Hydrochemical Framework and Water Quality Assessment of Groundwater in Amaravathi River Basin, Karur District, Tamil Nadu, India

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Abstract: *The present study highlights temporal variations of the groundwater quality and compares its suitability for drinking and agricultural purposes in Amaravathi River basin, Karur. Weathered, fissured and fractured crystalline rocks and the alluvial deposits comprise the chief aquifer systems in the district. Groundwater occurs under phreatic conditions in the weathered mantle and semi-confined conditions in the fractured zones. Twenty two groundwater samples were collected in February and May 2012, representing the post-monsoon and summer seasons respectively. Water samples were analyzed for physico-chemical parameters in the laboratory using the standard methods suggested by the American Public Health Association. Ionic abundance is in the order of* $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+} = Cl^{-} > HCO_3^{-} > SO_4^{2-}$*. From Schoeller scheme, water shows unpretentious variation in their ionic assemblage among different sample points. The prevalence of high total hardness and fluoride is attributed to the composition of litho units constituting the aquifers in the district. The piper trilinear diagrams were generated using major cations and anions to establish the hydrochemical regime. The plot shows that chemical composition obtained for groundwater fall in the field of* Ca^{2+}-Mg^{2+}-Cl^{-} *and mixed* Ca^{2+}-Mg^{2+}-HCO_3^{-} *type. The correlation matrices for 13 variables were prepared for both post-monsoon and summer periods using SPSS software package version 16.0. With regard to irrigation suitability based on specific Electrical Conductance and Sodium Absorption Ratio, it is observed that groundwater in the phreatic zone may cause high to very high salinity and medium to high alkali hazard when used for irrigation. Based on RSC and PI criteria majority of groundwater samples can be considered safe for irrigation use. The groundwater resources in the district are under semi critical category.*

Keywords: *Amaravathi River-Karur, Correlation matrices, Sodium Absorption Ratio, phreatic zone*

1. Introduction:

Water is a chief natural resource essential for the existence of life and is a basic human entity. Groundwater is one of the important sources of water used for drinking, irrigation and industrial purposes [1]. The composition of groundwater closely reflects the local geology and reaction of water with litho geochemical cycle. Reaction between rainwater and bed rocks releases the heavy metals and major anions into the groundwater's, thus geochemical and anthropogenic cycles play the most controlling factors to the source of major anions and heavy metals in natural groundwater. Mixing of groundwater with wastewaters or other anthropogenic pollutants could change the nature and chemical composition of groundwater [2]. Groundwater used for domestic and irrigation purposes can vary greatly in quality depending upon type and quantity of dissolved salts. It contains a wide variety of dissolved inorganic chemical constituents in various concentrations, resulting from chemical and biochemical interactions between water and the geological materials [1]. Low precipitation and overexploitation of groundwater resources in recent years have caused an extensive groundwater level decline [3]. In the study area, the mixing of untreated or partially treated effluents from dyeing and bleaching units into the river which adversely affects the nature of groundwater in the lower part of Amaravathi river basin. Agriculture is the most important economic activity; thus, a hydro-geochemical investigation was carried out to identify groundwater geochemistry and its suitability for irrigation and drinking purposes.

1.1 Site Description:

Amaravathi River rises from Namakkad at an elevation of 2300 m above MSL in the Western Ghats in Idukki District of Kerala state. It flows towards northeast and finally merges with the river Cauvery on its right bank. Amaravathi receives a number of small streams through the Karur of 282 km. Amaravathi basin lies between the latitudes11.20° N and 12.00° N and longitudes 77.28° E and 78.50° E in Karur. It covers total area of 8280 km^2 mainly constituting of four districts namely Coimbatore, Erode, Dindigul and Karur in

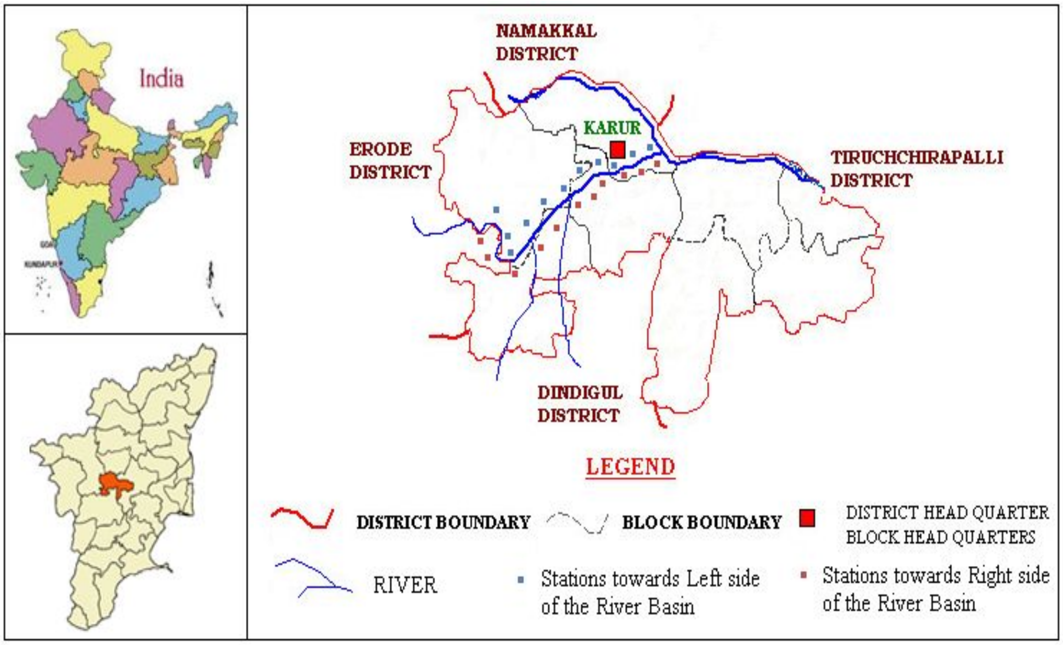

Figure 1: *Map of the study area and sampling locations*

Tamilnadu. Amaravathi is a tributary of Shanmuganadhi, Nankanchi and Kodaganar rivers which join at 60, 40 and 20 km upstream of Karur town respectively. Amaravathi enters into Karur district near Aravakurichi and merges with river Cauvery near Kattali village and the flow in the river is seasonal. Karur district is underlain entirely by Archaean Crystalline formations with recent alluvial deposits occurring along the river and streams courses. The hard consolidated crystalline rocks of Archaean age represent weathered, fissured and fractured formations of gneisses, granites, charnockites and other associated rocks. Ground water occurs under phreatic conditions and the maximum saturated thickness of these aquifers is up to 10 m depending upon the topographic conditions. The thickness of the weathered mantle of the hard rock's is varying from less than a meter to as much as 20.10 m. The city gets most of its seasonal rainfall from the North-East monsoon from late September to mid-November. The average annual rainfall is about 855 mm. About 45% of land area is utilized for Agriculture. 4.76% of the land area remains uncultivable land and 2.74% is forest area.

2. Materials and Methods:

Groundwater samples were collected from 22 stations during February and May 2012, representing the post-monsoon and summer seasons respectively. The location of sampling points is shown in Fig. 1. High-density polyethylene bottles were used for sample collection. The samples were filled up to the brim and were immediately sealed to avoid exposure to air and were labeled systematically. The labeled samples were analyzed in the laboratory for various physicochemical parameters. During sample collection, (handling and preservation) standard procedures recommended by the American Public Health Association [4] were followed to ensure data quality and consistency.

The pH and electrical conductivity (EC) were measured in situ by using water quality multi-parameter probe (Elico PE 138) and the major ions were analyzed using the standard methods suggested by the American Public Health Association [4]. Among the analyzed ions, sodium (Na^+) and potassium (K^+) were determined by using atomic absorption Spectrophotometer (Perkin Elmer A Analyst 400 Spectrophotometer). Total hardness (TH) as $CaCO_3$, calcium (Ca^{2+}), magnesium (Mg^{2+}), bicarbonate (HCO_3^-) and chloride (Cl) were analyzed by volumetric methods and sulfates ($SO4^{2-}$) were estimated by using the Vogel's titration method.

Nitrate was determined by colorimetric method. The hydro-geochemical facies (Piper diagram) and the Wilcox plot in the study area were plotted using AquaChem 4.0 software. The suitability of groundwater for agricultural and domestic purposes were evaluated by comparing the values of different

Table 1: *Statistics of groundwater Chemistry*

Parameters	Post-monsoon season				Summer season			
	Average	Minimum	Maximum	Std. Dev.	Average	Minimum	Maximum	Std. Dev.
pH	7.37	6.52	8.14	0.512	7.14	6.76	7.52	0.204
EC (µS/cm)	2819.86	857	8843	1982.35	3239.86	967	8851	2450.89
TDS (mg/L)	2179.40	628	7168	1617.47	2643.09	789	7226	1989.72
TH (mg/L)	844.90	316	3900	815.68	907.27	316	3092	762.43
Ca^{2+} (mg/L)	161.86	45	541	126.98	126.04	38	418	117.87
Mg^{2+} (mg/L)	108.22	16	622	128.99	141.22	33	555	133.72
Na^{+} (mg/L)	169.9	35.25	782.6	179.64	308.53	30.78	887.36	240.363
K^{+} (mg/L)	40.04	0	274.5	75.39	23.95	2.4	233.98	46.60
HCO_3^{-} (mg/L)	521.04	339	764	124.45	410.45	218	642	85.26
Cl^{-} (mg/L)	691.13	92	3046	741.15	722.95	99	3017	809.29
F^{-} (mg/L)	0.99	0.2	4	0.80	0.93	0.2	4	0.81
SO_4^{2-} (mg/L)	240.13	31	427	121.02	215.50	58	365	100.42
NO_3^{-} (mg/L)	0.309	0	1.4	0.294	0.65	0.07	1.1	0.26
SAR (meq/L)	5.92	1.79	26.86	6.16	9.49	1.49	24.87	5.56
Na % (meq/L)	42.77	11.40	83.88	21.80	54.20	20.74	79.64	15.42
RSC (meq/L)	2.50	-7.27	5.62	3.09	1.43	-6.64	4.67	2.56
PI (meq/L)	42.15	12.20	84.44	19.50	54.85	21.21	80.51	14.30

water quality parameters with those of the World Health Organization [5] and Bureau of Indian standards [6] guidelines values for drinking water. To assess the suitability of groundwater for irrigation uses the following hydrochemical parameters were computed by the equations:

1. Percentage sodium (%Na) = $(Na^{+}+K^{+})*100/(Ca^{2+}+Mg^{2+}+Na^{+}+K^{+})$
2. Residual sodium carbonate (RSC) = $(CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$
3. Sodium adsorption ratio (SAR) = $Na^{+} / \sqrt{(Ca^{2+} + Mg^{2+})/2}$
4. Permeability index (PI) = $(Na^{+} + \sqrt{HCO_3}) *100 / (Ca^{2+}+Mg^{2+}+Na^{+}+K^{+})$

(All ionic concentrations are expressed in meq/L).

2. Result and Discussion:

The statistical parameters like average, minimum, maximum and standard deviation of water quality parameters are represented in Table 1.

2.1 Drinking water suitability:

pH is the measure of the balance between the concentration of hydrogen ion and hydroxyl ions in water. The pH values of groundwater in the study area ranges from 6.52 to 8.14 and 6.76 to 7.52 in post-monsoon and summer season respectively. The average values of EC for the analyzed samples were 2819.86 μScm^{-1} and 3239.86 μScm^{-1} for both seasons.

High EC in the study area indicates the excess amount of salts in the groundwater. It is the index of the total content of dissolved substance in water, depends upon temperature, concentration and types of ions [7]. TDS value varies between a minimum of 628 and 789 mg/L and maximum of 7168 and 7226 mg/L for post-monsoon and summer seasons. It indicates that all the water samples exceeding the permissible limit (500 mg/L) suggested by WHO [5] and BIS [6].

Total hardness is varying from 316 to 3900 mg/L in post-monsoon and 316 to 3092 mg/L in summer season. Total hardness values exceed the desirable limit of 300 mg/L specified for drinking purpose [6]. The hardness of water is due to the presence of calcium and magnesium. The analytical result shows that HCO_3^{-} and Cl^{-} are the dominant anions in the groundwater. Bicarbonate is derived mainly from the weathering of carbonates and silicate minerals, dissolution of atmospheric CO_2, oxidation of organic matter and root respiration [8]. HCO_3^{-} was observed higher of 339 to 764 mg/L during post-monsoon than summer 218 to 642 mg/L. Concentration of Cl^{-} exceeds the desirable limit of 250 mg/L in 68 and 55 % of samples during post-monsoon and

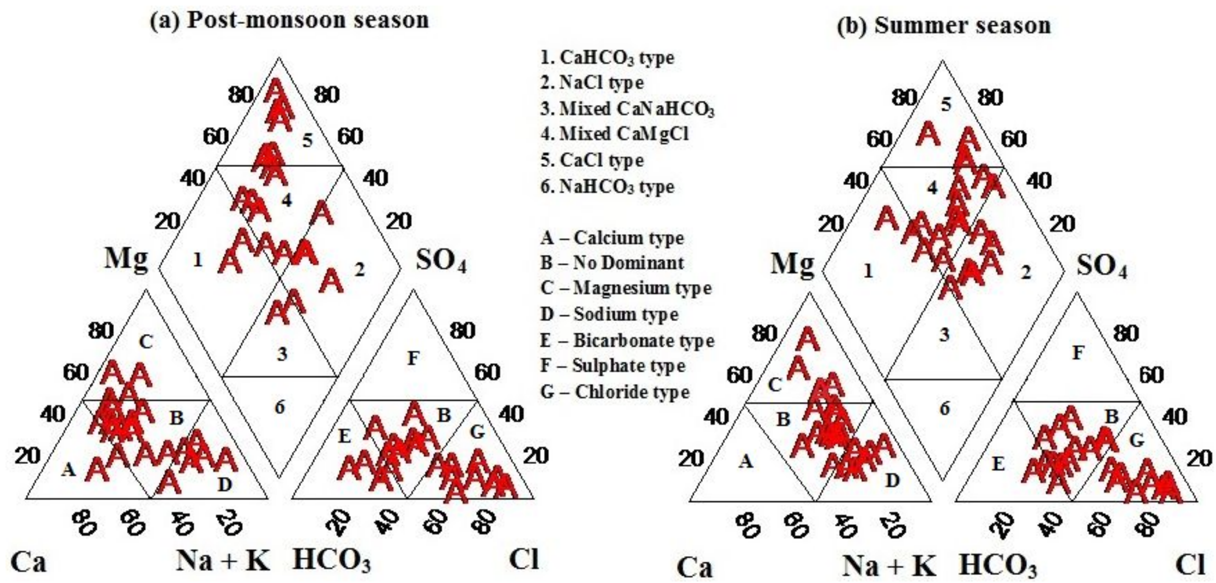

Figure 2: *Piper trilinear plot describing hydro-geochemical facies of the study area*

summer seasons. Excess concentration of Cl^- in drinking water gives a salty taste and has a laxative effect. Concentrations of NO_3^- and F^- in all the water samples are found within the safe limit of 45 and 1.5 mg/L [5] except three stations having high F^- value of above 1.5 mg/L. SO_4^{2-} which exceeds the permissible limit of 200 mg/L in 64 and 59 % samples in both the seasons.

Among the cations concentration of Ca^{2+} and Mg^{2+} in the study area exceeding their desirable limits of 75 and 50 mg/L in few stations. Ca^{2+} ranges from 45 to 541 mg/L in both seasons. Mg^{2+} values between 16 to 622 mg/L and 33 to 555 mg/L in both seasons. High concentration of Ca^{2+} for long periods may be a increased risk of kidney stones [9]. Na^+ concentrations obtained in their study ranged from 35.25 to 782.6 mg/L in post-monsoon and 30.78 to 887.36 mg/L in summer season. Except few stations, all the water samples were exceeding their permissible limit of 200 mg/L in summer than post-monsoon seasons. K^+ values ranges from undetectable to 274.5 mg/L and 2.4 to 233.98 mg/L in post-monsoon and summer seasons respectively. Recommended guideline value for potassium in drinking water is 12 mg/L [5], while 36% of samples in post-monsoon and summer season exceeding their limits.

2.2 Hydro-geochemical facies:

The Piper [10] diagram is very useful in determining relationships of different dissolved constituents and classification of water on the basis of its chemical characters. The triangular cationic fields of Piper diagram reveals that 55% (both seasons) of the groundwater samples fall into no dominant class, 22% in post-monsoon and 27% in summer season fall into sodium type, whereas in anionic triangle majority of the samples (40 & 45 %) in post-monsoon and summer season fall into chloride field and rest of the groundwater samples fall into bicarbonate an no dominant field (Fig. 2). The plot of chemical data on diamond shaped central field, which relates the cation and anion triangles reveals that plotted points fall in the 1, 2, 3, 4, and 5, fields. In all the groundwater samples, alkaline earth metals (Ca^{2+} + Mg^{2+}) exceed alkali metal cations (Na^+ + K^+) and strong acids (Cl^-) exceed the weak acid (HCO_3^-). The facies mapping approach applied to the present study shows that Ca^{2+}–Mg^{2+}– Cl^- is the dominant hydro-geochemical facies in 70 % of the groundwater samples, while 30 % groundwater samples occur as a mixed chemical character of Ca^{2+}–HCO_3^- and Na^+ – Cl^- hydro-geochemical facies.

2.3 Statistical Analysis:

Compositional relations among dissolved species can reveal the origin of solutes and the process that generated the observed water compositions [11]. The computed correlation matrix of the 13 measured parameters is given in Table 2. EC and TDS show a high positive correlation with Ca^{2+}, Mg^{2+}, Cl^-, (summer season) and total hardness (TH) in post-monsoon and summer seasons.

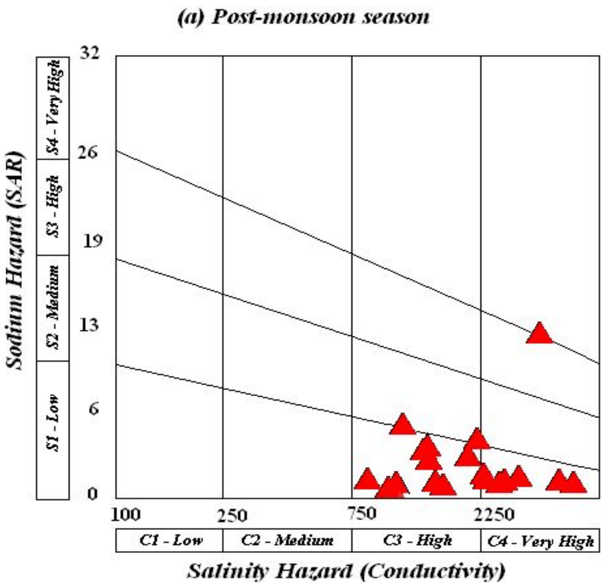

Figure 3: *U.S. Salinity diagram for classification of irrigation water*

The good correlations were between EC-TDS (0.997), EC-TH (0.932, 0.77), TDS-TH (0.929, 0.770), EC-Cl^- (0.989, 0.786), and moderate correlation of HCO_3^- with Na^+ (0.345) in post-monsoon season. Good correlations were also observed between Ca^{2+}–Cl^- (0.928), Ca^{2+}–TH (0.941, 0.863), Mg^{2+}–Cl^- (0.917, 0.676), Mg^{2+}–TH (0.977, 0.697), Na^+-Cl^- (0.881 in summer) suggest that a significant fractions of Ca^{2+}, Mg^{2+} and Na^+ are derived from weathering of silicate lithology. Furthermore, the weak positive correlations among other chemical variables suggests that, there are other minor geochemical and biochemical processes between these dissolved species, contributing to the water chemistry within the district.

2.4 Water quality for irrigation:

Salinity indices such as sodium percentage (Na %), sodium absorption ratio (SAR), permeability index (PI) and residual sodium carbonate (RSC) are important parameters for determining the suitability of groundwater for agricultural uses. Electrical conductivity (EC) and sodium concentration are very important in classifying irrigation water [12]. The salts present in the water, further affecting the growth of the plants directly, also have an effect on the soil structure, permeability and aeration, which indirectly affect the plant growth. Whereas a high salt concentration in water leads to formation of saline soil, a high sodium concentration leads to development of an alkaline soil. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of sodium adsorption ratio (SAR). The calculated value of SAR in the study area ranges from 1.79 to 26.86 (avg. 5.92) in post-monsoon and 1.49 to 24.87 with an average of 9.49 in summer season. In the US salinity diagram (Fig. 3), in which the EC is taken as salinity hazard and SAR as alkalinity hazard, shows that majority of the water samples fall in the category C3-S1 and C4-S1, indicating high to very high salinity in both the season and low alkali water in post-monsoon and medium in summer. High saline water cannot be used on soils, salt tolerant plants or crops should be selected for the high saline regions and the irrigation water must be applied in excess to provide considerable leaching.

Excess sodium combined with carbonate can lead to the formation of alkaline soils, while with the chloride it may form saline soil. Either type of sodium enriched soil will support little or no plant growth [8]. Sodium content in water is expressed in terms of percent sodium (%Na). The % Na value in the study area ranges between 11.40-83.88 % and 20.74-79.64 % (avg. 42.77 & 54.20 %) in post-monsoon and summer season, below the recommended limit of 60 % for irrigation water [6]. In addition to the SAR and Na%, the excess sum of carbonate and bicarbonate in groundwater over the sum of calcium and magnesium also influences the unsuitability of groundwater for irrigation. This is denoted as residual sodium carbonate (RSC). A high value of RSC in water leads to an increase in the adsorption of sodium on soil [13]. Irrigation waters having RSC values greater than 5 meq/L have been considered harmful to the growth of plants,

Table 2: *Correlation matrix for Post-monsoon and summer seasons*

Parameters	pH	EC	TDS	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	F^-	SO_4^{2-}	NO_3^-
(a) Post-monsoon													
pH	1.000	-0.542	-0.581	-0.511	-0.529	-0.471	0.302	0.258	0.446	-0.541	0.064	0.046	-0.026
EC		1.000	**0.997**	**0.932**	**0.900**	**0.896**	0.301	-0.212	-0.267	**0.989**	0.268	0.227	-0.001
TDS			1.000	**0.929**	**0.898**	**0.892**	0.272	-0.218	-0.287	**0.989**	0.258	0.233	-0.005
TH				1.000	**0.941**	**0.977**	0.090	-0.233	-0.308	**0.957**	0.101	0.099	-0.152
Ca^{2+}					1.000	**0.848**	0.054	-0.213	-0.343	**0.928**	0.013	0.129	-0.097
Mg^{2+}						1.000	0.105	-0.234	-0.270	**0.917**	0.149	0.070	-0.178
Na^{+}							1.000	0.120	0.345	0.233	**0.711**	0.115	0.188
K^{+}								1.000	0.326	-0.224	0.110	-0.021	0.139
HCO_3^-									1.000	-0.312	0.418	-0.116	0.321
Cl^-										1.000	0.187	0.194	-0.059
F^-											1.000	-0.022	0.221
SO_4^{2-}												1.000	0.169
NO_3^-													1.000
(b) Summer season													
pH	1.000	-0.139	-0.139	-0.331	-0.14	-0.483	-0.257	-0.309	-0.222	-0.279	-0.146	0.102	-0.210
EC		1.000	1.000	**0.771**	**0.626**	**0.541**	0.653	-0.187	-0.033	**0.786**	0.248	0.021	-0.102
TDS			1.000	**0.770**	**0.626**	**0.535**	0.651	-0.179	-0.030	**0.784**	0.245	0.021	-0.102
TH				1.000	**0.863**	**0.697**	0.790	-0.180	-0.091	**0.978**	0.151	0.141	0.077
Ca^{2+}						1.000	0.524	**0.708**	-0.089	-0.200	**0.838**	-0.015	0.167
Mg^{2+}						1.000	0.584	-0.197	-0.267	0.676	0.118	0.136	0.253
Na^{+}							1.000	-0.053	0.153	**0.881**	0.480	0.328	0.198
K^{+}								1.000	0.166	-0.177	-0.066	0.321	-0.038
HCO_3^-									1.000	-0.024	0.639	-0.102	0.144
Cl^-										1.000	0.255	0.202	0.059
F^-											1.000	0.068	0.165
SO_4^{2-}												1.000	-0.024
NO_3^-													1.000

while waters with RSC values above 2.5 meq/L are unsuitable for irrigation. A RSC value between -7.25 to 5.62 and -6.64 to 4.67 meq/L is considered as the marginal quality and value <1.25 meq/L as the safe limit for irrigation. The calculated average RSC values of groundwater of the study area are found below the 2.5 meq/L limits, suggesting that water is safe and suitable for irrigation purposes except few stations. The Schoeller scheme is used to study the comparative changes in the concentrations and ratios of water quality parameters for different samples. The result obtained indicates that Cl^- is dominant anion and cations are Ca^{2+} and Na^+. Based on the permeability index (PI), a water suitability classification for irrigation water was developed by Doneen [14]. The PI values in the study area vary from 12.20 to 84.44 during the post-monsoon period with an average value of about 40.01 (Table 1). While in summer season the PI value ranges from 21.21 to 80.51 with an average of 54.85. A classification based on PI was proposed by World Health Organization for assessing suitability of groundwater for irrigation purpose. According to the permeability index values, none of the samples falls under the class 3 (PI<25 %) and about 95 % belong to class 2 (PI ranged between 25 and 75 %) during the post-monsoon and summer season respectively.

3. Conclusion:

Hydrochemistry of the groundwater is dominated by Ca^{2+} and Na^+ in cationic concentration and Cl^- and HCO_3^- in anionic abundance. The sequence of the abundance of the major cation and anion is $Ca^{2+} > Na^+ > Mg^{2+} > K^+ = Cl^- > HCO_3^- > SO_4^{2-}$. The concentration of alkaline earth metals (Ca^{2+} and Mg^{2+}) exceeds alkali metals (Na^+ and K^+). The dominant hydro-geochemical facies of the groundwater in the study area is Ca^{2+}–Mg^{2+}– Cl^- and Na^+–Cl^- type. Based on the value of TDS and TH, almost all the samples are not safe for drinking purposes. USSL diagram shows C3-S1 and C4-S1 (C3-S2, C4-S2 in summer) are the most dominant classes found in the study area. High salinity in the study area showed the water is doubtful for irrigation. Based on RSC and PI values the water samples are fit for agriculture purposes. Special management for

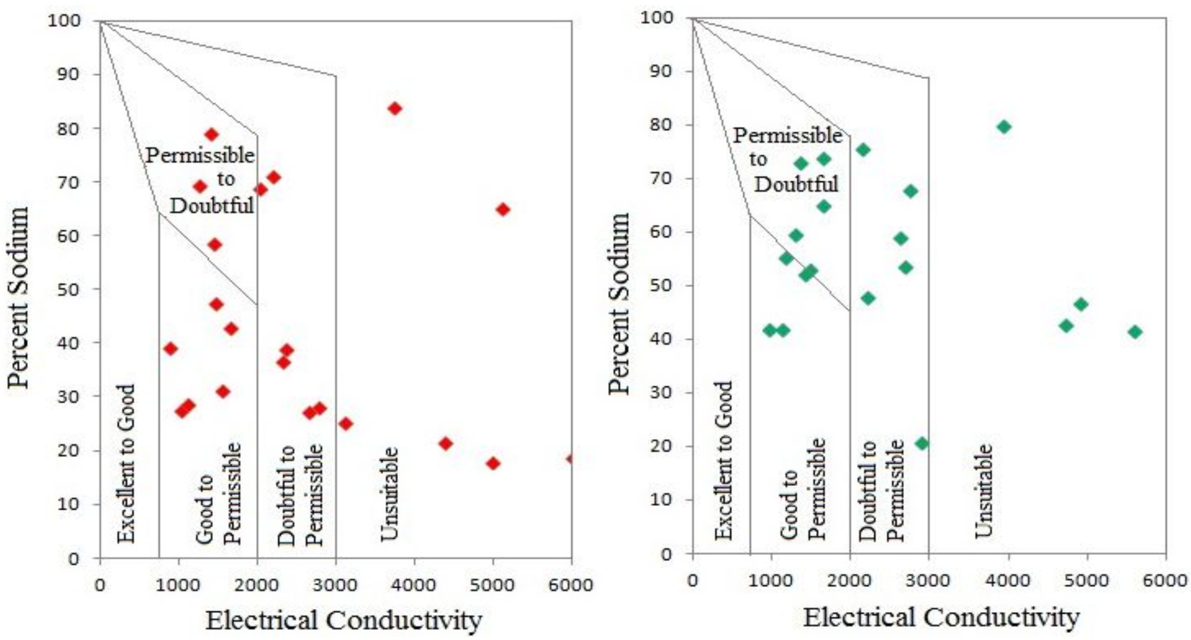

Figure 4: *Suitability of groundwater for irrigation in Wilcox diagram*

salinity is required and plants with good salt tolerance should be selected.

4. Acknowledgment

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