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Groundwater quality evaluation and its suitability for domestic and irrigation use in the hard rock terrain of Olakkur block, Tamilnadu, India

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KEYWORDS:

Corrosion;
Hydrogeochemical;
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Irrigation quality;
Groundwater quality

Ground water is the main source of water for agriculture and domestic use in the study area. This study was aimed to evaluate the groundwater quality for domestic and irrigational purposes. Groundwater samples were collected from twenty five locations in both pre-monsoon and post-monsoon months and examined for various physico-chemical parameters such as pH, total dissolved solids, total hardness, calcium, magnesium, sodium, potassium, bicarbonate, sulphate, Nitrate and chloride. To assess the domestic suitability of groundwater, all these parameters were compared with the standards of World Health Organization and Indian standards. Sodium Adsorption Ratio (SAR) and US salinity diagram were used to evaluate the groundwater for irrigation suitability. At some locations sodium and potassium values were higher than the prescribed limits. The SAR values were less than 10. Based on United States Salinity Laboratory Staff (USSL) diagram the dominant categories were C2-S1, C3-S1, C2-S1, C3-S1, C3-S2 in both pre and post-monsoon. Groundwater samples were classified as Na-HCO_3 and Na-Cl water type in pre-monsoon and Ca-Na-HCO_3 and Na-Cl types in post-monsoon. The geochemical analysis revealed that the groundwater samples were fit for domestic purpose. The irrigation quality assessment based on Sodium Adsorption ratio and US Salinity diagram suggested that, most of the groundwater samples were fit for irrigational activities except in certain locations where sodium and salinity values were high. Based on Piper water classification, mixing process and evaporation were the dominant geochemical process in the study area.

ABSTRACT

INTRODUCTION

In most parts of India ground water play a vital role and major source for drinking and agricultural purposes. The quality of groundwater is a function of physical and chemical parameters that are greatly influenced by anthropogenic activities and geological formations (Krishna Kumar et al., 2011). The chemistry of groundwater is not only related to lithology and rock water interaction but also reflects inputs from soil, atmosphere and pollutant sources such as saline intrusion, mining activities, industrial and domestic wastes (Babiker et al., 2007). Groundwater also gets polluted due to excessive irrigation practices (Sujatha and Reddy, 2003). Understanding

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geochemical evolution of groundwater in arid and semi-arid regions would be helpful for sustainable development, consumer protection from noxious substances/contaminants and proper management of water resources (Jalali, 2009; Furi et al., 2011). Geographic Information system (GIS) is an effective tool for assessing and mapping groundwater quality and its utilization for irrigation and drinking needs (Srinivasamoorthy et al., 2011; Ravikumar et al., 2013). The geological formations and anthropogenic activities are greatly influenced the groundwater quality in the study area. Agriculture practice is the major economic activity in the study area. Surface water resources are very scarce and groundwater resources represent water source for drinking and agricultural purposes for the people living in this area. It is widely accepted that the utilizations of groundwater resources are closely associated with their geochemical properties (Abderamane, 2013; Krishna Kumar et al., 2015). For effective and safe use of ground water for various agricultural and domestic uses, sufficient information should be available. However, there is no such study in the area. Therefore, the present study was attempted with the objective of assessing the groundwater quality and its suitability for drinking and irrigation purpose.

MATERIALS AND METHODS

Study area

The study area, Olakkur Block, is located between latitudes 12°10'00" and 12°25'00" N and longitudes 79°30'00" and 79°50'00" E, in Villupuram District (Figure 1) and covers an area of about 277.64 Sq.km. The study area falls in the following Survey of India topographic sheets 57P/11, 57P/12, 57P/15 and 57P/16. The area is bounded by the Kancheepuram district in the north Tiruvannamalai district in west, Marakanam block and Mailam block of Villupuram district in the east and south, respectively. Agriculture is the main activity where paddy is the principal crop, and crops such as sorghum, maize, ragi, pulses, chillies, groundnut, cotton and sugarcane are also cultivated.

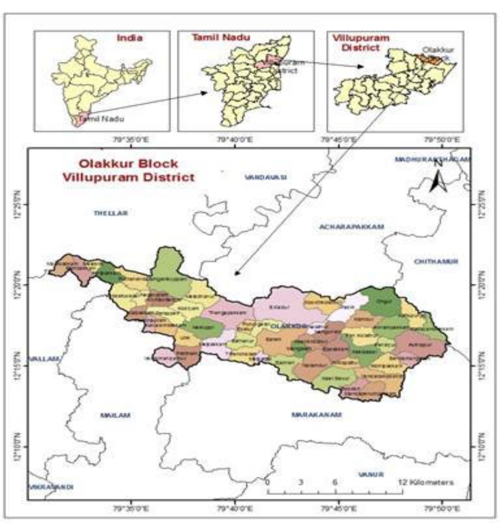

Figure 1Location map of the study area

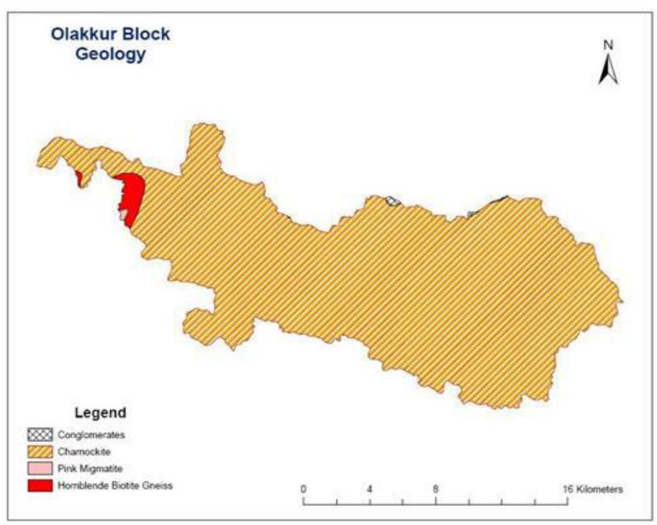

Figure 2 Geology map of the study area

Geology and Geomorphology

The Charnockite of Archaean age covers most part of the study area (Figure 2). Hornblende biotite gneiss and pink migmatite is seen along north western part of the study area. The rock shows typical granular texture with Quartzo-feldspathic composition. Conglomerate is exposed in north part near the Marakanam region. Thickness of weathering varies in different places and it depends on the mechanical and chemical action on the granitic rocks. Prominent vertical and oblique joints and fractures are observed from well inventories. The trend of the granitic gneiss is N60 °E and dipping towards S35°E which are noticed on the N-NE of Melmalayanur. The trend also varies from N35°E to N45°E on the northern and southern side of Gingee. This is due to the changes in tectonic disturbance, which also controls the movement of groundwater.

Charnockite is seen in North-West and South-East which extends up to Melmalayanur and NE till Gingee around Perumpugai village. It is composed of blue quartz, feldspar and hypersthene. In some part of the study area charnockiteacts as intrusive rock (Senthilkumar et al., 2014). The weathering thickness is moderate and the joints and fractures are limited. The Geo-morphological study area is based on the fact that the specific characteristics of each of the landform vary greatly in terms of shape, dimension, and thickness of the overburden material, permeability, porosity etc, depending on the underlying rock type, structural control, climate and vegetative cover. Geomorphology of the area dominantly consists of the deep buried pediment, shallow buried pediments and pediments.

Methodology

Base boundary map was prepared using Survey of India topo-sheets of the study area, and data such as rainfall, geomorphology, geology and land use were collected from central and state government agencies. During field study, groundwater samples were collected from 25 locations from both bore well and dug wells during pre-monsoon and post monsoon seasons in 2020. The samples were analysed for major ions by employing the standard water quality analysis procedures (APHA, 1995). Physical parameters such as pH and EC were measured using potable meters in the field. Major ions such as Ca, Mg were analyzed titrimetrically using Standard EDTA (0.2N) solution. Sodium (Na) and potassium (K) were estimated, using a Flame photometer (model CL354). Carbonate (CO_3) and bicarbonates (HCO_3) were analysed by standard HCl titration method and Sulphate (SO_4) was analyzed, using a spectrophotometer (model SL27). The Corrosivity ratio of water was calculated by using the formula of Ryznar (1944)

$$\text{Corrosivity Ratio (CR)} = \frac{\dfrac{Cl(mg/l)}{35.5} + \dfrac{2SO_4(mg/l)}{96}}{2\left(\dfrac{CO_3 + HCO_3(mg/l)}{100}\right)}$$

Total Hardness denotes the concentration of Calcium and Magnesium in water and is usually expressed as the equivalents of $CaCO_3$, calculated by the following formula

Total Hardness (TH) = 2.497 Ca+4.115 Mg (Karanth, 1991).

The spatial analysis of various physico-chemical parameters was carried out using the ArcGIS®9.1 software. An inverse distance weighed (IDW) algorithm was used to interpolate data spatially and estimate values between measurements. This interpolation technique calculates a value for each grid node by examining surrounding data points that lie within a user-defined search radius (Burrough and McDonnell, 1998). All of the data points are used in the interpolation process and the node value is calculated by averaging the weighted sum of all the points.

RESULTS AND DISCUSSION

Assessment of groundwater quality

The spatial distribution of total dissolved solids (TDS), total hardness (TH) and corrosivity ratio for pre and post-monsoon is shown in Figure 3.

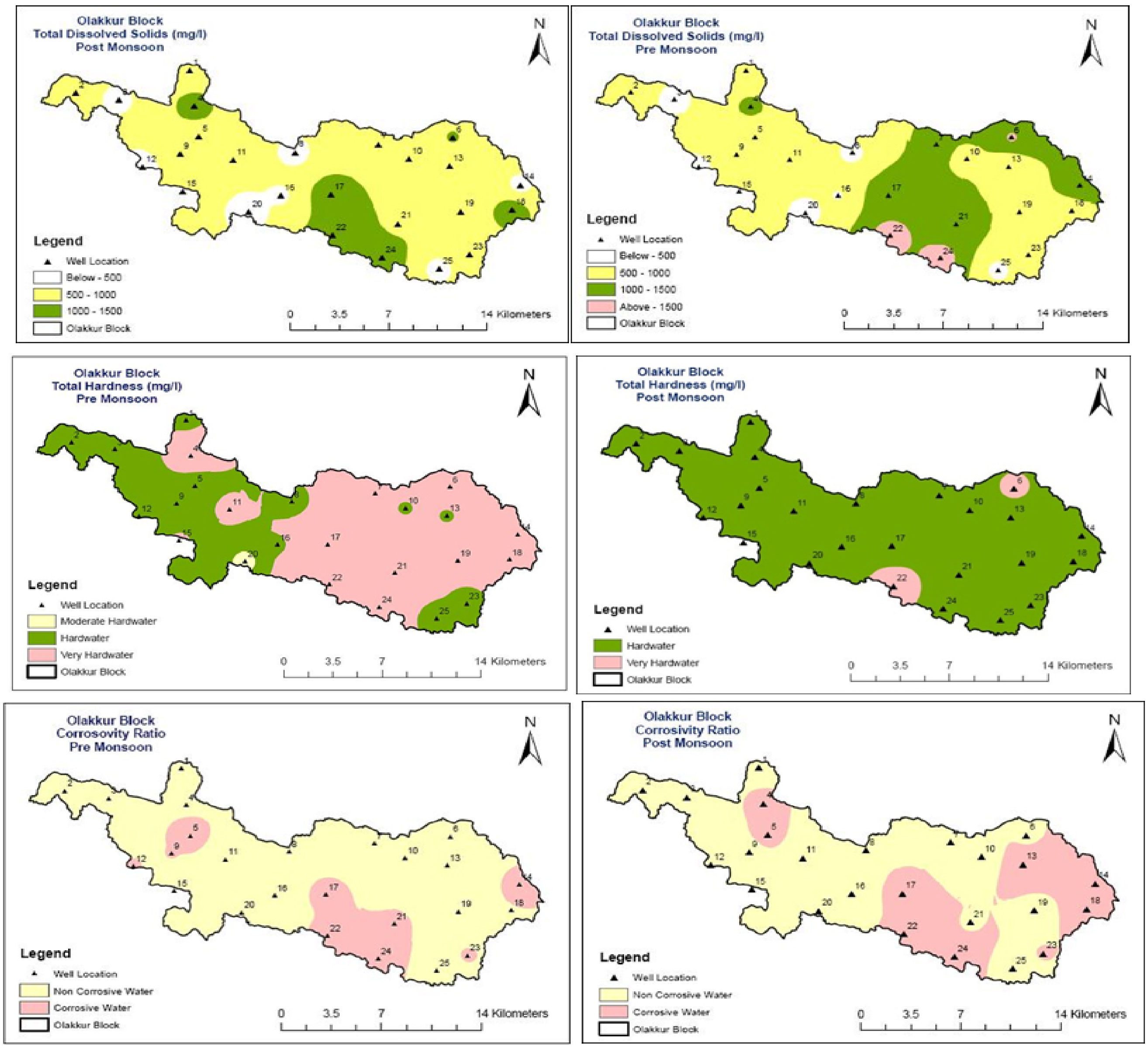

Figure 3: TDS, TH and Corrosivity ration for pre-monsoon and post-monsoon

The physico-chemical analysis of the groundwater samples for both seasons is presented in Table 1 & 2.

Table 1: Physico-chemical characteristics of groundwater in the study area Pre- monsoon

Sample locations	pH	TDS	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3	SAR
1	7	756	31	18	153	18	393	126	27	1	6
2	7.2	399	29	5	48.6	5.4	207	22	10	3	2
3	7.2	1106	50	31	223.2	24.8	442	253	64	10	7
4	7.3	1533	77	55	217	25	613	250	81	9	5
5	6.8	1078	44	27	207	23	431	156	140	8	7
6	7.4	417	21	18	58	6	167	69	35	2	3
7	7.1	627	59	9	89	10	313	82	21	9	3
8	6.9	910	20	38	150	17	437	119	40	4	5
9	6.8	721	59	13	152	25	346	164	43	2	5
10	7.2	1155	71	40	225	30	462	336	43	4	6
11	7	483	48	8	60	10	242	46	42	2	2
12	7	1428	45	68	335	15	571	465	26	6	8
13	7.3	767	64	13	129	21	345	123	79	6	4
14	6.7	357	22	4	61	7	171	41	25	2	4
15	7.5	966	32	26	189	21	386	192	51	7	7
16	7.3	900	77	8	176	20	360	211	59	4	6
17	6.8	1229	99	33	224	24	491	260	148	5	6
18	6.9	1778	118	49	366	41	711	446	166	3	8
19	7.5	963	30	18	230	26	385	250	36	6	9
20	6.9	1736	107	27	462	51	694	577	103	10	12
21	7.4	350	25	6	67	7	140	76	27	5	3
22	7.2	956	58	11	260	29	382	307	67	6	9
23	7.3	595	44	13	87	10	238	100	35	6	3
24	6.6	403	27	8	59	7	161	69	18	4	3
25	6.9	606	48	10	183	20	297	58	53	7	4

pH: The pH value of groundwater samples ranging from 6.6-7.5 and 6.7-7.7 during pre and post-monsoon, respectively. WHO standards reveals that all the groundwater samples from the study area during both monsoons exceed the most desirable limit of 6.5 but under maximum allowable limit of 8.5. The pH values indicate slightly acidic nature in some locations which could be attributed to the weathering process of underlain geology.

Table 2: Physico-chemical characteristics of groundwater in the study area Post- monsoon

Sample locations	pH	TDS	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3	SAR
1	7.4	602	32	15	71	8	313	31	12	2	3
2	7.1	438	21	12	51	6	228	15	18	4	3
3	7	1302	92	8	331	37	521	442	11	3	10
4	7.1	1022	105	9	171	19	409	223	56	9	5
5	7.1	763	47	12	159	18	305	161	67	8	6
6	7.2	378	23	15	59	6	151	81	27	2	3
7	6.8	550	42	5	89	10	275	73	9	8	4
8	7.1	777	35	27	105	12	373	73	40	5	4
9	7.4	637	55	17	99	11	306	123	24	2	3
10	7.2	378	25	9	73	8	151	100	10	4	4
11	6.7	441	35	10	71	8	221	61	35	2	3
12	7.1	1358	50	22	377	42	543	461	31	5	12
13	6.9	693	57	13	113	13	312	131	28	6	4
14	6.7	315	25	7	39	4	151	38	12	3	2
15	7.5	945	36	24	182	20	378	188	50	8	6
16	6.7	1225	80	19	281	31	490	346	67	3	8
17	6.8	925	49	21	195	22	381	215	64	4	7
18	6.9	1372	119	36	286	32	549	413	103	3	7
19	7.7	900	30	19	211	23	360	242	21	6	8
20	7.4	1369	82	23	383	42	547	499	88	10	11
21	7.4	350	25	6	67	7	140	76	27	5	3
22	7.5	882	54	11	242	27	353	291	63	5	9
23	7.4	546	39	12	80	9	218	91	32	5	3
24	6.8	336	23	8	50	5	134	62	14	3	3
25	7	546	22	4	40	4	68	44	48	6	2

Total dissolved solids (TDS): Different geological regions influence the concentration of TDS due to differences in the solubility of minerals (WHO, 2004). As the residence time of groundwater in the geological formation increased, the TDS and major ion concentrations are also increased (Norris et al., 1992). Based on WHO standards, the highest desirable limit for TDS is 500mg/l and maximum permissible limit is 1500 mg/l. In the study area, during pre-monsoon the TDS values exceeds maximum permissible limit at locations 6, 22 and 24. The remaining locations fall under the category of highest desirable limit at Locations 3, 8, 12, 16, 20 and 25 and maximum permissible limit at Locations 1, 2, 4, 5, 7, 9, 10, 11, 13, 14, 15, 17 18, 19, 21 and 23. During post-monsoon the groundwater quality has been changed as evidenced by the locations 6, 22 and 24 which are changed in to maximum permissible category from exceeding limit. The highest desirable limit category occurs at locations 3, 8, 12, 14, 16, 20 and 25 and maximum permissible limit category at 1, 2, 4, 5, 6 7, 9, 10, 11, 13, 15, 17 18, 19, 21, 22, 23 and 24. The classification of groundwater, according to Davis and De Wiest (1966), based on TDS is given in Table 3.

Table -3: Classification of groundwater based on TDS (Davis and De Wiest, 1966)

TDS (mg/l)	Water type	Samples (pre-monsoon)	Samples (post-monsoon)
<500	Desirable for drinking	3, 8, 12, 16, 20,25	3, 8, 12, 14,16, 20, 25
500-1000	Permissible for drinking	1, 2, 5, 9, 10, 11, 13, 15, 18, 19, 23	1, 2, 5, 7, 9, 10, 11, 13, 15, 19, 21, 23,
<3000	Useful for irrigation	4, 6, 7, 14, 17, 21, 22, 24	4, 6, 17, 18, 22, 24
>3000	Unfit for drinking and irrigation	------	------

Total Hardness (TH): The presence of carbonates and bicarbonates of calcium and magnesium, chlorides, nitrates and sulphates of calcium and magnesium cause total hardness in groundwater. According to Sawyer and McCarty (1967), based on TH, the groundwater is classified as soft (TH<75 mg/l), moderately hard (TH= 75-150 mg/l), hard (TH= 150-300 mg/l) and very hard (>300 mg/l). Spatial distribution of total hardness for pre and post-monsoon is shown in Figure 3. During pre-monsoon no soft water occurred in the study area but moderate hard water was found at location no. 20. Hard water mainly occurred in west and some eastern part of the study area at locations 1, 2, 3, 5, 8, 9, 10, 12, 13, 16, 23 and 25. Very hard water occurred at locations 4, 6, 7, 11, 14, 15, 17, 18, 19, 21, 22 and 24. In post-monsoon, the total hardness of the groundwater was remarkably changed. Except at locations 6 and 22, which showed very hard water, all other groundwater samples were observed as hard water. The drinking water quality was evaluated by comparing with the specifications of TH, TDS and other parameters set forth by the World Health Organization and Indian standards (Table 4).

Calcium and magnesium: Calcium and magnesium are abundantly occurred elements in natural waters in the form of bicarbonates, sulfate and chloride. Ca concentrations were varying from 21 to 118 mg/l in pre-monsoon and 21 to 119 mg/l in post-monsoon. The desirable limit of calcium concentration for drinking water as per the standards of WHO (2004) is 75 mg/l. During pre-monsoon and post-monsoon, 84% of the groundwater samples were under desirable limit. Only 16 % of the groundwater samples have crossed the desirable limit. The higher concentration of Ca could cause abdominal ailments in humans and encrustation and scaling in pipes. Magnesium content varied from 4 to 68 mg/l in pre-monsoon and 4 to 36 mg/l in post-monsoon. According to WHO standards, the desirable limit for Mg is 50 mg/l which shows that 92% and 100% groundwater samples from the study area fell under the desirable category during pre-monsoon and post-monsoon respectively.

Table -4: Parameter range WHO (2004) and ISI (2009) standards for drinking purpose

S.No	Water quality parameters	WHO Standards (2004)		Indian standard (ISI 10500,2009)		Pre-monsoon range in the study area	Post-monsoon range in the study area
		Most desirable limit	Max. allowable limit	Highest desirable	Max. permissible		
1	pH	6.5	8.5	6.5-8.5	No relaxation	6.6-7.5	6.7-7.7
2	TDS	500	1500	500	2000	350-1778	315-1372
3	TH (as $CaCO_3$)	100	500	200	600	71-495	71-445
4	Ca	75	200	75	200	21-118	21-119
5	Mg	50	150	30	No relaxation	4-68	4-36
6	Na	-	200	-	200	48-462	39-383
7	K	-	12	-	-	5-51	4-42
8	SO_4	200	400	200	400	18-166	9-103
9	Cl	200	600	250	1000	22-577	15-499
10	NO_3	40	50	45	No relaxation	1-10	2-10

Sodium and potassium (Na and K): The concentration of Na in the study area varied from 48 to 462 mg/l in pre-monsoon and 39 to 383 mg/l in post-monsoon. According to WHO standards (200 mg/l) 40% and 28 % of the groundwater samples exceeded the maximum allowable limit during pre and post-monsoon respectively. Water with high sodium content can be easily absorbed by soil which in turn determines the irrigation soil quality. High sodium concentration in the soils leads to development of an alkaline soil which results in alkaline hazard. The maximum allowable limit for K is 12 mg/l as per WHO standard but in pre-monsoon 68% of the groundwater samples exceeded the limit and during post-monsoon only 48 % of the samples exceeded the limit. The high concentration of K could be attributed to the dissolution of potash feldspar associated with charnockite in the study area.

Bicarbonate (HCO_3): The value of bicarbonate was observed from 140 to 711 mg/l and 68 to 549 mg/l during pre and post-monsoon respectively. Mineral dissolution plays the key role for higher concentration of HCO_3 in groundwater (Stumm and Morgan, 1996)

Sulphate (SO_4): The sources, residence time and different geochemical process influence the concentration of SO_4. Dissolution or weathering of gypsum and anhydrite minerals is the important geochemical process responsible for high concentration of SO_4 in groundwater. The SO_4 concentration in groundwater samples from the study area varied from 18 to 166 mg/l and 9 to 103 mg/l during pre and post-monsoon respectively. As per WHO standards, all groundwater samples were well within desirable limit of 200 mg/l in both the seasons.

Chloride (Cl): The chloride content in groundwater might be originated from different sources such as intrusion of salt water, weathering, leaching of various rock types, domestic and industrial waste discharges (Karanth, 1987). In the study area, the concentration of chloride ranged between 22 and 577 mg/l and 15-499 mg/l in which 40% and 36% of total water samples exceeded the most desirable limit of 200 mg/l set by WHO during pre and post-monsoon respectively. The excess of chloride in the water is usually taken as an index of pollution and considered as tracer for groundwater contamination (Loizidou and Kapetanios,1993).

Nitrate (NO_3): According to WHO, nitrate concentration in groundwater samples from the study area was within the prescribed limit of 50 mg/l in both the seasons. The values vary from 1 to 10 mg/l and 2-10 mg/l during pre and post-monsoon respectively. Nitrate concentration in the study area could be attributed to discharges of sewage effluents and agriculture chemicals.

Corrosivity ratio: Corrosion is basically an electrolytic process, which severely attacks and corrodes the metal surfaces. The rate at which corrosion proceeds depends upon a variety of chemical equilibrium reactions as well as upon certain physical factors like the temperature, pressure and velocity of flow (Ayers and Westcot, 1985). If the corrosivity ratio is less than 1, then the metal pipes can be used for transporting water, whereas PVC pipes must be used in areas where corrosivity ratio is more than 1. Out of total water samplestested, only few locations at 5, 9, 12, 14, 17, 21, 22, 23 and 24 were exceeded the limit of 1 in pre-monsoon. During post-monsoon the corrosivity ratio of the groundwater samples was more than 1 at locations 4, 5, 13, 14, 17, 18, 22, 23 and 24.

Piper's Trilinear Plot: The major cations and anions are plotted on Piper diagram (Piper, 1944) to assess the geochemical evolution of groundwater. This diagram is used to study the differences and similarities in the composition of groundwater and for classification of water types. The hydrochemical facies for the groundwater samples from the study area is shown in Figure 4. During pre-monsoon two major facies types are present which are Ca-Na-HCO_3 water type and Na-Cl water type. These water types suggest that the groundwater chemistry was controlled by a mixing process and evaporation process. In post monsoon also the major water types are Ca-Na-HCO_3 and Na-Cl types. A few samples however were mixed Ca-Mg-Cl type suggesting that same geochemical process was controlling the groundwater chemistry.

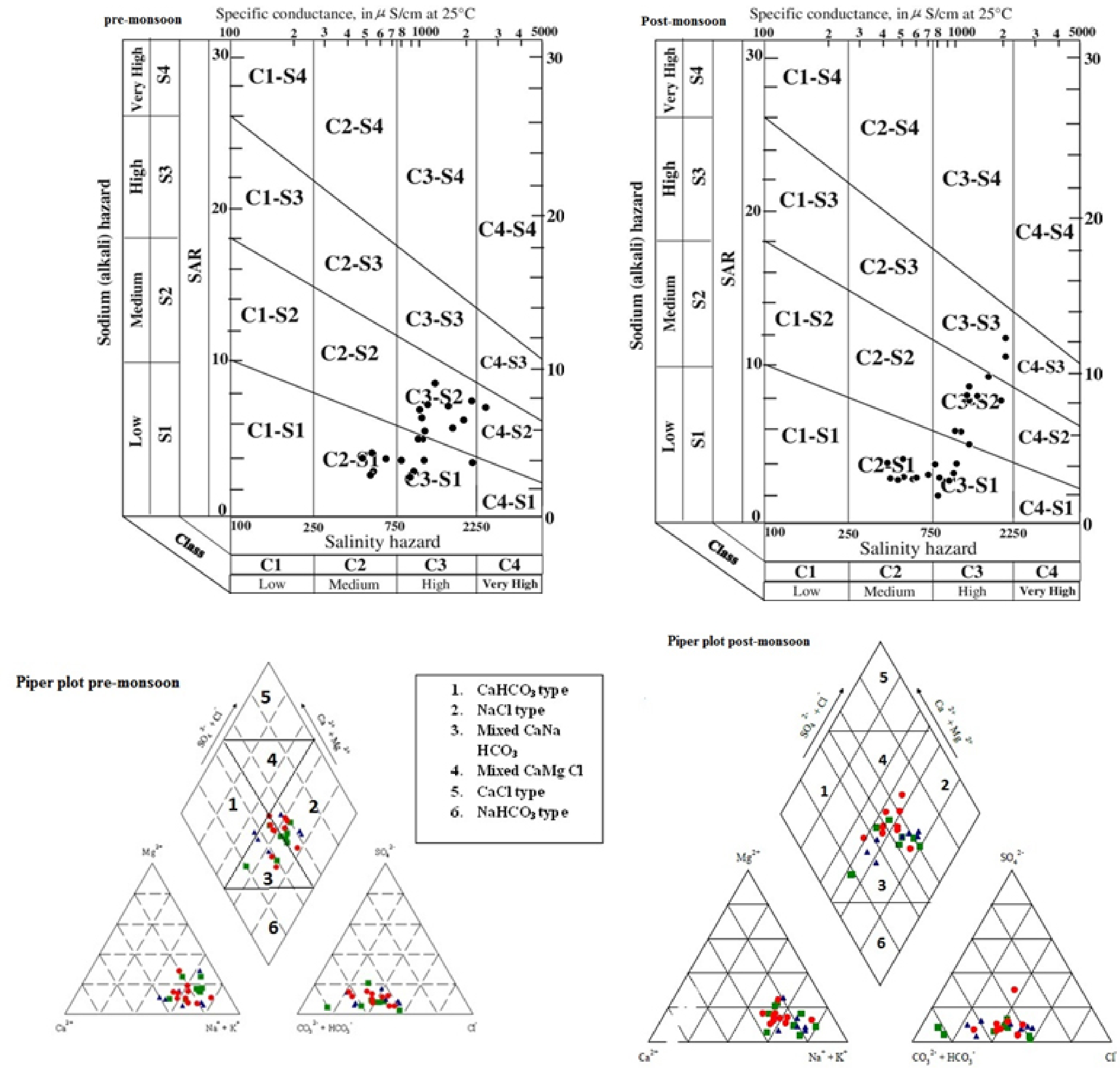

Figure- 4: US salinity and Piper plot for pre-monsoon and post-monsoon

Suitability of groundwater for irrigation

Sodium adsorption ratio (SAR): SAR ratio is a measure of alkali or sodium hazard to crops. More Na concentration in irrigation water can reduce permeability and free flow of air and water. This is due to exchange process by Na ions adsorbed by the clay particle replacing the Mg and Ca ions (Saleh et al., 1999; Yidana, 2010). The Sodium adsorption ratio is expressed as

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

where all ionic concentrations are expressed in meq/L.

The SAR value varied from 2 to 12 (Table 1 and 2) in both pre-monsoon and post-monsoon. Table 5a and 5b illustrates SAR classification of groundwater samples from the study area for both the season. During pre-monsoon 96% of groundwater samples were suitable for all types of crops and soil except for those crops sensitive to sodium. The remaining 4% of the ground water sample was suitable for coarse textured or organic soil with permeability. During post-monsoon 92% of the groundwater samples were suitable for all types of crops and soils except for those crops which were sensitive to sodium, and 8 % were suitable for coarse textured or organic soil with permeability.

Table- 5a: Suitability of water for irrigation with different value of SAR-Pre- monsoon

SAR	Suitability of Irrigation	Samples
1-10	Suitable for all types of crops and soil except for those crops sensitive to sodium	96%
10-18	Suitable for coarsed textured or organic soil with permeability	4%
18-26	Harmful for almost all soil	--
>26	Unsuitable for irrigation	--

Table- 5b: Suitability of water for irrigation with different value of SAR-Post- monsoon

SAR	Suitability of Irrigation	Samples
1-10	Suitable for all types of crops and soil except for those crops sensitive to sodium	92%
10-18	Suitable for coarse textured or organic soil with permeability	8%
18-26	Harmful for almost all soil	--
>26	Unsuitable for irrigation	--

US Salinity Diagram (1995): The analytical data was interpreted using USSL diagram to assess the groundwater quality for irrigation purpose. Figure 4 shows 60% samples were in C2-S1 and C3-S1 categories suggesting that the water can be used for irrigation activity in pre-monsoon. The remaining 40 % were in C3-S2 and C4-S2 indicating that groundwater is suitable for irrigational use with limited risk due to exchangeable sodium. In post-monsoon 56% of the samples belonged to C2-S1 and C3-S1 categories and 36 % samples were in C3-S2 category suggesting that the water can be used for irrigational purpose. The remaining 8% samples fell in C3-S3 category which shows high salinity and sodium hazard suggesting that water is not suitable for irrigation purpose.

CONCLUSIONS

The geology and geomorphology of the study area comprises of Charnockite of Archaean age and buried pediments respectively. In the present study, interpretation of geochemical analysis of groundwater samples revealed that, TH and TDS values were found to be suitable for drinking purposes. Based on TH values very hard water occurred at locations 4, 6, 7, 11, 14, 15, 17, 18, 19, 21, 22 and 24. Total dissolved solids in groundwater were less than 2000 mg/l in both the seasons. In some locations the sodium and potassium concentrations were higher than the prescribed limit Corrosivity ratio of the groundwater samples was more than 1 at some sampling points suggesting that PVC pipe must be used in those areas. Except for a very few locations SAR valuewas less than 10 signifying the suitability of groundwater for irrigation purpose. Based on USSL diagram, the dominant categories were C2-S1, C3-S1, C2-S1, C3-S1, C3-S2 in both pre and post-monsoon, suggesting that the groundwater is suitable for irrigational activities excepting a few locations which fall under the C3-S3 category indicating high sodium hazard. According to Piper diagram most of the samples were classified as Na-HCO_3 water type and Na-Cl water type in pre-monsoon and Ca-Na-HCO_3 and Na-Cl types in post-monsoon. The interpretation of these water types suggests that, mixing and evaporation processes are the two dominant geochemical processes in the study area.

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