

Hydrogeochemical Characteristics of Groundwater: A Case Study from Kadavanar Watershed, Amaravathi Sub-basin, Cauvery River, South India

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The aim of this study is to the groundwater chemistry at Kadavanar watershed, Cauvery river, South-India. This paper demonstrated that the interrelationship of rock types and groundwater chemistry using piper trilinear diagram and multi-rectangular diagram (MDRs). Well-developed sampling technique was used for this study. Four km equal grids were designed in plain region. Each intersect points are selected for groundwater sample locations. Groundwater samples 147 m.l. were collected on April 2016 (Pre-monsoon). Groundwater samples were analyzed for major ions (pH, EC, Ca^{2+} , K^+ , Na^+ , Mg^{2+} , HCO_3^- , SO_4^{2-} , NO_3^- , CO_3^{2-}). Analytical results were used, to prepare the Piper Triangles Diagram and multi-rectangular diagram (MRD), Gibb's, USSL and Wilcox diagrams with respect to geology. As per the piper triangles diagram reveals that 53.06 % samples fall under Sodium chloride (NaCl) alkalies exceed alkaline earth class. Concluded that the Multi-rectangular diagram (MRD) interpretation result is reflected same as reveals piper triangles diagram result. Gibb's diagram shows that the chemical concentration of the groundwater in mainly depends upon the rock water-interaction. Other irrigational classification diagrams such as USSL (63.95 %) and Wilcox's (67.35 %) diagrams interpretation reveal that the majority of the groundwater samples fell under suitable for agricultural uses.

[Key words; Watershed, Equal grids, Groundwater, Piper Triangles Diagram, Pink migmatite]

Introduction

Groundwater has been extensively used in the recent past due to its comparatively constant quality and natural reliability. But increase of pollution in recent years due to hazardous waste materials stored or disposed on or in the ground has led to many problems in view of its social utilization. A programme of study for geochemical relationship of the field evaluation, regarding the source and environmental conditions, origin and occurrences of groundwater, source of pollution and other related aspects having a bearing on the chemical concentration of groundwater.

Source of pollution may be natural i.e., through environment or due to encroachment by the civilization upon the natural phenomenon subjected to domestic, industrial or agricultural developments. In any case, contaminants are present in solution and consequently are carried with the flowing water. These contaminants are frequently retarded and altered by interactions with the groundwater environment due to absorption, precipitation by chemical reaction (or) decay and reduction by bacterial activity and volatilization of gases¹.

In Kadavanar watershed, surface water as well as groundwater is getting contaminated and rendering it unusable for drinking and irrigation in several parts of the river basin. Industrial effluents which are untreated or partially treated are let out into the river and extensive applications of fertilizers in the agricultural areas are the main source of pollution which needs special study.

In the present manuscript, the attempt is to evaluate the groundwater chemistry. Earlier studies in the present ideas were focused on various aspects such as ^{2, 3, 4, 5, 6, 7}.

Study Area

Kadavanar watershed (Figure 1) lies between longitudes (from 77°37'31.418"E to 78°13'47.821"E) and (from 10°10'57.612"N to 10°52'49.549"N). It is located in two districts (Major part in Dindigul district and small part in Karur district). Kadavanar watershed an area about is 2254.66 sq.km. This watershed catchment area such as Kallar reserved forest (Western part), Sirumalai Reserved forest (Southern part), Karandamalai reserved forest (Southwest direction), Ayyalur

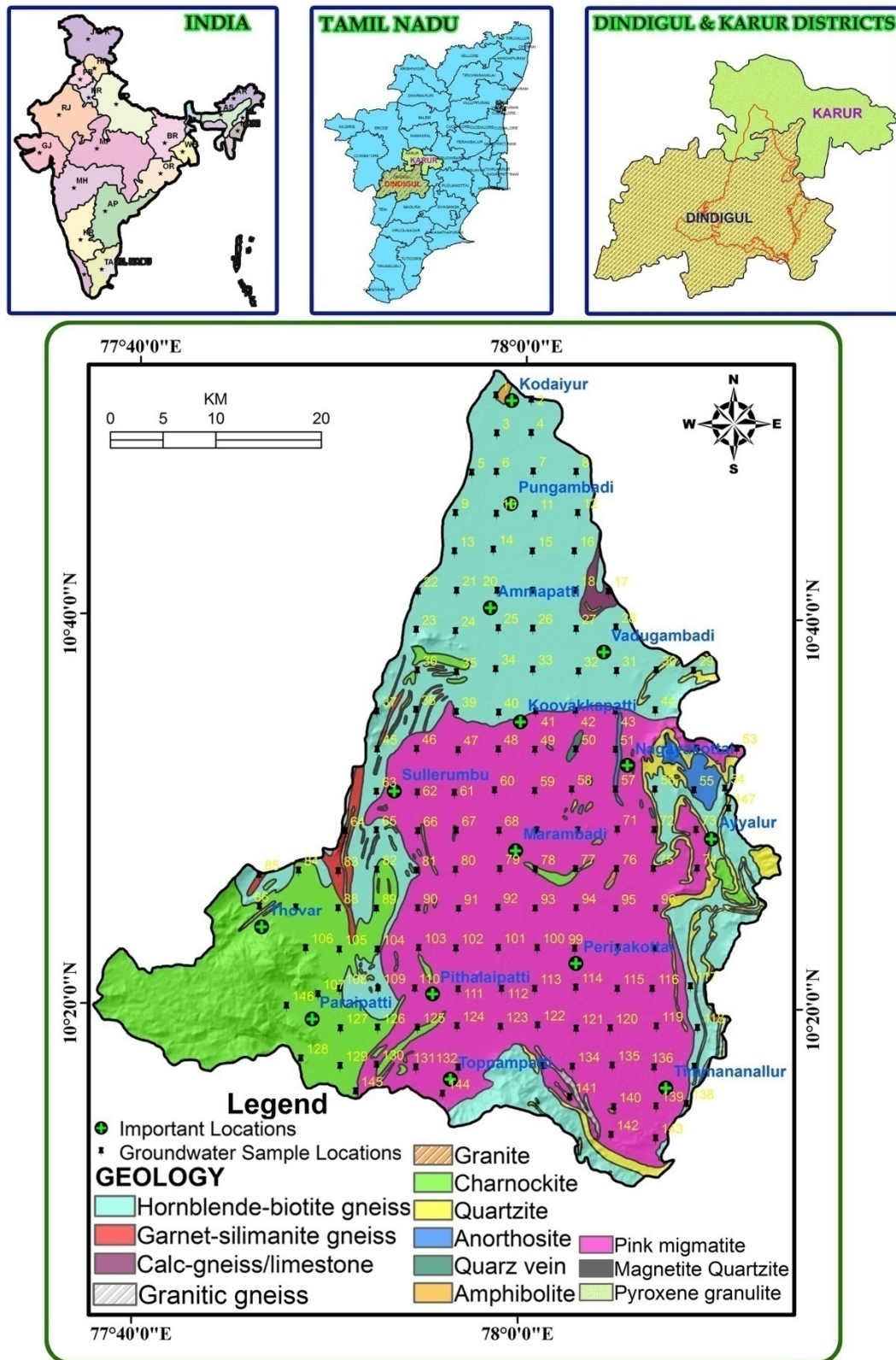


Fig. 1 — Kadavanar Watershed with Groundwater Sample Sites Spatial Map

reserved forest (Eastern part) and Toppaiswamimalai reserved forest (Northeast direction).

Geologically, the watershed consists of thirteen rock types. Groundwater samples were collected from major eight rock types such as Calc-gneiss/limestone, Pink migmatite, Anorthosite, Charnockite, Garnet-Silimanite gneiss, Quartzite and Quartz vein Hornblende-biotite gneiss. Kadavanan watershed area has the general trend of this group of rocks are dipping towards north direction.

Methodology

Base map from topographical maps such as 58F/11,13,14,15 and 58J/1,2,3,4. All the drainages are digitized in ArcGIS platform. Connect each first order streams and obtain the Kadavanan watershed boundary. Four km equal grids were designed in plain region. Each intersect points are selected for groundwater sample locations. Around 147 groundwater samples were collected in April 2016 (Pre-monsoon). The pre-cleaned polyethylene bottles were used for collecting all the water samples from open and bore wells. Suitable preservatives were added immediately after collection and analyzed for various constituents as described below:

Groundwater samples were analyzed in major ions (pH, EC, Ca^{2+} , K^+ , Na^+ , Mg^{2+} , HCO_3^- , SO_4^{2-} , NO_3^- , CO_3^-). Analytical results were taken into Rockworks software to prepare the Geology wise symbology from Piper Triangles Diagram and Multi-rectangular diagram (MRDs). Detailed interpretations are given below⁸.

The major cations and anions were plotted on the Piper trilinear diagram and projected on to a common diamond – shaped field to know the type of water. Our new method uses a series of graphs collectively called a multi – rectangular diagram (MRD) as it uses multiple rectangles to present the chemical composition of ground water. The technique of using MRDs⁽⁸⁾ has been applied successfully to ground water samples collected in the Chaj Doab area of Pakistan, and is presented here as an explicitly, but also provides a more lucid hydrochemical classification⁹.

Several graphical representations have been proposed and developed from time to time. In most of the specification, the suitability of the natural water for irrigation has been suggested, on the presumption that water will be used under average conditions with respect to soil characters. Irrigational specifications are mostly based on the chemical properties of the natural water and their effect on the plant growth and development.

Gibb's plot is introduced by Gibbs¹⁰ to control the chemical composition of major dissolved salt of water. This diagram reveals the reasons for the chemical concentration of groundwater.

Irrigation water quality criteria developed by U.S. Salinity Laboratory¹¹ has received wide acceptance in many countries. Total salt concentration and probable sodium hazard of the irrigation water are the two major constituents of the criteria. Four major classes of salinity and sodium hazard were proposed to assess irrigation water quality. Salinity hazard is based on electrical conductivity (EC) and sodium adsorption ratio (SAR) is used.

Irrigational classification was given by Wilcox¹², it is useful for the interpretation of water analysis. The horizontal axes in the diagram represent the electrical conductivity. The vertical axes represent the sodium percentage in the irrigation water. Wilcox diagram has been used to determine the suitability of groundwater of the area for irrigational purposes.

Results and Discussion

The groundwater ionic concentration consisting of minimum, maximum, average and standard deviation are in Table 1. The salient points of the ion concentration of the groundwater are as follows:

Geology wise ionic concentration reveals that the calcium concentration of groundwater for Pink migmatite > Hornblende-biotite gneiss > Garnet-silimanite gneiss > Charnockite > Anorthosite > Quartzite. The Magnesium ionic concentration variations are Hornblende-biotite gneiss > Garnet-silimanite gneiss > Pink migmatite > Charnockite > Anorthosite > Quartzite¹³.

Other hydrogeochemical parameter like Electrical conductivity, power of hydrogen concentration, Sodium, Chloride, Potassium, total dissolved solids values are arranged in this form as Pink migmatite > Hornblende-biotite gneiss > Charnockite > Garnet-silimanite gneiss > Anorthosite > Quartzite. Over view of this interpretation reveals that pink migmatite (high grade metamorphic rock) portion of groundwater is more concentrated compare with other portion. The high concentrations are due to the heavy rock water interaction as well as high weathering^(13,7).

Geology Wise Symbology Piper Triangles Diagram

Piper¹⁴ introduced the triangles diagram, as it consisted of two triangles and one Rhombohedral rectangular shapes. First triangle can have three variables as it's three axes are plotting three cations

Table 1 — Geology wise chemical concentration

Sl.No.	Ions	Min.	Max.	Avg.	Std.Dev.
Pink migmatite – 66 Samples					
1	Ca ²⁺ mg/l	0.90	17.17	5.68	3.04
2	Mg ²⁺ mg/l	0.25	9.91	4.46	2.69
3	Na ⁺ mg/l	1.30	47.83	14.77	9.90
4	K ⁺ mg/l	0.15	10.23	0.95	1.27
5	HCO ₃ ⁻ mg/l	1.06	14.74	5.49	3.11
6	CO ₃ ²⁻ mg/l	0.00	0.00	0.00	0.00
7	SO ₄ ²⁻ mg/l	0.52	28.11	8.43	5.56
8	Cl ⁻ mg/l	0.90	45.69	11.34	8.69
9	EC* μ S/cm	260.00	8750.00	2730.98	1698.47
10	TDS mg/l	182.00	6125.00	1911.69	1188.93
11	pH	6.76	8.52	7.42	0.38
Hornblende-biotite gneiss – 50 Samples					
1	Ca ²⁺ mg/l	1.64	11.58	4.23	2.63
2	Mg ²⁺ mg/l	0.32	10.82	3.18	2.61
3	Na ⁺ mg/l	2.61	36.96	10.52	8.69
4	K ⁺ mg/l	0.13	5.12	0.65	0.77
5	HCO ₃ ⁻ mg/l	0.84	13.92	4.06	3.01
6	CO ₃ ²⁻ mg/l	0.00	0.00	0.00	0.00
7	SO ₄ ²⁻ mg/l	1.33	22.69	6.32	4.98
8	Cl ⁻ mg/l	1.13	29.10	7.75	6.78
9	EC* μ S/cm	502.00	6710.00	1962.70	1501.31
10	TDS mg/l	351.40	4697.00	1373.89	1050.92
11	pH	6.60	8.35	7.55	0.39
Charnockite – 20 Samples					
1	Ca ²⁺ mg/l	2.24	9.98	4.71	2.44
2	Mg ²⁺ mg/l	1.18	8.29	3.64	2.30
3	Na ⁺ mg/l	3.04	32.61	12.25	8.33
4	K ⁺ mg/l	0.13	2.30	0.73	0.54
5	HCO ₃ ⁻ mg/l	1.35	9.32	4.60	2.37
6	CO ₃ ²⁻ mg/l	0.00	0.00	0.00	0.00
7	SO ₄ ²⁻ mg/l	1.54	19.99	7.32	4.97
8	Cl ⁻ mg/l	1.80	25.72	8.91	6.37
9	EC* μ S/cm	688.00	5810.00	2253.15	1442.90
10	TDS mg/l	481.60	4067.00	1577.21	1010.03
11	pH	7.08	8.03	7.45	0.28
Quartzite – 4 Samples					
1	Ca ²⁺ mg/l	2.00	5.87	4.32	1.85
2	Mg ²⁺ mg/l	1.03	5.33	3.52	1.94
3	Na ⁺ mg/l	3.61	11.30	8.05	3.69
4	K ⁺ mg/l	0.20	1.02	0.54	0.37
5	HCO ₃ ⁻ mg/l	1.37	10.47	5.69	3.76
6	CO ₃ ²⁻ mg/l	0.00	0.00	0.00	0.00
7	SO ₄ ²⁻ mg/l	2.50	5.10	4.16	1.15
8	Cl ⁻ mg/l	2.82	10.60	5.95	3.54
9	EC* μ S/cm	740.00	2350.00	1651.25	745.03
10	TDS mg/l	518.00	1645.00	1155.88	521.52
11	pH	6.94	7.83	7.31	0.39

(contd.)

Table 1 — Geology wise chemical concentration (*contd.*)

Sl.No.	Ions	Min.	Max.	Avg.	Std.Dev.
Garnet-silimanite gneiss – 3 Samples					
1	Ca ²⁺ mg/l	3.35	11.34	6.26	4.41
2	Mg ²⁺ mg/l	1.89	10.11	4.74	4.65
3	Na ⁺ mg/l	7.65	27.39	14.55	11.13
4	K ⁺ mg/l	0.41	1.53	0.92	0.57
5	HCO ₃ ⁻ mg/l	2.25	8.58	4.41	3.61
6	CO ₃ ²⁻ mg/l	0.00	0.00	0.00	0.00
7	SO ₄ ²⁻ mg/l	4.50	15.91	8.68	6.29
8	Cl ⁻ mg/l	6.32	24.93	12.90	10.44
9	EC* μ S/cm	1458.00	5590.00	2926.33	2310.84
10	TDS mg/l	1020.60	3913.00	2048.43	1617.59
11	pH	7.21	7.62	7.46	0.22
Anorthosite – 2 Samples					
1	Ca ²⁺ mg/l	4.43	9.02	6.73	3.25
2	Mg ²⁺ mg/l	2.96	7.66	5.31	3.32
3	Na ⁺ mg/l	8.09	22.61	15.35	10.27
4	K ⁺ mg/l	0.46	1.28	0.87	0.58
5	HCO ₃ ⁻ mg/l	4.44	8.37	6.40	2.78
6	CO ₃ ²⁻ mg/l	0.00	0.00	0.00	0.00
7	SO ₄ ²⁻ mg/l	3.79	14.57	9.18	7.63
8	Cl ⁻ mg/l	7.22	16.69	11.96	6.70
9	EC* μ S/cm	1676.00	4370.00	3023.00	1904.95
10	TDS mg/l	1173.20	3059.00	2116.10	1333.46
11	pH	7.35	7.59	7.47	0.17

Calc-gneiss/Lime stone – 1 Sample

Quartz vein – 1 Sample

(Ca²⁺, Mg²⁺, Na⁺ + K⁺) expressed as percentages of total cations in meq/l and hence, a single point is obtained on the cations triangle. The other triangle is for anions (SO₄²⁻, Cl⁻, HCO₃⁻ + CO₃²⁻) in the same way (Figure 2). These two points each within the triangles are projected into a central diamond (rhombohedral rectangular) shaped area by parallels to the upper edges of the central area.

Percentage of individual ions is evaluated from each respective group of cations and anions separately. The percentages of cations (anions) are plotted on the left (right) triangle. Every axis of each triangle is divided between 0 and 100 units, which represent the percentage of the particular ion or group of Lumped ions drawn on that axis.

The Piper ¹⁴ Trilinear Diagram is most useful to understand the chemical relationships among groundwater. Results Table 2a and cations triangle reveals that 82 samples out of 147 are plotted in No dominant domain and 65 samples out of 147 are plotted in Na⁺ and K⁺ dominant domain. The lithological composition of the aquifer's matrix is

dominated by pink migmatite and hornblende-biotite gneiss rocks. Cations triangle shows that 55.78 % of the groundwater samples fell in No dominant domain. It is more suitable for all purposes.

The anion triangle (Table 2a) shows that 60.54% of groundwater samples fall in Cl⁻ dominant domain and 38.78 % of the samples are in No dominant domain. The lithological composition of the aquifer's matrix is dominated by pink migmatite, hornblende-biotite gneiss and charnockite rocks.

Rectangular shape is sub-divided in to nine categories and detailed classifications were given in Table 2b. Figure 2 reveals that 78 out of 147 groundwater samples fall under (Ca²⁺ + Mg²⁺) exceeding alkalies (Na⁺ + K⁺) class and 69 out of 147 groundwater samples fell under Alkalies exceed alkaline earths class.

All the groundwater samples except one sample (S.No. 16) under Weak acids (CO₃²⁻ + HCO₃⁻) exceed strong acids (SO₄²⁻ + Cl⁻) class. Geology wise sodium chloride type such as Pink migmatite – 36 out of 66 samples, Hornblende-biotite gneiss – 20 out of 50

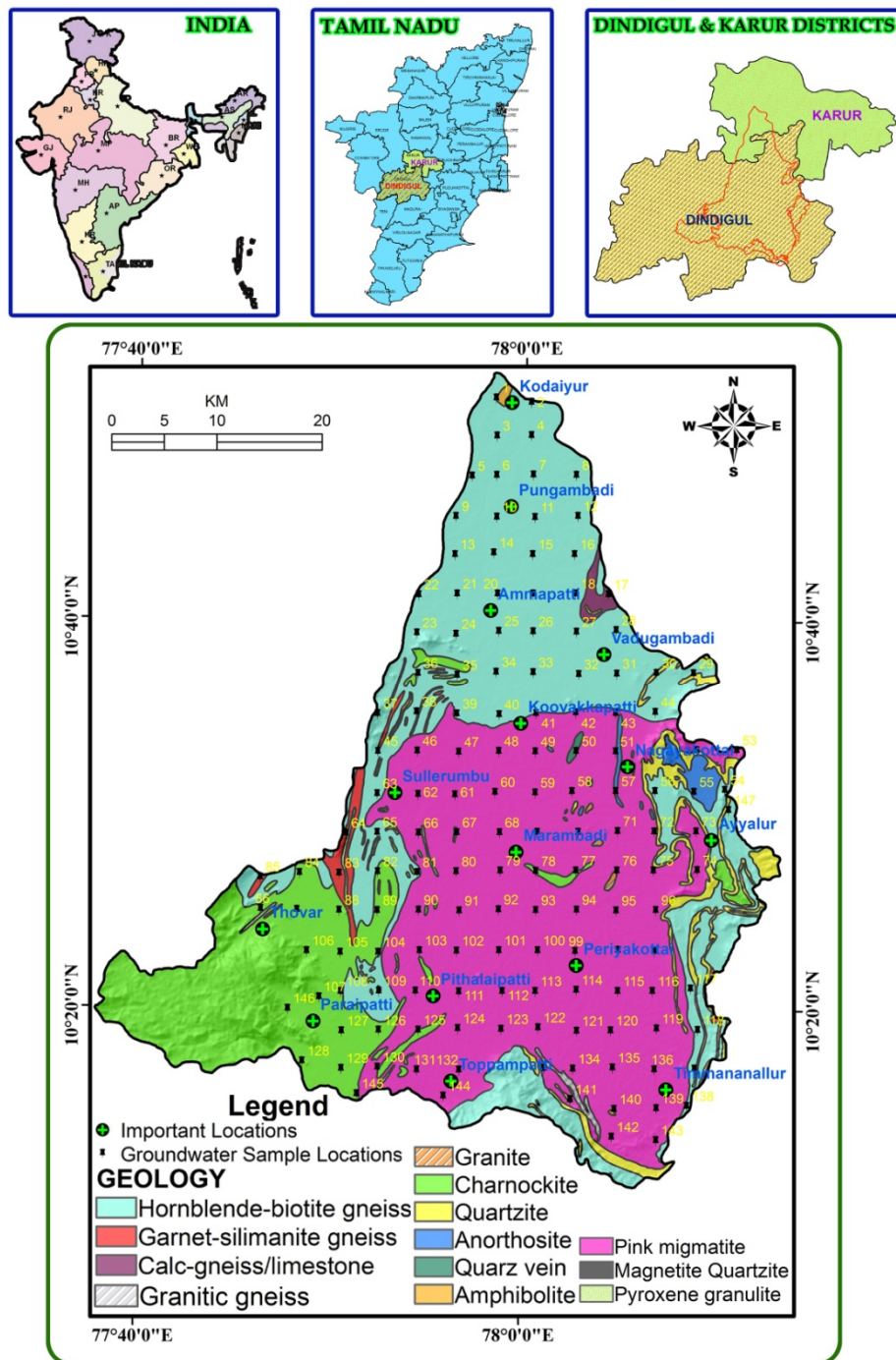


Fig. 2 — Geology wise Piper Triangles Diagram

samples, Charnockite–12 out of 20 samples, Garnet-silimanite gneiss – 1 out of 3 samples. Therefore, partial amount of the groundwater chemical concentrations is depending upon rock water interaction. Rest of the groundwater samples fell under mixed type (No Cation-Anion exceed 50 %). Moreover, from the field observation and almost

linear trends of plot, it is evident that mixing of two kinds of water took place in varying proportions.

We can anticipate that the rock weathering would have controlled the Na^+ , Cl^- and HCO_3^- content of groundwater. Natural groundwater would have been influenced by minerals. The gneissic rock bodies of the region are mainly consisting of quartz, potash

Table 2a — Geology wise Piper Triangular Diagram Results

Table 2a — Geology wise Piper Triangular Diagram Results										
Major Elements	Triangular portions	Representation of Triangular portions	Sample details							
			Pink migmatite	Hornblende-biotite gneiss	Charnockite	Quartzite	Garnet-silimanite gneiss	Anorthosite	Calc-gneiss/limestone	Quartz vein
Cations	A	Ca ²⁺ Domain	-	-	-	-	-	-	-	-
	B	No dominant domain	41,42,43,46,48,49,51, 58,61,62,67,68,71,75, 79,80,93,97,101,102, 103,111,113,114,116, 120,121,124,132,133, 134,135,140,143. (34)	1,2,3,4,5,6,7,8,10, 11,13,14,16,20,22, 23,24,31,33,35,36, 37,40,45,56,63,81, 109,117,137,138. (31)	84,88,89,105, 52,141. (4)	29,30, 127,128,129, 146. (8)	83 (1)	55,57. (2)	17. (1)	50. (1)
	C	Mg ²⁺ domain	-	-	-	-	-	-	-	-
	D	Na ⁺ and K ⁺ Domain	47,53,59,60,66,69,70, 72,73,74,76,90,91,92, 94,96,98,99,100,110, 112,115,119,122,123, 130,131,136,139,142, 144. (32)	9,12,15,18,19, 21,25,26,27,28, 32,34,38,39,44, 54,65,118,147. (19)	77,78,82,86, 87,104,106, 107,108,125, 126,145. (12)	-	64,85. (2)	-	-	-
	Anions	E	HCO ₃ ⁻ domain	-	16 (1)	-	-	-	-	-
F		SO ₄ ²⁻ domain	-	-	-	-	-	-	-	-
G		Cl ⁻ domain	41,42,43,46,47,51,53, 60,66,69,70,71,72,73, 74,76,79,90,91,93,94, 95,96,98,99,100,102, 110,113,115,116,119, 122,123,132,133,134, 135,136,142,144. (41)	2,7,9,10,12,15, 18,19,22,25,26, 27,28,31,32,34, 35,36,44,45,54, 56,65,81,118, 147. (26)	77,78,87,88, 104,105,106, 107,108,126, 141. (4)	29,30,5 64,83,85. (3)	55,57 (2)	-	-	
H		No dominant domain	48,49,58,59,61,62,67, 68,75,80,92,97,101, 103,111,112,114,120, 121,124,130,131, 139,140,143. (25)	1,3,4,5,6,8,11, 13,14,20,21,23, 24,33,37,38,39, 40,63,109,117, 137,138. (23)	82,84,86,89, 125,128,145, (7)	-	-	-	17. (1)	50. (1)

feldspar (Orthoclase and microcline), soda feldspar, and biotite amphibole minerals. Alteration of biotite and feldspar group of minerals is also common feature in gneissic rocks. These altered minerals may have influenced the ionic composition of groundwater.

Multi – Rectangular Diagram

A new multi-rectangular diagram (MRD) plotting technique that uses multi-rectangular coordinates has been introduced to classifying groundwater samples chemically. This simple approach has advantages over more traditional triangular coordinate methods as it can accommodate larger number of samples without cluttering the plotted diagram. Using this new approach, the meq/L percentages of the total cations/anions are plotted in the same way as they are

used in classical trilinear diagrams. MRD_s were used successfully to differentiate groundwater types in the Chij Doab area of Pakistan to illustrate the use of this new approach.

The plotted 147 groundwater chemical analyses of April 2016 (Pre-monsoon) expressed as concentrations (meq/L) of cations and anions, are given in Table 1. The pre-monsoon chemical concentration (meq/L) values are singled out and plotted in the corresponding rectangles, as show in Fig. 3. In this demonstration MRD, sodium chloride (pink migmatite) rectangle present in 49 samples out of 66 samples, rest of the groundwater samples occurred in sodium sulphate and sodium bi-carbonate. Hornblende biotite gneissic portion groundwater samples contain sodium chloride in, 33 field samples out of 50 samples. Rest of the groundwater

Table 2b — Trilinear Portion Interpretation Results

Triangular Representation of portions	Triangular portions	Sample details							
		Pink migmatite	Hornblende-biotite gneiss	Charnockite	Quartzite	Garnet-silimanite gneiss	Anorthosite	Calc-gneiss/limestone	Quartz vein
1	(Ca ²⁺ + Mg ²⁺) exceed alkalies (Na ⁺ + K ⁺)	41,42,46,49,51, 58,61, 62,67,68,71,75, 79,80, 93,97,101,102,103,110,111,113, 114,116,120,123,124,130,131,143. (30)	1,2,3,4,5,6,7,8,11, 13,14,16,20,22,23,24,31,33,35,36,37, 40,45,56,63,81,109, 117,137,138. (30)	84,88,89,105 29,30,52, 64,85. (2)	141. (4)	55,57. (2)		17. (1)	50. (1)
2	Alkalies exceed alkaline earths	43,47,48,53,59, 60,66, 69,70,72,73,74, 76,90, 91,92,94,95,96, 98,99, 100,112,115,119,121, 122,132,133,134,135, 136,139,140,142,144. (36)	9,10,12,15,18,19, 21,25,26,27,28,32, 34,38,39,44,54,65, 118,147. (20)	77,78,82,86, 87,104,406,1 07,108,125,1 26,145. (12)	-	83. (1)	-	-	-
3	Weak acids (CO ₃ ⁻ + HCO ₃ ⁻) exceed strong acids (SO ₄ ²⁻ + Cl ⁻)	All the samples	All the samples Except 16	All the samples	All the samples	All the samples	All the samples	All the samples	All the samples
4	Strong acids exceeds Weak acids	-	16	-	-	-	-	-	-
5	Magnesium bicarbonate type	-	-	-	-	-	-	-	-
6	Calcium Chloride type	-	-	-	-	-	-	-	-
7	Sodium Chloride type	43,47,48,53,59, 60,66, 69,70,72,73,74, 76,90, 91,92,94,95,96, 98,99, 100,112,115,119,121, 122,132,133,134,135, 136,139,140,142,144. (36)	9,10,12,15,18,19, 21,25,26,27,28,32, 34,38,39,44,54,65, 118,147. (20)	77,78,82,86, 87,104,406,1 07,108,125,1 26,145. (12)	-	83. (1)	-	-	-
8	Sodium bicarbonate type								
9	Mixed type (No Cation-Anion exceed 50%)	41,42,46,49,51, 58,61, 62,67,68,71,75, 79,80, 93,97,101,102,103,110,111,113, 114,116,120,123,124,130,131,143. (30)	1,2,3,4,5,6,7,8,11, 13,14,20,22,23,24,31,33,35,36,37,40,45, 56,63,81,109, 117,137,138. (29)	84,88,89,105 29,30,52, 64,85. (2)	141. (4)	55,57. (2)		17. (1)	50. (1)

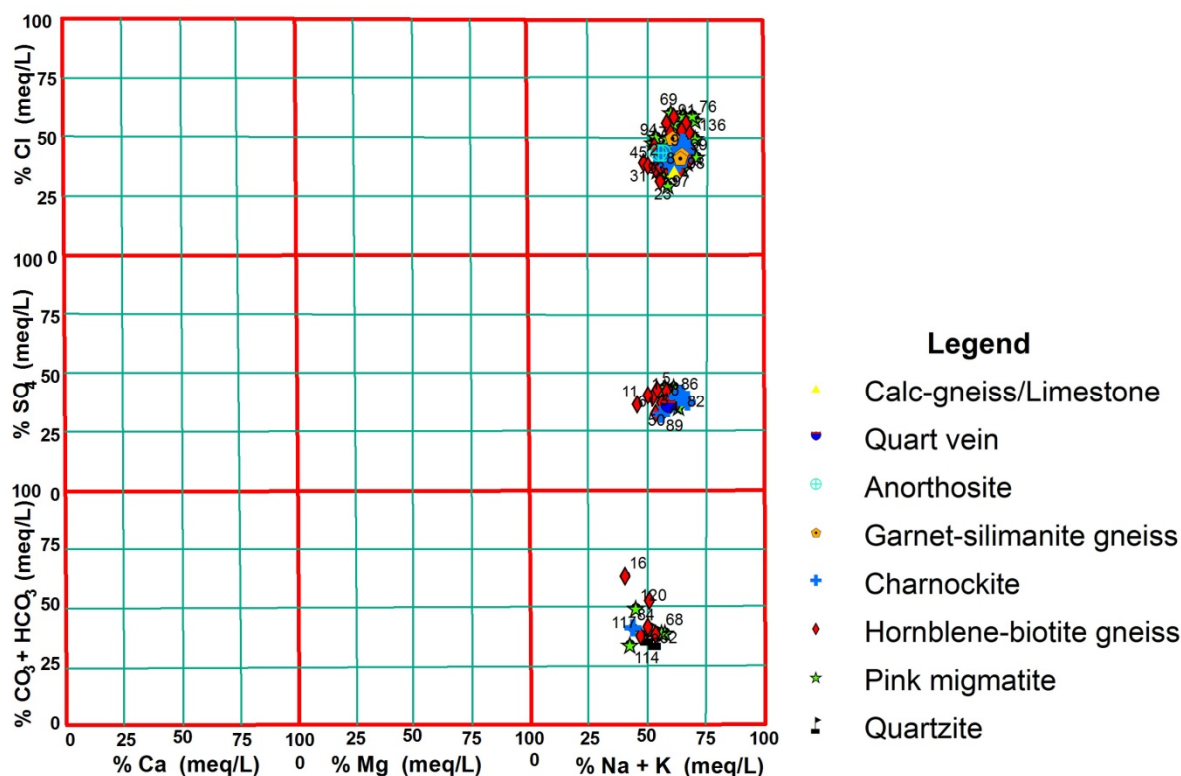


Fig. 3 — Multi-rectangular diagram

samples occurred in sodium sulphate (12 samples) and sodium bi-carbonate (5 samples). Next dominating rock type is a Charnockite region groundwater samples MRDs result reflected same of the above result. Hence, the major three rock types groundwater sample results are same pattern, but NaCl type of sample percentage is gradually decreasing in the order of Pink migmatite > Hornblende biotite gneiss > Charnockite. Weathering of feldspar minerals increased from charnockite to pink migmatite. Overall dominating water type is NaCl sub-basin groundwater. Sodium from feldspar and microcline minerals. Chloride from Sodalite and apatite are the only common minerals and chloride as the essential constituents through mica, and hornblende. Chloride anions to originate in the groundwater from several factors like weathering, leaching of sedimentary rocks and soils, windblown salt in rainfall, domestic and industrial wastes, and municipal sewages^{15,16}.

It is concluded that the Kadavanar sub-basin groundwater chemistry is mainly depends upon the rock types (Geology). However, some rectangles may remain empty. Therefore, analyses of all the groundwater samples are represented 70.08 % in

NaCl field, 10.2 % in NaHCO₃ field and 19.72 % in NaSO₄ field.

Mechanisms of controlling the chemistry of groundwater

Gibbs¹⁰ has discussed some of the mechanisms that control the chemical composition of major dissolved salt of water. The mechanism responsible for the controls of sub-surface water chemistry of the earth¹⁰ can be identified by using Gibbs plot. These plots have been used in this study. The data plots of water samples of the present study are shown in Figure 4. It's observed that chemical composition of the groundwater in this study area was dominated by rock dominance. Fluctuations of water level in the wells were likely to bring change in groundwater. Generally unconfined aquifer water chemistry is mainly depends up the soil and rocks¹⁷.

U.S. Salinity Laboratory (1954)

The U.S. Salinity Laboratory has published a diagram in which the values of SAR are plotted on an arithmetical scale against Electrical conductance (EC) on a log scale and different classes of water have been marked on the diagram. The data plot of the natural

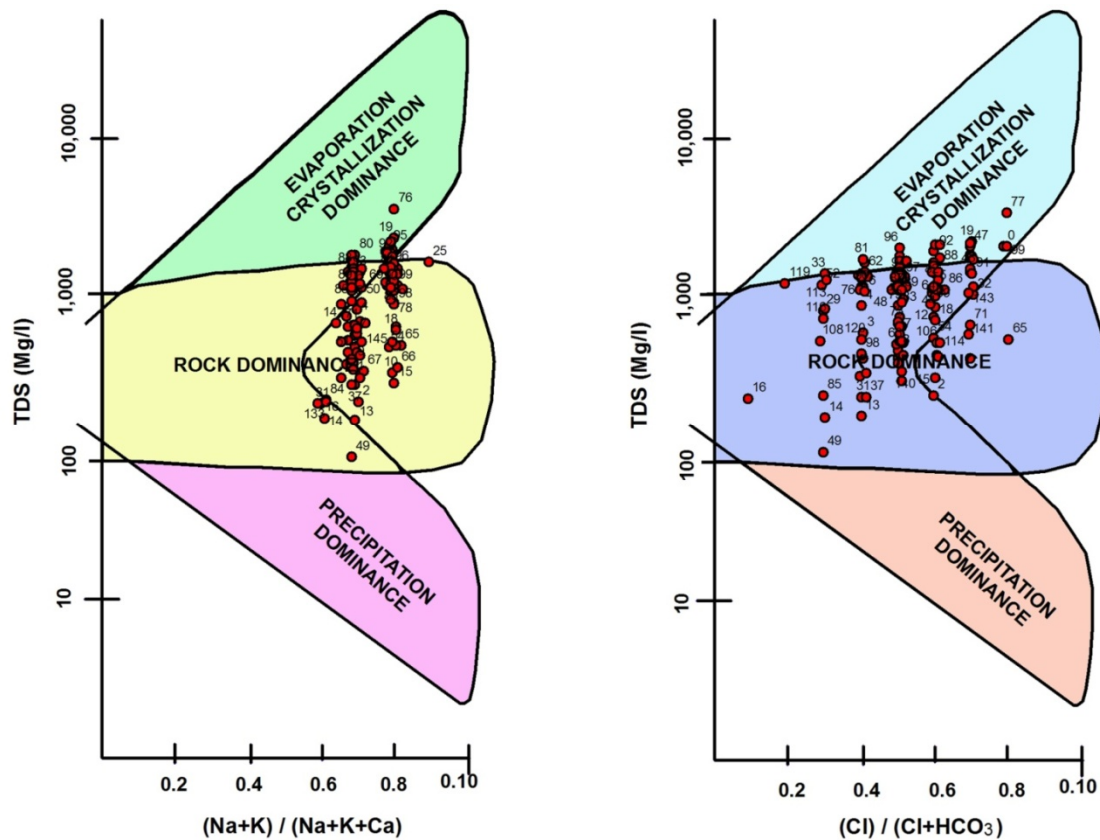


Fig. 4 — Mechanisms of controlling the hydro-geochemistry of groundwater

waters of pre-monsoon season on U.S. Salinity Laboratory Staff diagram (Figure 5 and Table 5) indicates that the groundwater of the area belongs to seven classes.

C3S1 (40.82 %) of groundwater samples are good for irrigational purposes. Which suggest that natural water of the area can be used for all types of crops on soil of medium to high permeability. C3S2 (15.65 %) of groundwater samples belongs to moderate use for irrigational purposes. Rest of the C4S2 (22.45 %), C4S3 (10.88 %) and C4S4 (2.72 %) of the groundwater samples fall under Not suitable for agricultural uses. However, in case of low permeability soil, this water can be used for growing moderate to good salt tolerant crop with some leaching precautions.

Wilcox's Diagram (1955)

Wilcox's has proposed another classification scheme for rating irrigation water on the basis of specific electrical conductance, Sodium-percentage (Na^+ %) is calculated by the following formula.

A critical examination on Fig. 6 and Table 6 for all the water of the area less than 20 %, thus they are

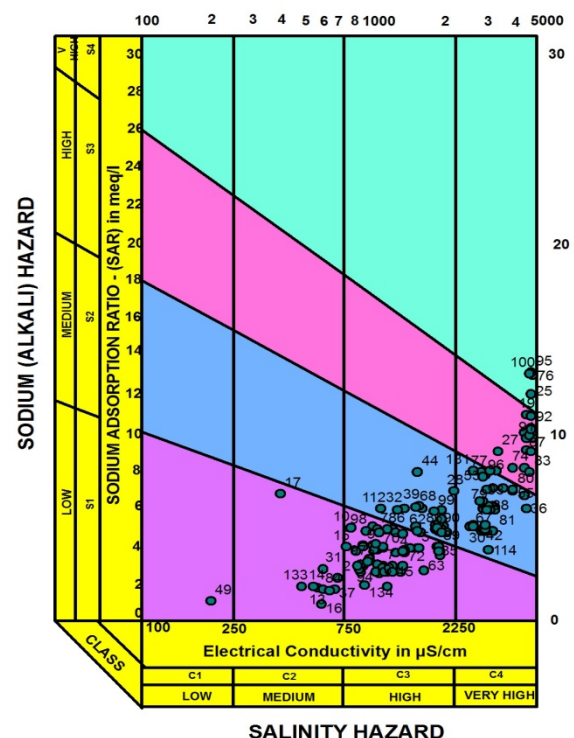


Fig. 5 — U.S. Salinity Laboratory (1954) Diagram

Table 3 — Results of Multi-rectangular diagram (MRDs)

Rock types	Groundwater types	Sample Nos.	Geology wise %	Overall %
Pink migmatite (66 Samples out of 147 Samples)	NaCl	41,42,43,46,47,51,53,60, 62,66,69,70,71,72,73,74, 76,79,80,90,91,92,93,94, 95,96,97,98,99,100,102, 103,110,113,115,116,119, 122,123,131,132,133,134, 135,136,139,140,142,144.(49)	74.24%	33.33%
	NaHCO ₃	49,58,67,68,101,114,120.(7)	10.61%	4.76%
	NaSO ₄	48,59,61,75,11,112,121, 124,130,143.(10)	15.15%	6.80%
Hornblende-biotite gneiss (50 Samples out of 147 Samples)	NaCl	2,7,8,9,10,11,12,13,15,18, 19,20,22,23,24,25,26,27,28, 31,32,34,35,36,44,45,54,56, 63,65,81,118,147.(33)	66%	22.45%
	NaHCO ₃	14,16,33,109,117.(5)	10%	3.40%
	NaSO ₄	1,3,4,5,6,21,37,38,39,40, 137,138.(12)	24%	8.16%
Charnockite (20 Samples out of 147 Samples)	NaCl	77,78,87,88,104,105,106, 107,108,126,127,129,146,(13)	65%	8.84%
	NaHCO ₃	84.(1)	5%	0.68%
	NaSO ₄	82,86,89,125,128,145.(6)	30%	4.08%
Quartzite (4 Samples out of 147 Samples)	NaCl	30,141.(2)	50%	1.36%
	NaHCO ₃	29,52.(2)	50%	1.36%
Quartzite Garnet-silimanite gneiss (3 Samples out of 147 Samples)	NaCl	64,83,85.(3)	100%	2.04%
Anorthosite (2 Samples out of 147 Samples)	NaCl	55,57.(2)	100%	1.36%
Calc-gneiss/limestone (1 Samples out of 147 Samples)	NaCl	17.(1)	100%	0.68%
Quartz vein (1 Samples out of 147 Samples)	NaSO ₄	50(1)	100%	0.68%

Table 4 — GIBB'S Classification

Domains	Well locations Cations	Well locations Anions
Evaporation Crystallization	19,36,47,70,76,80,83,87,91,92,95,100,102,104, 110,118,130,136,147. (19)	19,25,36,47,70,77,81,84,88,92,93,96,99,103,109, 117,135,146,147. (19)
Rock water interaction	All the Samples Except Above Mentioned (128)	All the Samples Except Above Mentioned (128)
Precipitation	-	-

excellent for irrigation during pre-monsoon spell. As per the Wilcox's interpretation reveals that only 14 samples are under Excellent to Permissible category, 65 samples show value ranging Permissible to Doubtful Class, 20 samples fall under Doubtful to Unsuitable Class and 48 samples for not suitable for

irrigational purposes. Most of the groundwater samples can be safely used for irrigation purposes.

$$\text{Na}^+ \% = \frac{(\text{Na}^+ + \text{K}^+) \times 100}{(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+)}$$

Where all concentrations are expressed in epm.

Table 5 — Pre-monsoon Suitability of Irrigation – USSL

Sl.No.	Domains	Terminology	Well locations Pre-Monsoon	Percentage
1	C1S1 Domain	Good Category	49. (1)	0.68%
	C2S1 Domain	Good Category	2,13,14,16,17,31,37,84,133,141 (10)	6.80%
2	C3S1 Domain	Good Category	1,3,4,5,6,7,8,9,10,11,12,15,18,20,29,35,41,45,50,51,52,54,56,57,59,60,63,64,65,66,70,71,72,78,85,89,94,97,98,105,106,107,109,111,113,115,116,117,121,127,128,134,137,138,139,140,142,145,146. (60)	40.82%
3	C3S2 Domain	Moderate Category	21,26,28,32,34,38,39,48,62,68,75,82,86,90,99,103,112,119,122,123,124,125,144. (23)	15.65%
4	C4S2 Domain	Bad Category	22,23,24,30,33,36,40,42,46,53,58,67,73,77,79,80,81,88,93,96,101,102,108,114,120,126,129,130,131,132,135,143. (33)	22.45%
5	C4S3 Domain	Bad Category	19,27,43,47,61,69,74,83,87,91,92,104,110,18,136,147. (16)	10.88%
6	C4S4 Domain	Bad Category	25,76,95,100. (4)	2.72%

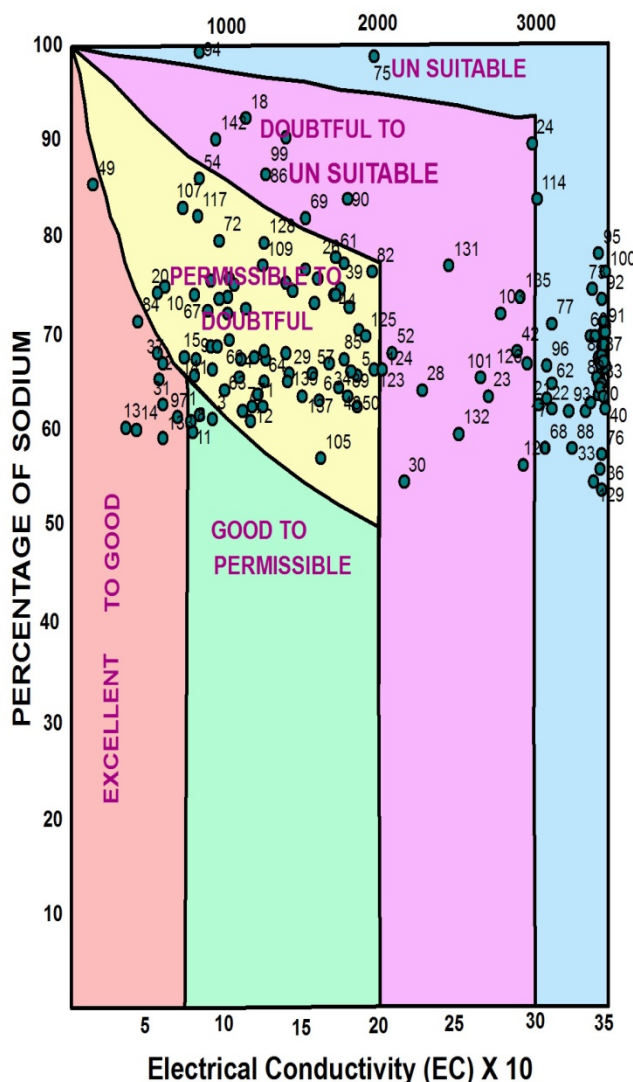


Fig. 6 — Wilcox's plot for Irrigation Suitability

Table 6 — Pre-monsoon Irrigation Suitability of Wilcox's plot

Season	Domains	Well locations
Pre-monsoon	Excellent to Good	2,13,14,16,31,37,49,84,
(or)	Class	97,133. (10)
Hot season	Good to Permissible	1,3,8,11. (4)
	Class	
	Permissible to	4,5,6,7,9,10,12,15,20,26,2
	Doubtful Class	9,32,34,35,38,39,41,44,45
		,48,50,51,54,56,57,59,61,
		63,64,65,66,67,71,72,78,8
		2,85,89,98,105,106,107,1
		09,111,112,113,115,116,1
		17,119,121,122,123,125,1
		27,128,134,137,138,139,1
		40,141,144,145,146. (65)
	Doubtful to	18,23,24,28,30,42,52,69,8
	Unsuitable Class	6,90,99,101,103,120,124,
		126,131,132,135,142. (20)
	Unsuitable Class	17,19,21,22,25,27,33,36,4
		0,43,46,47,53,55,58,60,
		62,68,70,73,74,75,76,77,7
		9,80,81,83,87,88,91,92,93
		,94,95,96,100,102,104,10
		8,110,114,118,129,130,13
		6,143,147. (48)

Conclusion

As per the piper triangles diagram cations triangle shows that 53.06 % of the samples fell in Na^+ and K^+ dominant domain. Anions triangle shows that 60.54 % of samples fall in Cl^- dominant domain. Sodium chloride (NaCl) is dominating salt type, so it is permanent hardness of groundwater. Rectangular portion reveals that 53.06 % samples fall under Sodium chloride (NaCl) alkalies exceed alkaline earth class.

Concluded that the Multi-rectangular diagram (MRD) interpretation result is reflected same as

reveals piper triangles diagram result. This type of samples dominates the following sequence of the rocks such as Pink migmatite > Hornblende-biotite gneiss > Charnockite > Garnet-silimanite gneiss > Anorthosite > Quartzite. Over view of this interpretation reveals that pink migmatite (High grade metamorphic rock) portion of groundwater is more concentrated compare with other portion. Because of the high concentration, due to the heavy rock water interaction as well as high weathering.

Gibb's diagram shows that chemical composition of the groundwater samples was dominated by rock dominance. The chemical concentration of the groundwater in mainly depends upon the rock water-interaction.

Another irrigational classification diagrams such as USSL (63.95 %) and Wilcox's (67.35 %) diagrams interpretation reveals that the majority of the groundwater samples fell under suitable for agricultural uses.

The groundwater chemistry is mainly depending upon lithology and precipitation of Kadavanar region. Over view of this interpretation reveals that pink migmatite (High grade metamorphic rock) portion of groundwater is more concentrated compare with another portion. Because of the high concentration, due to the altered minerals may have influenced the ionic composition of groundwater.

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References

- 1 Bear, J., Verruijt, A., Modeling Groundwater Flow and Pollution, 1987.
- 2 John Devadas, D., SubbaRao, N., Thirupathi Rao, B., Srinivasa Rao, KV., Subrahmanyam, Hydrogeochemistry of the Sarada river basin, Visakhapatnam district, Andhra Pradesh, India, *Environ. Geol.* 52 (2007), 1331-1342.
- 3 Subramani, T., Rajmohan, N., Elango, L., Groundwater geochemistry and identification of hydrogeochemical processes in a hard rock region, Southern India. *Environ. Monit. Assess.* 162 (2010) pp.123-137.
- 4 Nandimandalam Janardhana Raju, Shukla, U.K. Prahlad Ram, Hydrogeochemistry for the assessment of groundwater quality in Varanasi: a fast-urbanizing center in Uttar Pradesh, India. *Environ. Monit. Assess.* 173, (2010), 279-300.
- 5 Subba Rao, N., Surya Rao, P., Venktram Reddy, G., Nagamani, M., Vidyasagar, G., Satyanarayana, N.L.V.V., Chemical characteristics of groundwater and assessment of groundwater quality in Varaha river basin, Visakhapatnam District, Andhra Pradesh, India. *Environ. Monit. Assess.* 184 (2012), 5189-5214.
- 6 Singaraja C., Chidambaram, S., Anandhan, P., Prasanna, MV., Thivya C., Thilagavathi, R., Sarathidasan, J., Determination of the utility of groundwater with respect to the geochemical parameters: a case study from Tuticorin District of Tamil Nadu, India, *Environ. Dev. Sustain.* 16 (2014), 689-721.
- 7 Kalaivanan, K., Gurugnanam, B., Hamid Reza Pourghasemi, Suresh, M., Kumaravel, M., Spatial assessment of groundwater quality using water quality index and hydrochemical indices in the Kodavanar sub-basin, Tamil Nadu, India. *Sustain. Water Resour. Manag.* (2017), DOI 10.1007/s40899-017-0148-x.
- 8 Ahmad, N., Evaluation of groundwater resources in the upper middle part of Chaj Doab Area, Pakistan. Unpublished Ph.D. Thesis, Department of Meteorological Engineering, Technical University of Istanbul, Turkey, 1998.
- 9 Suresh, M., Integrated hydrogeological studies of Upper Thirumanimuthar Sub-basin, Cauvery River, Tamil Nadu, India. Unpublished Thesis, 2009.
- 10 Gibbs, R.J., Water chemistry of Amazon river. *Geochim. Cosmochim. Acta* 36 (1972) 1061-1066.
- 11 US Salinity Laboratory Staff, Diagnosis and improvement of saline and alkali soils. USDA, Handbook 60, U.S. Government Printing Office, Washington D.C, 1954.
- 12 Wilcox, LV., Classification and use of irrigation waters. USDA, Circular 969, Washington, DC, 1955.
- 13 Gurugnanam, B., Suresh M., Vasudevan, S., Dharanirajan, K., Sivanatarajan, G., GIS Study for Locating Village Wise Suitable Ground Water Quality Zones in Parts of Veeranam Catchments Area, Tamil Nadu, South India. *J. of App. Geochemistry*, 12., (2010), PP. 84-94.
- 14 Piper, A.M., A graphic procedure in the geochemical interpretation of water analysis. *Trans. Am. Geophys. Union* 25, (1944), pp. 914-923.
- 15 Karanth, K.R., *Groundwater assessment, development and management*: Tata McGraw-Hill publishing Company Limited, New Delhi. (1987), 720p.
- 16 Hem, JD., *Study and Interpretation of Chemical Characteristics of Natural Water*. 3rd Edition, Geological Survey Water-Supply Paper 2254, United States Government Printing Office, Washington DC, (1985), pp.117-120.
- 17 Gurugnanam, B., GIS based integrated Approach for Groundwater studies in Gomukhi-Manimuktha sub-basin, Vellar, Tamil Nadu, India. Unpublished Ph.D., thesis, Annamalai University. (2003), PP.20 -24.