0	0.00	-0.05	0.00	104
14	11^{0}25'13.4"	79^{0}41'13.2"	4085	31	1.37	-6.68	0.34	37	4007	32	1.17	-3.01	0.39	47
15	11^{0}25'3.2"	79^{0}41'14.9"	850	46	1.66	-1.12	0.70	68	822	23	0.52	-0.37	0.28	75
16	11^{0}25'39.9"	79^{0}39'43.6"	1947	47	3.30	-3.77	0.84	60	1708	33	0.93	-0.10	0.43	75
17	11^{0}26'14.5"	79^{0}39'1.1"	2272	44	2.46	-3.36	0.71	57	2008	24	0.71	-0.70	0.31	64
18	11^{0}26'15.2"	79^{0}39'21.5"	3008	53	3.94	-4.23	1.04	63	2678	10	0.25	0.08	0.11	63
19	11^{0}26'15.7"	79^{0}38'55.1"	2495	47	3.14	-4.70	0.84	57	2171	9	0.20	-0.31	0.09	65
20	11^{0}24'13.9"	79^{0}38'15.8"	2372	70	5.93	-1.01	2.26	83	2066	83	6.28	0.08	4.73	102
21	11^{0}21'46.6"	79^{0}41'45.6"	742	61	3.80	1.10	1.46	85	698	63	2.94	2.98	1.68	115

TABLE III. Irrigation water quality based on EC values.

EC (µS/cm)	Class	Samples Falling in Dissimilar Seasons			
		Pre Monsoon		Post Monsoon	
		%	No. of samples and Sample Nos.	%	No. of samples and Sample Nos.
0 – 250	Low	Nil		4.76	1 (13)
251- 750	Medium	9.52	2 (13, 21)	14.2	3 (5,13,21)
751 – 2250	High	52.38	11 (2,3,4,5,7,9,10,11,12,15,16)	61.9	13 (2,3,4,6,7,9, 10,11,12,15,16,17,20)
2251 - 6000	Very High	38.09	8 (1,6,8,14,17,18,19,20)	19.0	4 (1,8,14,18)

TABLE IV. Classification of water based on SP values.

SP	Class	Samples Falling in Dissimilar Seasons			
		Pre Monsoon		Post Monsoon	
		%	No. of samples and Sample Nos.	%	No. of samples and Sample Nos.
<20	Excellent	Nil		14,28	3 (2,11,13)
20- 40	Good	9.50	2 (11,14)	42.85	9 (7,9,10,14,15,16,17,18,19)
40 – 60	Permissible	47.6	10 (1,2,3,4,6,15,16,17,18,19)	14.28	3 (4,6,8)
60 - 80	Doubtful	38.0	8 (7,8,9,10,12,13,20,21)	19.04	4 (3,5,12,21)
>80	Unsuitable	4.70	1 (5)	9.52	2 (1,20)

TABLE V. Classification of water based on SAR values.

SAR	Class	Samples Falling in Dissimilar Seasons			
		Pre Monsoon		Post Monsoon	
		%	No. of samples and Sample Nos.	%	No. of samples and Sample Nos.
<10	Excellent	95.23	20 (1-21 Except 5)	95.23	20 (1-20, Except 1)
10- 18	Good	4.76	1 (5)	4.76	1 (1)
18 – 26	Fair	Nil		Nil	
>26	Poor	Nil		Nil	

TABLE VI. Classification of water based on RSC values.

RSC	Class	Samples Falling in Dissimilar Seasons			
		Pre Monsoon		Post Monsoon	
		%	No. of samples and Sample Nos.	%	No. of samples and Sample Nos.
< 1.25	Safe	85.71	18 (Except 5,7,8)	66.66	14 (2,6,9,10-20)
1.25 – 2,50	Marginal	Nil		9.52	2 (3,7)
>2.5	Unsuitable	14.28	3 (5,7,8)	23.80	5 (1,4,5,8,21)

TABLE VII. Classification of water based on KR values.

KR	Class	Samples Falling in Dissimilar Seasons			
		Pre Monsoon		Post Monsoon	
		%	No. of samples and Sample Nos.	%	No. of samples and Sample Nos.
<1	Safe	71.42	15 (Except ,12,13,18,20,21)	57.14	12 (2,7,9,10,11,13-19)
> 1	Unsuitable	28.57	6 (5,12,13,18,20,21)	42.85	9 (1,3,4,5,6,8,12,20,21)

TABLE VIII. Statistical summary of different indexes of groundwater quality.

Parameter	PreMonsoon						PostMonsoon					
	EC (µs/cm)	SP (%)	SAR	RSC (meq/l)	KR (%)	PI %)	EC (µs/cm)	SP (%)	SAR	RSC (meq/l)	KR (%)	PI (%)
Mean	**2092**	54	4.06	-1.81	1.41	69	1671	40	2.15	0.81	1.25	86
Min	**405**	31	1.37	-7.30	0.34	37	312	0	0.00	-3.01	0.00	43
Max	**6014**	86	12.04	6.66	6.02	101	4007	86	10.56	8.39	6.17	141
SD	**1370**	13	2.40	3.43	1.19	17	938	26	2.60	2.49	1.66	27

V. RESULTS AND DISCUSSION

Good quality water is ensuring the potential to cause maximum yield under good soil and water management practices. Water quality for irrigation refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality. The most important characteristics of water which determine suitability of ground water for irrigation purpose are as follows:

1) Salinity Hazard
2) Sodium Adsorption Ratio
3) Residual Sodium Carbonate
4) Sodium Percentage
5) Kelly's Ratio

The results are obtained from hydrogeochemical analysis of water samples for both the monsoon periods. The calculated summary statistics of the analytical for both pre-monsoon and Postmonsoon were presented in table I and different characteristics indexes of groundwater quality are presented in table II. The electrical conductivity and its safe limits for crops of different degrees of salt tolerances under varying conditions are given in table III. The water quality is commonly expressed by classes of relative suitability for irrigation with reference to salinity levels. The recommended classification with respect to Electrical Conductivity (EC), Sodium Percentage (SP), Sodium Absorption Ratio (SAR) and Residual Sodium Carbonate (RSC) and Kelly's Ratio (KR) are given in table IV, V, VI, and VII respectively.

Electrical Conductivity

EC is the most important parameter to determine the soluble salts in samples, the significant water quality standard on crop productivity which was the water salinity hazard. The high EC water primarily reduces the osmotic activity of plants and thus interferes with absorption of water and nutrients from the soil. The amount of water transpired through a crop was directly related to yield; therefore, irrigation water with high EC reduces yield potential. In the study area, the classification for EC is given (Handa, 1969) in table III. It indicated that overall the water quality was medium to very high EC category in pre and postmonsoon.

Sodium Percentage

Sodium is an important factor in irrigation water quality which causes a most troublesome in water quality evaluation. Excessive sodium percentage leads to development of an alkaline soil that can cause soil physical problems and reducing the infiltration rate (W. P. Kelly, 1951, .Joshi et al., 2009). Normally high amount of sodium containing water is of special concern due to absorbed sodium by plant roots which is transported to leaves where it can accumulate and cause injury (S. Begum and M. G. Rasul, 2009). Thus, finer the soil texture and the greater the organic matter content, the greater the impact of sodium on water infiltration and aeration. The classification for SP was given (Wilcox, 1955) in Table IV. It is indicating the overall ground water quality of the samples which are falling under good to permissible category in pre monsoon and Excellent to permissible in postmonsoon seasons. Each season has one doubtful category.

Sodium Adsorption Ratio

Sodium hazard is usually expressed in terms of Sodium adsorption ratio and is of important parameter for the determination of the suitability of irrigation water. Excess sodium in water produces the undesirable effects of changing soil properties and reducing soil permeability (Biswas et al., 2002). The sodium hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations. If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium Is absorbed by the soil. 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 dispersion of the clay particles. In the study area all the groundwater samples have SAR values falls excellent class to good in both season and are acceptable for irrigation. The classification for SAR as is given (Richards, 1954) in table V.

Residual Sodium Carbonate

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. One of the empirical approaches was based on the assumption that calcium and magnesium precipitate as carbonate, considering this hypothesis (Eaton, 1950) proposed by the concept of residual sodium carbonate (RSC) for the measurement of high carbonate waters. The water with high RSC has high pH and land irrigated with such water becomes infertile owing to deposition of sodium carbonate as known from the black color of the soil. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation. The classification for RSC is given (Richards, 1954) in table VI. In the present study area, RSC values are mostly falling safe category in pre and post monsoon seasons respectively rest of them falls in unsuitable category, hence, most of water samples are considered as safe for irrigation.

Kelly's Ratio

Ground water quality for irrigation was also classified based on Kelly's ratios (Kelly, 1963), Kelly's ratio was more than 1 indicating an excess level of sodium in water; therefore the water Kelly's ratio of less than 1 was suitable for irrigation. In the study KR values 28.57 % and 42.85% fall unsafe category in pre and post monsoon seasons respectively (Pl. see Table VII); Thus, only 55% of the groundwater quality suitable for irrigation.

Permeability Index

The soil permeability is mainly affected by long term use of irrigation water which is a criterion for assessing the suitability of water for irrigation. Based on PI water can be classified as class I, Class II and Class III orders. Class I and Class II water was categorized as good for irrigation with 75% or more maximum permeability. Class III water was unsuitable with 25% of maximum permeability (Doneen, 1964; Raghunath, 1987). In the present study area the minimum and maximum permeability is 37 and 101%, 43 and 141% in pre and post monsoon seasons respectively in table VIII; hence, the groundwater quality was suitable for irrigation. Hence, the groundwater quality is suitable for irrigation.

VI. Conclusion and Recommendations

Interpretation of physical and chemical analysis revealed that the ground water quality of the study area has high salinity and high sodium in nature. The analysis of the samples indicated that the about 70% of the samples are safe for irrigation purposes and plants without any special practices. But, based on EC, 50% of the samples fall under the high salinity (751 to 2250 µS/cm) and 30% fall under very high salinity category; it is suitable for horticultural crops with some special practices. Even with adequate drainage, special management for salinity control may be required and plants with good tolerance should be selected. Similarly, sodium percentage also found about 42% fall under doubtful in premonsoon and the postmonsoon is 28%, which indicate the high sodium percentage in the soil salinity. Observed from the analyzed results of groundwater quality was diminutive and changed due to monsoon impacts of a lesser amount of rain fall, runoff, infiltration and rock water interaction (geogenic reaction) in the study area. Therefore, the study concluded that proper management and periodic monitoring of quality parameters are required to ensure successful, safe and long term use of groundwater for irrigation.

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