RESEARCH ARTICLE

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Seasonal Variation of Groundwater Quality for Irrigational uses in Gadilam River Basin, Tamil Nadu, India

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Abstract: The present research work pertains to the Gadilam river basin groundwater quality for irrigation uses with respect to the Archaean formation, the Quaternary formation, the Tertiary formation and the Cretaceous formation. Experiments were carried out for two seasons (rainy season and summer season) for two successive years (November 2018 and June 2019). Overall, 120 groundwater samples were collected from the Gadilam river basin, excluding the reserved forest area. The 50 samples were collected from the Archaean formation, 34 samples from the Quaternary formation, and 35 samples from the Tertiary Formation. The remaining sample is from the Cretaceous formation. Based on the obtained analysed data, the following agricultural water quality parameters were calculated using the following expressions: The irrigational quality parameters are used, such as sodium percentage (Na%), sodium adsorption ratio (SAR), Kelly's ratio (KR), permeability index (PI), magnesium ratio (MR), residual sodium carbonate (RSC), and potential salinity (PS) are calculated and assessed for irrigation purposes.

Keywords: Gadilam River, Groundwater, Sodium Percentage, Permeability Index, Potential Salinity.

Introduction

Groundwater is one of the primary resources available on earth. Groundwater is essential for drinking, domestic, agricultural and other activities in the daily lives of humankind. Groundwater is constituted of various dissolved minerals, some of which are useful for the soil and plants, whereas some may pose a threat to them [1,2]. The agricultural sector is by far the biggest user of freshwater. In Asian countries, an estimated 85–90% of all fresh water used is for agriculture [3].

Since the chemical quality of water is the key aspect, the other important factors are: topography of land, maturity and composition of the soil, climate, the amount of water used and methods of its applications, depth to the water table, the type of crop grown, time of cropping and methods of crop management. Good quality water with proper cropping practises allows for maximum crop yield with proper soil and water management [4]. For successful agricultural practices, it is very important to consider the hazards that affect crop productivity.

The uses of groundwater were categorised based upon its chemistry. A study on groundwater for agricultural utility based upon Sodium percentage (Na%), Sodium adsorption ratio (SAR), Kelly's ratio (KR), Permeability index (PI), Magnesium ratio (MR), Residual sodium carbonate (RSC), Potential salinity (PS) was discussed by [5,6]. Diagrams for utility purposes have been developed by the [7] United State Salinity Laboratory (1954) plot. The impact of intensive agriculture on the geochemistry of groundwater recharged in regional aquifers was studied by [8].

Many authors, including [9-18] have done similar types of studies.

Study Area

The Gadilam river basin is located in the northern part of Tamil Nadu. This river, which originates from Viluppuram district, confluences with the Bay of Bengal Sea at Cuddalure district. It has been an important basin since time immemorial, serving as a focal point for many historical events ranging from the early Pallava Kings (10th century AD) to the late British Period.The major towns of Panruti, Nellikuppam and Cuddalore are the major towns developed in a contiguous manner in the study area.

The Gadilam rising in the Kallakurichi taluk flows eastwards across the district. After passing South of Cuddalore New Town, it runs into the Bay of Bengal by two mouths rounding up the ruined Fort St. Davis. It is reported that the river gets a supply of occasional floodwater from the Ponnaiyar River through the Malattat River. The Gadilam River basin is extended from 11°26'31.797" N to 11°56'29.633" N latitudes and 78°59'10.675" E to 79°47'15.793" E longitudes (Figure 1).

Methodology

The Gadilam River Basin map is prepared by delineating the drainage systems from Survey of India topographical maps 58I/13, 58M/1, 58M/2, 58M/5, 58M/6, 58M/7, 58M/9, 58M/10, 58M/11 and 58M/15 on a 1:50,000 scale and updating

It is suitable for recent satellite imagery. The geology map is prepared from a GSI map at 1:50,000 scale, and it gives the details of lithology and structure in the field by their distinct texture, structure and colour. The Gadilam river upper basin shows the Archaean formation and the lower basin shows Tertiary uplands in the south and recent alluvium (Quaternary) in the north (Figure1).

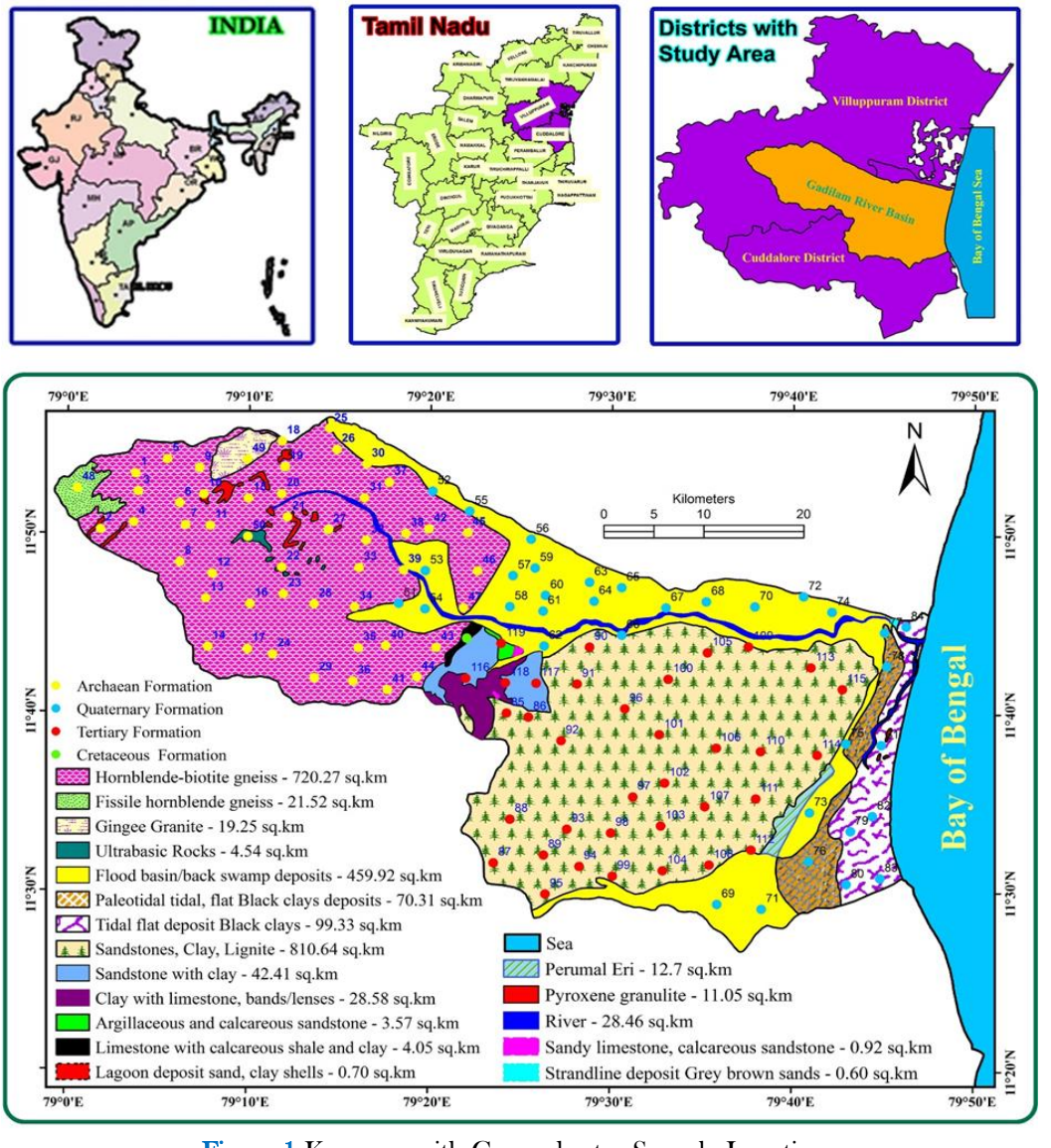

Figure 1 Key map with Groundwater Sample Locations

Overall, 120 groundwater samples were collected from the Gadilam river basin, except for the reserved forest. Figure 1 shows the distribution of 50 samples from the Archaean formation (Hornblende-biotite gneiss, Fissile hornblende gneiss, Gingee Granite and Ultrabasic Rocks). The next 34 samples are from the Quaternary formation (Flood basin/back swamp deposits, Paleotidal tidal, flat Black clay deposits, and tidal flat deposits of Black clay). Another 35 samples from the Tertiary formation (sandstones, clay, lignite, sandstone with clay, clay with limestone, bands/lenses, argillaceous and calcareous sandstone) One sample comes from the Cretaceous formation (limestone with calcareous shale and clay). These are selected wells where the people are getting water mainly for drinking and agricultural purposes. These water

samples were taken from open and bore wells, some places from hand pumps. Groundwater samples were collected in November 2018, at the end of the Gaja cyclone. Cyclonic Storm Gaja was the fifth named twister of the 2018 North Indian Ocean tornado season and June 2019. Based on the obtained analysed data, the following agricultural water quality parameters were calculated using the following expressions: The irrigational quality parameters are used, such as Sodium percentage (Na%), Sodium adsorption ratio (SAR), Kelly's ratio (KR), Permeability index (PI), Magnesium ratio (MR), Residual sodium carbonate (RSC), Potential salinity (PS) are calculated and assess the suitability for irrigation purposes.

Sodium percentage (Na%) - The percentage of sodium is used to study the sodium hazard for the assessment of groundwater quality for irrigation purposes.

Sodium adsorption ratio (SAR) - The sodium adsorption ratio is another one of the sodium hazard parameters for the assessment of groundwater quality for irrigation purposes.

Kelly's ratio (KR) - Kelley's (1963) [19] suggested sodium measured against Ca^{2+} and Mg^{2+} be used to calculate Kelley's ratio [20].

Permeability index (PI) - Doneen's (1946) [21] introduced for soil permeability was affected by the excess amount of dissolved Ca^{2+}, Mg^{2+}, Na^{+} and HCO_3^{-} in water.

Magnesium Ratio (MR) - Generally, Ca^{2+} and Mg^{2+} ions are sustaining a state of equilibrium in groundwater.

Residual Sodium Carbonate (RSC) - RSC is an important parameter for groundwater suitability for irrigational uses. To determine the RSC of dissolved Ca^{2+}, Mg^{2+}, CO_3^{2-} and HCO_3^{-} in water [22].

Potential Salinity (PS) - Estimates the hazard of high salt concentration due to Cl and SO_4 which can increase the osmotic potential of the soil solution.

USSL Diagrams - USSL diagram has been used to assess groundwater suitability for irrigational uses. This diagram was introduced by the United State Salinity Laboratory. The groundwater chemistry data is plotted on the USSL diagram in various seasons, like rainy and summer.

Results and Discussion

The irrigational quality parameters are used, such as Sodium percentage (Na%), Sodium adsorption ratio (SAR), Kelly's ratio (KR), Permeability index (PI), Magnesium ratio (MR), Residual sodium carbonate (RSC), Potential salinity (PS) are calculated and assess the suitability for irrigation purposes.

In tables such as Archaean Formation Table 1, Quaternary Formation Table 2, and Tertiary Formation Table 3, the geologically minimum, maximum, and average values of irrigation parameters were observed.

Sodium percentage (Na%)

The percentage of sodium is used to study the sodium hazard for the assessment of groundwater quality for irrigation purposes. The percentage of sodium values are calculated in the ranges of 34.44% to 68.91% (rainy season) and 43.76 to 68.01% (summer season) in the Archaean. Quaternary formation was observed with a Na% range of 32.59 to 82.75% (rainy season) and 40.55 to 80.82% (summer season). Tertiary formation Na % values range from 34.68 to 62.41%, respectively (Tables 1 to 3).

Table 1 Mean values of Irrigation parameters - Archaean

Irrigational Quality Parameters	Archaean – 50 Samples					
	November 2018			June 2019		
	Min.	Max.	Ave.	Min.	Max.	Ave.
Na%	34.44	68.91	47.88	43.76	68.01	53.98
SAR	1.51	5.10	3.21	1.85	7.18	3.94
KR	0.47	2.05	0.86	0.70	1.90	1.07
PI	45.16	82.32	62.27	52.39	87.87	66.93
MR	42.28	49.18	46.19	22.88	45.74	37.64
RSC	-10.08	-0.34	-2.81	-9.04	0.85	-2.44
PS	454	2600	1448.70	537	2810	1572.82

Table 2 Mean values of Irrigation parameters - Quaternary

Irrigational Quality Parameters	Quaternary – 34 Samples					
	November 2018			June 2019		
	Min.	Max.	Ave.	Min.	Max.	Ave.
Na%	32.59	82.75	52.09	40.55	80.82	56.22
SAR	1.17	15.10	3.86	1.72	9.84	3.78
KR	0.45	4.37	1.12	0.62	3.77	1.26
PI	48.97	88.73	68.27	55.35	97.81	72.08
MR	27.55	48.60	44.83	16.59	44.72	33.48
RSC	-7.12	2.80	-1.73	-364	3.67	-1.24
PS	372	3400	1377.74	532	3150	1196.79

The Archaean formation percentage of sodium values (60-80%-Double class) were observed at station Maiyanur-48 for groundwater samples in November 2018 and Kulappakkam-25, Kurumbur-28, Kunnattur-30, and 33 in June 2019 respectively. In the rainy and summer seasons, 98.6% and 92 % of groundwater samples fall under the category of "good to permissible."

The Quaternary formation percentage of sodium values is found in the range of 60-80% at stations 53, 65, and 83 for groundwater samples in November 2018 and 55, 56, 57, 58,

60, 68, 70, 73, 79, and 83 in June 2019 respectively. The following stations: 82 (rainy) and 54 (summer) come under the unsuitable category.

Table 3 Mean values of Irrigation parameters - Tertiary

Irrigational Quality Parameters	Tertiary – 35 Samples					
	November 2018			June 2019		
	Min.	Max.	Ave.	Min.	Max.	Ave.
Na%	34.68	62.41	48.09	42.41	76.91	54.32
SAR	1.11	4.68	2.45	1.45	6.33	3.21
KR	0.49	1.54	0.87	0.60	2.92	1.10
PI	51.18	82.91	69.11	50.45	91.90	71.92
MR	34.08	54.07	43.55	21.81	44.08	33.86
RSC	-6.04	0.94	-1.35	-7.63	0.59	-1.46
PS	288	1887	809.57	380	2572	1048.69

In June 2019, the tertiary formation values of sodium were found to be in the 60–80% range at stations 101, 86, 89, 90, 106, and 111. These stations fall under the category of doubtful. There is no water sample that falls under the excellent category in all formations (Table 4).

A high percentage of sodium value in irrigation water may stunt the plant's growth and reduce soil permeability [23, 13]. Hence, the present study indicates that the groundwater samples are suitable for irrigation based on the percentage of sodium.

Sodium Adsorption Ratio (SAR)

The sodium adsorption ratio is another one of the sodium hazard parameters for the assessment of groundwater quality for irrigation purposes. The SAR values are calculated in the ranges between 5.10 to 1.51 meq/L (rainy season) and 7.18 to 1.85 meq/L (summer season) in the Archaean. Quaternary formation was observed with SAR ranges from 15.10 to 1.17 meq/L (rainy season) and 9.84 to 1.72 meq/L (summer season). Tertiary formation SAR values ranged from 4.68 to 1.11 meq/L, respectively (Tables 1 to 3).

SAR values for Archaean and Tertiary formations (6 meq/L – no problem) were observed at all groundwater sampling stations in November 2018.Only one sample for each formation, such as the 30th station (Archaean) and the 86th station, came under increased problems in June 2019 and June 2020, respectively. In the rainy and summer seasons, 100% and 98 % of groundwater samples fall under the category of "no problem".

The Quaternary formation SAR values are found in the range of 6-9 meq/L at stations 53 for groundwater samples in November 2018 and 56 in June 2019, respectively. The following stations: 82, 83 (rainy) and 54, 79 (summer) come under the unsuitable category. These stations fall under the category of increasing problems and severe problems (Table 5).

Table 4 Sodium Percentage (Na%)

Formations	Sodium Percentage	Class	November - 2018		June - 2019	
			No. of Samples	% of samples	No. of Samples	% of samples
Archaean 50 Samples	<20	Excellent	Nil	Nil	Nil	Nil
	20 to 40	Good	2	4 %	Nil	Nil
	40 to 60	Permissible	47	94 %	46	92 %
	60 to 80	Doubtful	1	2 %	4	8 %
	>80	Unsuitable	Nil	Nil	Nil	Nil
Quarter Nary 34 Samples	<20	Excellent	Nil	Nil	Nil	Nil
	20 to 40	Good	3	9 %	Nil	Nil
	40 to 60	Permissible	27	79 %	23	68 %
	60 to 80	Doubtful	3	9 %	10	29 %
	>80	Unsuitable	1	3 %	1	3 %
Tertiary 35 Samples	<20	Excellent	Nil	Nil	Nil	Nil
	20 to 40	Good	3	9 %	Nil	Nil
	40 to 60	Permissible	31	89 %	30	86 %
	60 to 80	Doubtful	1	3 %	5	14 %
	>80	Unsuitable	Nil	Nil	Nil	Nil
Cretaceous 1 Sample	40 to 60	Permissible	1	100 %	1	100

Kelley's Ratio (KR)

Kelley's (1963) [19] suggested sodium measured against Ca^{2+} and Mg^{2+} be used to calculate [20]. The KR values are calculated in the ranges of 2.05 to 0.47 meq/L (rainy season) and 1.90 to 0.70 meq/L (summer season) in the Archaean. Quaternary formation was observed in KR ranges from 4.37 to 0.45 meq/L (rainy season) and 3.77 to 0.62 meq/L (summer season). Tertiary formation KR values range from 1.54 to 0.49 meq/L (rainy season) and 2.92 to 0.60 meq/L, respectively (Tables 1 to 3).

The Archaean formation KR values are found at less than 1 meq/L at 92 % of the groundwater samples in November 2018 and 46 % of the samples in June 2019 respectively. The Quaternary formation KR values are found at less than 1 meq/L at 59 % of groundwater stations in November 2018 and 38 % in June 2019 respectively. The Tertiary formation KR values are found at less than 1 meq/L at 77 % of groundwater stations in November 2018 and 40 % of stations in June 2019 respectively. These stations come under the category of "Safe" (Table 6).

Permeability Index (PI)

Doneen's (1946) [21] introduced the concept of soil permeability, which was affected by the excess amount of dissolved Ca2+, Mg2+, Na+ and HCO3- in water. The permeability index is directly related to crop yield [24].

The PI values are found in the ranges from 82.32 to 45.16 % (rainy season) and 87.87 to 52.39 % (summer season) in the Archaean. In this Quaternary formation, PI ranged from 88.73 to 48.97 % (rainy season) and 97.81 to 55.35 % (summer season). Tertiary formation PI values ranged from 82.91 to 51.18% (rainy season) and 91.90 to 50.45% (Tables 1–3, respectively).

The Archaean, Quaternary, and Tertiary formations' PI values (25-75 % and more than 75 %) are observed at all the stations of groundwater samples in both seasons. These stations come under the category of "Good" and "Very good" (Table 7).

Magnesium Ratio (MR)

In general, Ca2+ and Mg2+ ions maintain equilibrium in groundwater. The MR values are found in the ranges of 49.18 to 42.28 meq/L (rainy season) and 45.74 to 22.88 meq/L (summer season) in the Archaean.

Table 5 Sodium Adsorption Ratio (SAR)

Formations	SAR Value	Class	November - 2018		June - 2019	
			No. of Samples	% of samp les	No. of Samples	% of Samples
Archaean 50 Samples	<6	No problem	50	100 %	49	98 %
	6 to 9	Increase problem	Nil	Nil	1	2 %
	>9	Severe problem	Nil	Nil	Nil	Nil
Quarternary 34 Samples	<6	No problem	31	91 %	31	91 %
	6 to 9	Increase problem	1	3 %	1	3 %
	>9	Severe problem	2	6 %	2	6 %
Tertiary 35 Samples	<6	No problem	35	100 %	34	97 %
	6 to 9	Increase problem	Nil	Nil	1	3 %
	>9	Severe problem	Nil	Nil	Nil	Nil
Cretaceous 1 Sample	<6	No problem	1	100 %	1	100 %

In the Quaternary formation, MR ranged from 48.60 to 27.55 meq/L (rainy season) and 44.72 to 16.59 meq/L (summer season). Tertiary formation PI values range from 54.07 to 34.08 meq/L (rainy season) and 44.08 to 21.81 meq/L, respectively (Tables 1 to 3).

The Archaean, Quaternary, and Tertiary formation MR values (less than 50 meq/L – suitable) are observed at all the stations of groundwater samples in both seasons. These stations

come under the category of "suitable" except for one station (92 Kattugudalur), which falls into the "harmful" category in tertiary formation during the rainy season (Table 8).

Table 6 Kelley's Ratio (KR)

Geological Formations	Kelly's Ratio	Class	November - 2018		June - 2019	
			No. of Samples	% of Samples	No. of Samples	% of Samples
Archaean 50 Samples	<1	Safe	46	92 %	23	46 %
	>1	Unsafe	4	8 %	27	54 %
Quaternary 34 Samples	<1	Safe	20	59 %	13	38 %
	>1	Unsafe	14	41 %	21	62 %
Tertiary 35 Samples	<1	Safe	27	77 %	14	40 %
	>1	Unsafe	8	23 %	21	60 %
Cretaceous 1 Sample	<1	Safe	1	100	1	100

Table 7 Permeability Index (PI)

Formations	Permeability Index	Class	November - 2018		June - 2019	
			No. of Samples	% of Samples	No. of Samples	% of samples
Archaean 50 Samples	<25	Poor	Nil	Nil	Nil	Nil
	25 to 75	Good	49	98 %	46	92 %
	>75	Very good	1	2 %	4	8 %
Quarternary 34 Samples	<25	Poor	Nil	Nil	Nil	Nil
	25 to 75	Good	26	76 %	24	71 %
	>75	Very good	8	24 %	10	29 %
Tertiary 35 Samples	<25	Poor	Nil	Nil	Nil	Nil
	25 to 75	Good	26	74 %	22	63 %
	>75	Very good	9	26 %	13	37 %
Cretaceous 1 Sample	25 to 75	Good	1	100 %	1	100 %

Residual Sodium Carbonate (RSC)

RSC is an important parameter for groundwater suitability for irrigational uses. To determine the RSC of dissolved Ca^{2+}, Mg^{2+}, CO_3^{2-} and HCO_3^- in water [22].

The RSC values are found in the ranges from 0.34 to -10.08 meq/L (rainy season) and 0.85 to -9.04 meq/L (summer season) in the Archaean. Quaternary formation was observed in RSC ranges from 2.80 to -7.12 meq/L (rainy season) and 3.67 to -3.64 meq/L (summer

season). Tertiary formation RSC values ranged from 0.94 to -6.04 meq/L (rainy season) and 0.59 to -7.63 meq/L, respectively (Tables 1 to 3).

The Archaean and Tertiary formations' RSC values (less than 1.25 meq/L – Good) are observed at all the stations of groundwater samples in both seasons. These stations come under the category of "Good".

The Quaternary formation RSC values are found in the range of 1.25-2.50 meq/L (Doubtful) at stations 65th and 58th in November 2018 and June 2019 respectively. The following stations: 53rd (rainy) and 54th (summer) come under the unsuitable category (Table 9).

Table 8 Magnesium Ratio (MR)

Formations	Magnesium Ratio	Class	November - 2018		June - 2019	
			No. of Samples	% of samples	No. of Samples	% of samples
Archaean 50 Samples	<50	Suitable	50	100 %	50	100 %
	>50	Harmful	Nil	Nil	Nil	Nil
Quarternary 34 Samples	<50	Suitable	34	100 %	34	100 %
	>50	Harmful	Nil	Nil	Nil	Nil
Tertiary 35 Samples	<50	Suitable	34	97 %	35	100 %
	>50	Harmful	1	3 %	Nil	Nil
Cretaceous 1 Sample	<50	Suitable	1	100 %	1	100 %

Potential Salinity (PS)

Potential salinity (PS) estimates the hazard of high salt concentration due to Cl and SO4 which can increase the osmotic potential of the soil solution when the available moisture in the soil is lower than 50%. Based on this parameter, water can be classified into three classes [25]. Besides EC, PS also controls the suitability of water for irrigation [26].

Potential salinity values of groundwater samples are observed in the ranges between 2600 and 454 µmohs/cm (rainy season) and 2810 to 537 µmohs/cm (summer season) in Archaean. Quaternary formation was observed PS ranges from 3400 to 372 µmohs/cm (rainy season) and 3150 to 532 µmohs/cm (summer season). Tertiary formation PS values range from 1887 to 288 µmohs/cm respectively. Higher potential salinity values have a high Cl concentration (Tables 1 to 3).

The Archaean formation PS values (2001-3000 µmohs/cm - Doubtful class) are observed at stations 6,13,17,25,28,38,39,47 for groundwater samples in November 2018 and

6,7,16,24,27,30,34,37,38,47 in June 2019 respectively. 78 % of groundwater samples fall under the category of permissible in rainy and summer seasons.

The Quaternary formation PS values are found in the range of (2001-3000 µmohs/cm - Doubtful class) at stations 53,54,84 for groundwater samples in November 2018 and 56 in June 2019 respectively. The following stations 82,83 (rainy) 79 (summer) come under the unsuitable category. 86 % and 94 % of groundwater samples fall under the category of "good to permissible" in rainy and summer seasons.

The tertiary formation values of PS are observed in the range of (2001-3000 µmohs/cm - Doubtful class) at stations "Nil" for groundwater samples in November 2018 and "93, 109" samples in June 2019 respectively. These stations fall under the category of doubtful. 100 % of groundwater samples fall under the category of "Good to Permissible" in the rainy and summer seasons. There is no water sample that falls under the excellent category in all formations (Table 9).

Table 9 Residual Sodium Carbonate (RSC)

Formations	RSC Value	Class	November - 2018		June - 2019	
			No. of Samples	%of samples	No. of Samples	% of samples
Archaean 50 Samples	<1.25	Good	50	100 %	50	100 %
	1.25 to 2.50	Doubtful	Nil	Nil	Nil	Nil
	>2.50	Unsuitable	Nil	Nil	Nil	Nil
Quarternary 34 Samples	<1.25	Good	32	94 %	32	94 %
	1.25 to 2.50	Doubtful	1	3 %	1	3 %
	>2.50	Unsuitable	1	3 %	1	3 %
Tertiary 35 Samples	<1.25	Good	35	100 %	35	100 %
	1.25 to 2.50	Doubtful	Nil	Nil	Nil	Nil
	>2.50	Unsuitable	Nil	Nil	Nil	Nil
Cretaceous 1 Sample	<1.25	Good	1	100 %	1	100 %

High potential salinity values are indicated as not suitable for irrigation uses. The high PS area can be prescribed for high sulphate content derived from mines [27]. Hence, the present study indicates that more than 86 % of groundwater samples are suitable for irrigation based on their potential salinity.

Table 10 Potential Salinity (PS)

Formations	EC (µmohs/cm) at 25°C	Class	November - 2018		June - 2019	
			No. of Samples	% of samples	No. of Samples	% of samples
Archaean 50 Samples	<250	Excellent	Nil	Nil	Nil	Nil
	251 to 750	Good	3	6 %	1	2 %
	751 to 2000	Permissible	39	78 %	39	78 %
	2001 to 3000	Doubtful	8	16 %	10	20 %
	>3000	Unsuitable	Nil	Nil	Nil	Nil
Quaternary 34 Samples	<250	Excellent	Nil	Nil	Nil	Nil
	251 to 750	Good	7	21 %	6	18 %
	751 to 2000	Permissible	22	65 %	26	76 %
	2001 to 3000	Doubtful	3	9 %	1	3 %
	>3000	Unsuitable	2	6 %	1	3 %
Tertiary 35 Samples	<250	Excellent	Nil	Nil	Nil	Nil
	2251 to 750	Good	17	49 %	13	37 %
	751 to 2000	Permissible	18	51 %	20	57 %
	2001 to 3000	Doubtful	Nil	Nil	2	6 %
	>3000	Unsuitable	Nil	Nil	Nil	Nil
Cretaceous 1 Sample	751 to 2000	Permissible	1	100	1	100

USSL Diagrams

The USSL diagram has been used to assess groundwater suitability for irrigational uses. This diagram was introduced by the United State Salinity Laboratory. Groundwater chemistry data are plotted on the USSL diagram in different seasons such as rainy and summer [28]. The Archaean formation USSL diagrams (Figures 2 to 3) results are observed at stations 13, 25, 38, and 39 for groundwater samples that come under the (C4S2 class) not suitable for irrigational uses in the rainy season and 6, 7, 24, 30, 34, 37, and 47 of the samples fall under the same class in the summer season. The following samples come under the moderate class (C3S2) at 6, 47 in the rainy season and 13, 14, 17, 20, 23, 25, 27, 38, and 46 in the summer season. The rest of the groundwater samples fall under the category of (C2S1, C3S1) suitable for irrigational uses in both seasons. The Quaternary formation USSL diagrams (Figures 4 to 5) results are observed at stations 53, 84, 83, and 82 for groundwater samples that come under the (C4S2, C4S3, and C4S4 class) In the rainy season, the samples are unsuitable for irrigational purposes, and in the summer season, 56, 79 of the samples fall into the same categories. The following samples come under the moderate class (C3S2) at 58, 64 in the rainy season and 54, 55, and 60 in the summer season. The rest of the groundwater samples fall under the category of (C2S1, C3S1) suitable for irrigational uses in both seasons. The Tertiary formation USSL

diagrams (Figures 6 to 7) results are observed at all stations that come under the (C2S1, C3S1 class) suitable for irrigational uses in the rainy season. The following samples come under the moderate class (C3S2, C4S1) at 86, 97, 105, 106, 109 in the rainy season, and the 93rd sample falls under the bad class in the summer season. The rest of the groundwater samples fall under the category of (C2S1, C3S1) suitable for irrigational uses in both seasons.

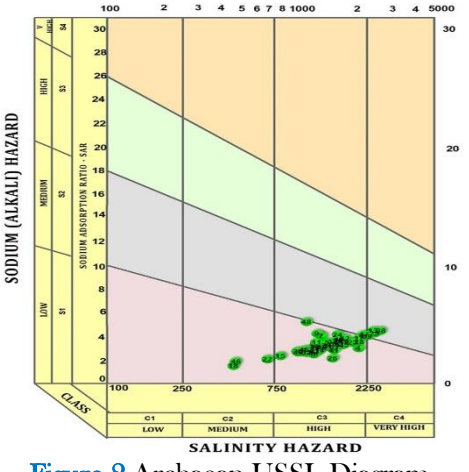

Figure 2 Archaean USSL Diagram November 2018

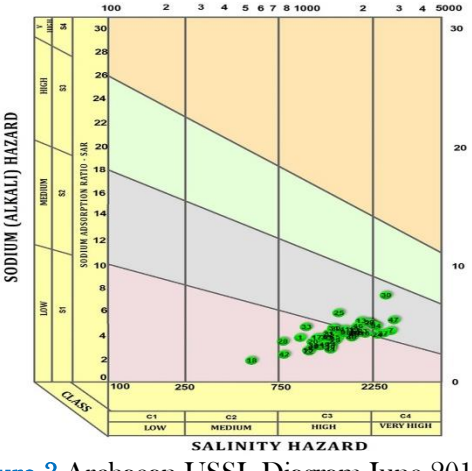

Figure 3 Archaean USSL Diagram June 2019

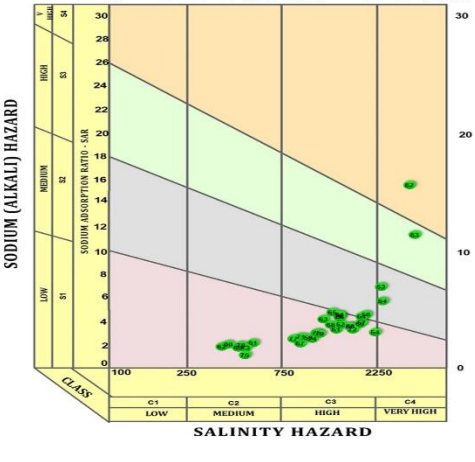

Figure 4 Quaternary USSL Diagram November 2018

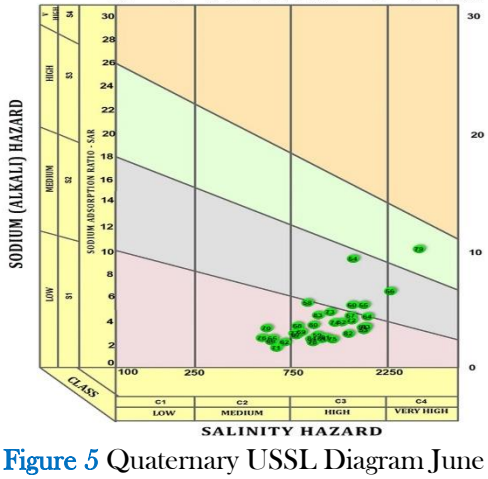

Figure 5 Quaternary USSL Diagram June 2019

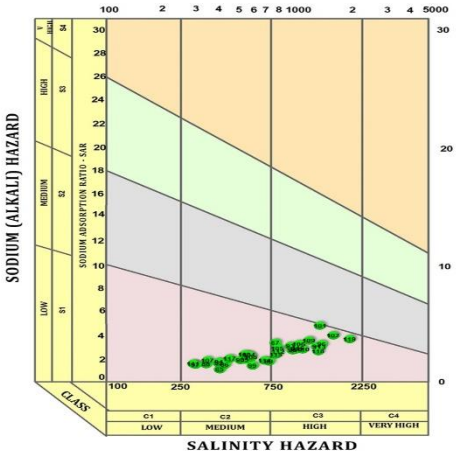

Figure 6 Tertiary USSL Diagram November 2018

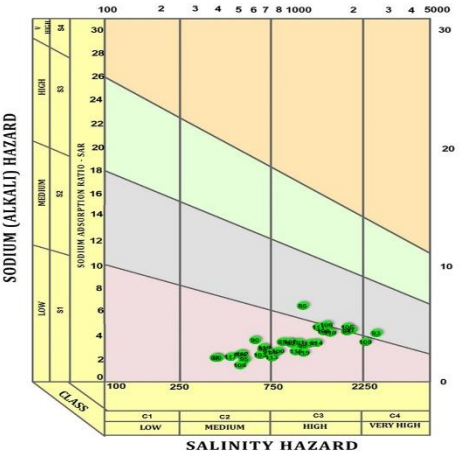

Figure 7 Tertiary USSL Diagram June 2019

Conclusion

The irrigation suitability of groundwater based on Permeability index (PI), Magnesium ratio (MR) parameter interpretation reveals that 100 % of groundwater samples fall under the category of good to permissible for all three formations in the rainy and summer seasons.

Sodium percentage (Na%), Sodium adsorption ratio (SAR), Residual sodium carbonate (RSC), Potential salinity (PS) parameters are more than 90 % of the groundwater samples suitable for irrigation uses of all three formations in the rainy and summer seasons.

Archaean and Quaternary formations 86% of the stations are suitable for irrigation in both seasons. The tertiary formation USSL diagrams are observed at all stations and come under the (C2S1, C3S1 class) suitable for irrigational uses in the rainy season.

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