

Groundwater Characterization and Quality Assessment by using GIS and Geo Statistics from Pandalgudi Region, Virudhunagar District, Tamilnadu, India

A. V. Udayanapillai^a, M. Kalammal^b

^{a,b} P.G Studies and Research Centre, Department of Geology, V.O.Chidambaram College, India
avpillai@gmail.com, kaligeo86@yahoo.com

Abstract: *Twenty four representative groundwater samples collected during pre-monsoon and post monsoon seasons in 2014 from Pandalgudi region, Virudhunagar district, Tamilnadu, were analyzed for various physico-chemical parameters such as pH, TDS, EC, Cations Ca^{2+} , Mg^{2+} , Na^+ , K^+ and Anions HCO_3^- , SO_4^- , Cl^- , F^- and NO_3^- . The GIS based, thematic iso-quality geospatial contour maps for the integrated parameters of cations Ca^{2+} - Mg^{2+} , Na^+ - K^+ and anions HCO_3^- - SO_4^- - Cl^- , were generated by the software Arc GIS 10.1. The geo statistical evaluation such as Multiple Correlations, Principal Component Analysis and Cluster Analysis of groundwater quality parameters was carried out by the geo-statistics software 'PAST'. Further, the water quality parameters were illustrated with Gibbs and Piper method. Finally, water qualities of the study area are compared with BIS and WHO standards of drinking water and other standards such as livestock and irrigation purposes.*

Keywords: *Physico-Chemical parameters; Arc GIS 10.1; PAST; Gibbs; Piper; BIS; WHO; Drinking water; Livestock; Irrigation*

1. INTRODUCTION

Groundwater is more vital distributed resources in the earth. Utilization and necessity of groundwater for agriculture, industries and domestic purposes are being increased in developing countries. Further, due to overgrowth of population, socio-economic development, swift urbanization and environmental degradation, water stress has been emerged as a real threat for human lives (Kalammal and Udayanapillai, 2016). Many places in the world have already been under severe water stress. Numerous researchers have reported their research on hydro geochemical studies of groundwater, not only in India, but also in various part of the world ((Kumaresan and Riyazuddin, 2006; Tatawat and Singh Chandel, 2007; Sadashivaiah et al., 2008; Semwal and Jangwan, 2009; Dinesh Kumar Tank and Singh Chandel, 2010; Biswajeet Pradhan and Saied Pirasteh, 2011; Senthil Kumar, et al., 2014; Shahidullah et al., 2000; Pradhan and Chandrasekharan et al., 2009; Nwankwoala and Udom 2011; Ahmed Al-ameri et al., 2012; Ghoraba and Khan et al., 2013; Ghulam Hussian, Abdullah Al-Zarah and Latif, 2014). The quality of groundwater is highly affected spatially and temporally by various factors such as lithology, aquifer chemistry, rock-water interaction and its circulation, microbial action, pollution and seawater intrusion (Udayanapillai et al, 2012). These complex processes which make various hydro geochemical characterization, occurring in wide range of lithology from the age of Archaean crystalline rock to Recent alluvium. Different lithological condition in India makes tremendous changes in the hydro geochemistry of groundwater (Chanda and Chakarabarty, 2001). Many villages centered on Pandalgudi region of Virudhunagar district are utilizing groundwater long time for domestic and irrigation purposes. Except one or two minor reports, no much research work has been concentrated previously on the above study area pertaining to geochemistry of groundwater. Due to the welfare of the society of the study area, an attempt has been made in this paper to evaluate the geochemical characterization of groundwater utilizing GIS based techniques and geo statistical evaluation.

2. STUDY AREA

The study area is located above the Vaippar river basin and bounded with an aerial distance between 90 sqs Km, centered on Pandalgudi town. The area falls in the survey of India Toposheet no 58/K3, prepared in the scale of 1:63360. It lies between the latitude from N 9° 15' to N 9° 30' and longitudes

from E 78° 0' to E 78° 15' (Figure. 1). The area has been well connected with national and state highway road net work. The topography of the study area is generally flat and plain with devoid of any hill outcrop. It has the maximum elevation of 82m from the MSL. Drainage patterns are dendritic and the drainage slope directions are generally facing towards south and south east direction and merge into the Vaippar river basin located at the south. The area generally experiences tropical climate and receives an average rainfall of 700 mms per annum influenced by south west and north east monsoons. Lake irrigation and well irrigation is generally practiced in most part of the area.

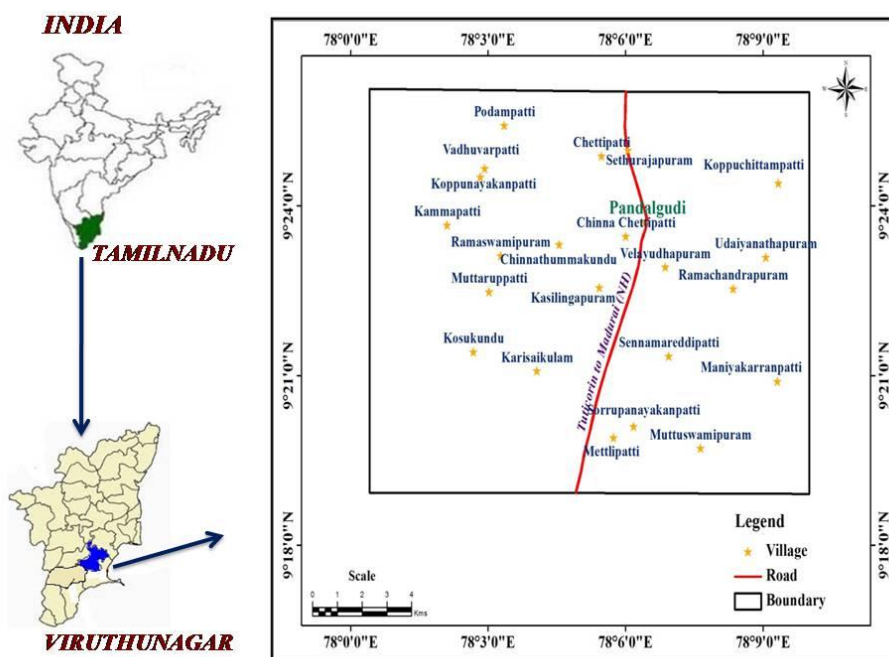


Fig1. The Location map of the study area

2.1. Geology

Proterozoic formation is the basement rocks which consist of quartzite, crystalline limestone, calc-granulite, hornblende – biotite gneiss, charnockite or pyroxene granulite, granite and pegmatite (Narayanasamy and Purnalakshmi, 1967). Weathered, a fissured cracks, shear zones and joints in the basement rock act as a good groundwater potential zone in the study area. Proterozoic formation is overlain by a thick calcrete with a thickness of 1.20m which is believed to be the age of Holocene to Pleistocene deposits. The calcrete is overlain by the Recent alluvium of black soil and detached batches of red sandy loamy soil. The general stratigraphy of the study area are shown Table 1.\

Table1. Stratigraphical Succession in and around Pandalgudi area

Age		Stratigraphy
Recent (1500 year)		Black cotton soil, Red soil, Sandy loamy soil and Calcrete, as Cap rocks
Proterozoic	520 Ma	Pink granites, White granites and Pegmatites
	550 Ma	Charnockite (With bands of Pyroxene granulites and intrusive of Pink granite veins)
	>2000Ma	Hornblende Biotite gneisses with enclaves of calc-silicate rocks, veins of crystalline limestone band.

Table2. Average water quality parameters of two seasons in which all values in mg/l, except EC its $\mu\text{S}/\text{Cm}$

S.No	Village	Latitude	Longitude	Ca	Mg	Na	K	F	Cl	SO ₄	CO ₃	HCO ₃	NO ₃	pH	EC	TDS
1	Podampatti	78.05	9.4166	12.4	10.56	140	4	0.17	32.54	38.62	38	648.8	0.8	7.5	1191	819.6
2	Ramalingapuram	78.0666	9.4333	940	457	830	30	0.19	4013	736.21	0	98	1.1	7.5	12565	8632
3	Chidamparapuram	78.0666	9.4333	71.6	14.53	13	11	0.23	140.3	46.37	10	331.6	0.3	7	888	435.3
4	Chettikurchi	78.0833	9.4333	44.4	17.23	48	72	0.22	117.62	61.55	10	331.6	0	7.1	1003	654.9
5	Valvangi	78.0833	9.4333	87.6	22.1	57	78	0.18	103.44	153.29	14	392.6	0.1	7.2	1283	850.1
6	Periyanayagipuram	78.111	9.4333	227	86	285	40	0.19	766	1106	60	232	0	7.4	4080	2525
7	Ayankarisalkulam	78.067	9.351	344	87.28	390	50	0.21	443.76	942.18	14	270.6	0.8	7	4063	2491
8	Kosukundu	78.0333	9.357	41.2	25.99	55	9	0.24	75.02	74.4	14	197.4	2	7.2	799	490.2

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9	Mutharpatti	78.0519	9.3666	122	44	78	29	0.23	269	997	0	207	0	7.4	2265	880
10	Ramaswamipuram	78.05	9.3833	112	45.72	68	21	0.23	141.8	57.79	0	475.8	0.1	7.1	1291	768.6
11	Chinnathummakundu	78.0666	9.3833	30	55.17	575	5	0.18	429.58	526.67	10	661	1.2	7.1	3365	2674
12	Lakshmiapuram	78.0333	9.3833	97.2	15.48	16	15	0.15	75.08	53.3	10	282.8	1.2	7.1	822	478
13	Kanmaipatti	78.0166	9.3833	158	88.25	274	26	0.19	273	713.82	10	417	0.8	7.1	2980	2051.8
14	Koppunayanpatti	78.0333	9.408	38	31.83	102	70	0.24	245.24	103.75	14	295	0.4	7.3	1354	953.8
15	Vadhuvarpatti	78.0333	9.411	249.2	122.2	110	6	0.2	429.58	431.26	10	270.6	0.5	7	2758	1832.2
16	Sethurajapuram	78.0833	9.4166	75.6	31.83	23	8	0.16	32.54	157.88	14	173	0.12	7.3	791	484.4
17	Pandalgudi	78.0833	9.4166	200	47	93	17	0.24	411	989	0	281	0	7.7	2745	1188
18	Koppuchittampatti	78.155	9.407	61	43	38	11	0.21	43	990	0.26	366	24	7.9	1835	536
19	Maniyakkaranpatti	78.155	9.3333	302	265.3	940	10	0.23	103.4	1345	10	404.8	1.3	7.1	5901	5918
20	Surruppanayakanpatti	78.103	9.3333	215.6	28.91	49	20	0.21	174.34	62.47	10	205	3	7	1466	1081.9
21	Maravarperungudi	78.1666	9.3833	3	10	132	3	0.19	113	73	1.75	366	0	8.4	936	799
22	Pungamarathupatti	78.1666	9.3833	19	23	92	2	0.2	142	183	0.4	171	0	8.2	900	653
23	Mettlipatti	78.0833	9.3333	70	67.82	39	9	0.19	131.8	77.89	10	356	2.4	7	1210	728.1
24	Muthuswamipuram	78.1166	9.3166	38	26	635	110	0.24	440	475	0	720	48	7	3480	2715

2.2. Materials and methods

Twenty four average representative groundwater samples from both open wells and dug wells collected during both pre monsoons and post monsoons periods during 2014 were analyzed by adopting the standard analytical procedure (APHA, 1998). Moreover, well inventory details such as location, geology, well shape and dimensions and depth of water table were also observed, while collecting the samples Physical parameters pH, TDS and EC, cations Ca^{2+} , Mg^{2+} , Na^+ and K^+ , anions HCO_3^- , SO_4^- , Cl^- , F^- and NO_3^- of the groundwater samples were analyzed. The estimated parameters of water quality study such as TH, NCH, Na%, EC, SAR, PI and TDS (Ragunath, 1996) are compared with experimental results of 12 parameters for characterization of groundwater quality.

The GIS based geospatial iso quality contour maps by using Arc GIS 10.1 software, for the integrated parameters of cations $\text{Ca}^{2+} - \text{Mg}^{2+}$, $\text{Na}^+ - \text{K}^+$ and anions $\text{HCO}_3^- - \text{SO}_4^- - \text{Cl}^-$ are prepared by IDW interpolation technique and overlay analysis. Statistical evaluation of Multiple Correlation, PCA and Cluster analysis of groundwater quality parameters were carried out by using geo statical computer software programme by PAST. A computer programmed Aquachem. 4.0 was used for calculation and graphical representation of Gibbs, Piper and USSL diagrams. The characterization of groundwater qualities of the study area is compared with BIS (2012) and WHO (2011) drinking water standard and other standards of livestock (Ramakrishnan 1998) use and irrigation purposes (Richard 1954).

3. RESULT AND DISCUSSION

The average values of the analytical result of 12 parameters of 24 averages water samples of both pre-monsoon and post-monsoon are given in (Table. 2). The integrated parameters of $\text{Ca}^{2+} - \text{Mg}^{2+}$ and $\text{Na}^+ - \text{K}^+$, HCO_3^- , SO_4^- and Cl^- are taken into consideration for the GIS based spatial evaluation study. The other parameters such as F^- , NO_3^- , EC, TDS and pH are smaller in values. So, they are not considered for drawing iso-spatial maps.

3.1. Calcium and Magnesium

The analytical data onto the study area show the Ca^{2+} and Mg^{2+} contents varying from 3mg/l to 940mg/l and 10mg/l to 457mg/l respectively. The concentration of calcium in groundwater depends on the solubility of CaCO_3 , SO_4^- and rarely Chloride (Biswajeet Pradhan and Saied Pirasteh, 2011). Magnesium is known to occur naturally to magnesium bearing minerals in the rocks (Gnanachandraswamy et al, 2014). The spatial distribution of integrated $\text{Ca}^{2+} - \text{Mg}^{2+}$ maps (Fig. 2a) indicate that Ramalingapuram, Ramaswamipuram, Koppuchittampatti, Ayankarisalkulam and Maniyakkaranpatti wells show higher concentration (above 100ppm) of $\text{Ca}^{2+} - \text{Mg}^{2+}$ level in the study area. Dissolution of calc-granulite, crystalline limestone and weathering of other calc-alkaline metamorphic rocks such as Hornblende-biotite-gneiss, charnockite, granite and black soil causes for $\text{Ca}^{2+} - \text{Mg}^{2+}$ sources in the groundwater. This has been supported by many researchers (Garrels, 1976; Lakshmanan et al, 2003; Al-katheeri et al, 2009; Semwal and Jangwam, 2009; Chandrasekhar Reddy et al, 2012; Ayyandurai et al. 2011; Kaliammal and Udayanapillai, 2016).

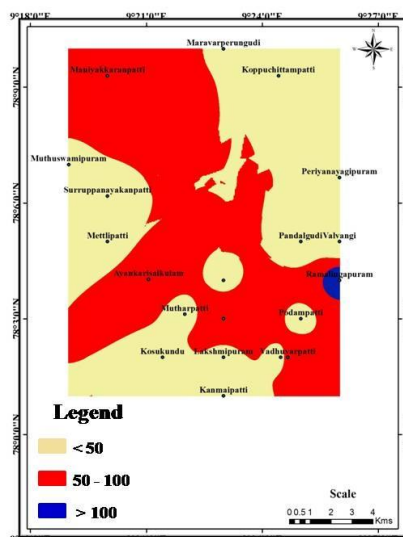


Fig2a. Integrated spatial distribution map of the Calcium and Magnesium

3.2. Sodium and Potassium

The analytical result of Na^+ and K^+ contents of the samples vary from 13 mg/l to 940mg/l and 2mg/l to 110 mg/l respectively. Sources of Na^+ are generally from halite, sea spray, hot spring, brine and some silicates or rare minerals such as (Nahcolite) (Ghorabha and Khan, 2013). But Na^+ and K^+ sources in the study area is due to from the weathering of Na^+ and K^+ rich feldspar, hornblende, aegirine-augite and clay minerals montmorillite and Illite derived from the source rocks such as khondalite, charnockite, granite and black soil respectively. The spatial distribution integration map of Na^+ and K^+ (Fig. 2b) illustrate Ayankarisalkulam, Ramalingapuram, Sarruppanayakanpatti, Muthuswamipuram, Maniyakaranpatti and Chinnathummakundu villages which show higher concentration $\text{Na}^+ - \text{K}^+$ content (> 50) level in the study area.

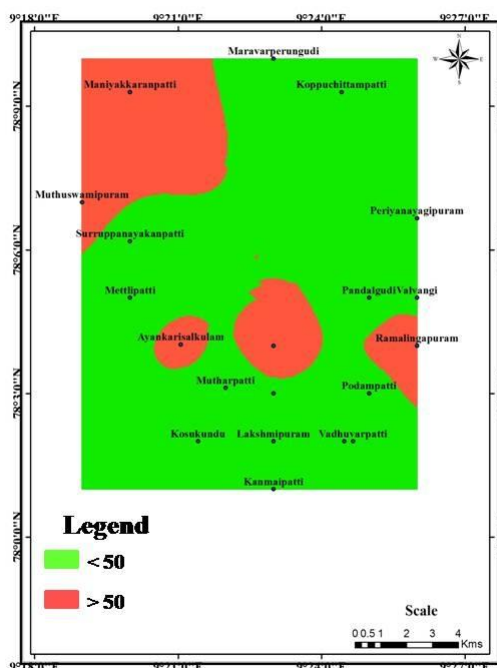


Fig2b. Integrated spatial distribution map of the Sodium and Potassium

3.3. Bicarbonate, Sulphate and Chloride

The concentration HCO_3^- , Cl^- and SO_4^- contents in the samples vary from 171mg/l, 38.62mg/l and 32.54mg/l to 720mg/l, 990mg/l and 4013mg/l respectively. Sources of bicarbonate are obtained from the minerals calcite, dolomite and aragonite etc and the prime contributing rocks are crystalline limestone, calc granulite and calcrete. The dissolving Ca^{2+} and HCO_3^- ion from groundwater derived

from the sources rocks of calc-alkaline igneous rocks form calcrete by evapotranspiration process (Udayanapillai et al, 2014). So, the occurrence of more calcrete deposits to indicate the evidence that groundwater is generally more alkaline in nature.

The higher Cl^- content of groundwater may be attributed by soluble chloride from rock, sea water ingress (Sridhar et al, 2013) and black soil (Lakshmanan et al, 2003). The Cl^- content of the study area is mainly obtained from rock sources and black soil. The sources of SO_4^- are generally obtained from the sulphur, sulphides, sulphates of heavy metals, gypsum, anhydrite and pyrite. Sulphate content of the study area is mainly obtained from rock sources. The integrated iso-quality geospatial maps of HCO_3^- , Cl^- and SO_4^- illustrate Ramalingapuram and Perianayakipuram villages which show higher HCO_3^- , Cl^- and SO_4^- content (> 500) levels in the study area (Fig. 2c).

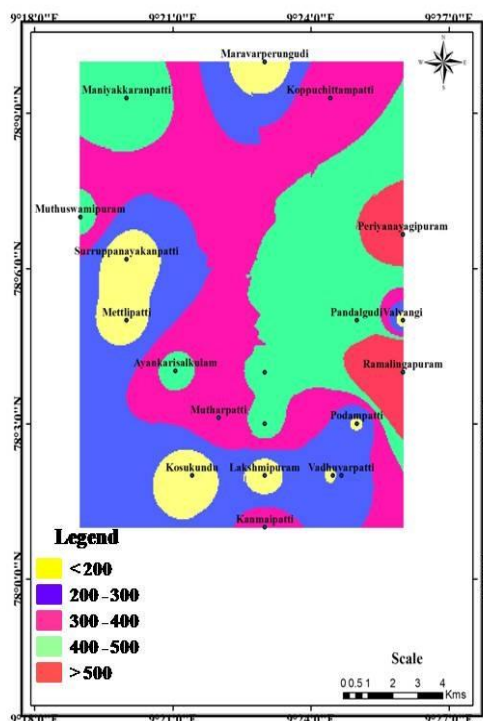


Fig2c. Integrated spatial distribution map of the Bicarbonate, Chloride and Sulphate

4. STATISTICAL EVALUATION

4.1. Multiple Correlations

Multiple correlations are a basic statistical tool to show the degree of dependency on geochemical variables with one another. It is commonly used to measure and establish the relationships between average variables. It also helps to distinguish the relevant hydro geochemistry facias. Numerous researchers have discussed the multiple correlation in geochemistry of groundwater (Hegde 2006; Srinivasamoorthy et al, 2010; Srivastava et al, 2012; Vandana Parth et al, 2011; Akpah et al, 2013; Gomaa et al, 2014; Emmanuel Morgan Attua et al, 2014; Asa Rani and Suresh Babu, 2008; Ameh, 2014; Belkhiri et al, 2011; Alhassan H. Ismail et al, 2015). The multiple diagonally symmetrical linear correlation matrices of Ca^{2+} , Mg^{2+} , Na^+ , K^+ , HCO_3^- , SO_4^- , Cl^- , F^- and NO_3^- , pH, EC and TDS of the study area samples are given in (Table. 3). Good correlations between the above variables are given in bold. The bivariate relation between the variable Ca^{2+} , Mg^{2+} vs EC, Na^+ , K^+ vs EC, HCO_3^- , Cl^- vs EC, Cl^- vs EC, Ca^{2+} vs Mg^{2+} and Na^+ vs K^+ generally show positive correlation (Fadoua Hamzaoui Azasa et al, 2009; Udayanapillai et al, 2012). The relationship of above variables in the study area also shows existing same positive correlation, except HCO_3^- vs EC, which shows a very low degree of insignificant negative correlation ($r = -0.09$). The Na^+ and K^+ are mainly obtained from the weathering of calc-alkaline group of rocks and carbonate sources are mainly obtained from the per alkaline group of rocks. The correlation studies between TDS vs Na^+ , Ca^{2+} , Mg^{2+} shows positive correlations which indicate that the combined operation of chemical weathering, groundwater movement and river basin recharge controlled the chemistry of groundwater in the study area.

Table3. The multiple correlation matrix of water quality parameters

1	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	F ⁻	Cl ⁻	SO ₄ ⁻	HCO ₃ ⁻	NO ₃ ⁻	pH	EC	TDS
Ca ²⁺	1											
Mg ²⁺	0.919	1										
Na ⁺	0.610	0.770	1									
K ⁺	0.449	0.327	0.380	1								
F ⁻	-0.001	0.004	0.102	0.277	1							
Cl ⁻	0.932	0.857	0.587	0.508	-0.055	1						
SO ₄ ⁻	0.162	0.272	0.418	-0.036	0.283	-0.002	1					
HCO ₃ ⁻	-0.338	-0.199	0.305	0.096	-0.060	-0.223	0.026	1				
NO ₃ ⁻	-0.160	-0.124	0.222	0.362	0.270	-0.062	0.137	0.518	1			
pH	-0.081	-0.068	-0.143	-0.262	-0.096	0.048	0.022	-0.161	-0.047	1		
EC	0.939	0.951	0.812	0.480	0.033	0.925	0.299	-0.094	0.007	-0.047	1	
TDS	0.895	0.962	0.884	0.448	0.029	0.869	0.276	-0.028	0.006	-0.083	0.979	1

4.2. Principal Component Analysis

Because of the demand for a rapid and simultaneous comparison and correlation between all the chemical variables, PCA has been utilized by many early researchers, in groundwater studies (Anderson 1958; Wilks 1963; Chachadi and Mahapatra 1983). Many subsequent research works have also been discussed by many authors of the 21st century (Prashant K. et al, 2015; Sridhar Kumar et al, 2014; Usman Nasiru Usman et al, 2014; Srivastava Yehia Ahmed Idris, 2013). The assumptions of PCA are mainly based on linearity, importance of mean and co-variance, dynamics of large variances and orthogonal lines of best fit to the data. The Eigen value, percentage of cumulative variance and component loading scores are the important function of PCA analysis. The PCA has been performed by using basic computer programme "PAST". The Eigen value, % of total variance, % of cumulative variance and selected 4 principal component loading scores values of parameter of the study area are given in (Tables. 4a-b).

Table4a. Principal components Eigen values variances cumulative variances

PC	Eigenvalue	% Variance	Cumulative variance	PCA Component
1	5.6555	47.13	47.13	I EC + TDS
2	2.0408	17.01	64.137	II SO ₄ ⁻ + EC
3	1.2432	10.36	74.498	III HCO ₃ ⁻ + EC + TDS
4	1.1555	9.63	84.127	IV SO ₄ ⁻ + Na ⁺ + TDS + Cl ⁻
5	0.9438	7.87	91.992	
6	0.4291	3.58	95.568	
7	0.3147	2.62	98.19	
8	0.1435	1.19	99.386	
9	0.0452	0.38	99.763	
10	0.0265	0.22	99.984	
11	0.0014	0.01	99.996	
12	0.0001	0.0009	99.996	

Table4b. Component loading score for 4 Principal Components

PC	Parameters	Component loading score PC 1	Component loading score PC 2	Component loading score PC 3	Component loading score PC 4
1	Ca ²⁺	-2.04	0.03	-0.10	-0.35
2	Mg ²⁺	-2.58	-0.02	-0.07	-0.04
3	Na ⁺	-1.87	-0.28	-0.27	0.44
4	K ⁺	-2.71	-0.10	0.01	-0.06
5	F ⁻	-2.96	-0.04	-0.03	-0.02
6	Cl ⁻	-1.03	-0.10	-0.57	-0.80
7	SO ₄ ⁻	-0.43	2.02	-0.06	0.58
8	HCO ₃ ⁻	0.15	-0.80	1.69	0.15
9	NO ₃ ⁻	-2.94	-0.03	-0.02	-0.01
10	pH	-2.89	-0.05	-0.01	-0.02
11	EC	12.37	0.70	0.32	-0.39
12	TDS	6.95	-1.30	-0.86	0.56

The scree plot based on PCA and components and Eigenvalues with variances are given in (Fig. 3). Many authors represent the scree plot of physico-chemical parameter of groundwater chemistry (Ayeni and Soneye, 2013; Alhassan H. Ismail et al, 2014). It could be observed from the table 4 that percentage of variance contribution to 4 PCA components are having the variance between 47.13%, 17.01%, 10.36% and 9.61% respectively. The principal component factors are selected above the

value of 1.0 Eigen values. Cumulatively, the 4 PCA components account for 84.13% of total variance. From the component loading on the parameter (Fig. 3), it could be seen that each component is primarily associated with only a few parameters and they are given as follows; I Component – EC + TDS; II Component – SO_4^- + EC; III Component – HCO_3^- + EC and TDS; IV Component – SO_4^- + Na^+ + TDS and Cl^- . The first principal component weighed on positive direction of variable axis with the positive loading score of 12.37 and 6.95 for the parameters EC and TDS respectively. This contributes maximum 47.13% of total variance between the parameter. The second PCA component accounts for 17.01% of variance and is loaded onto SO_4^- and EC with positive component loading values 2.02 and 0.70 respectively. The third PCA components contribute to the variance between 10.36% and are loaded into the parameters of HCO_3^- , EC, TDS and Cl^- with highest positive and negative loading values of 1.69, 0.32, -0.86 and -0.57 respectively. The fourth PCA component accounts for the variance between 9.63% and is loaded with parameters of SO_4^- , TDS, Na^+ and Cl^- with the loading value of 0.58, 0.56, 0.44 and -0.8 respectively.

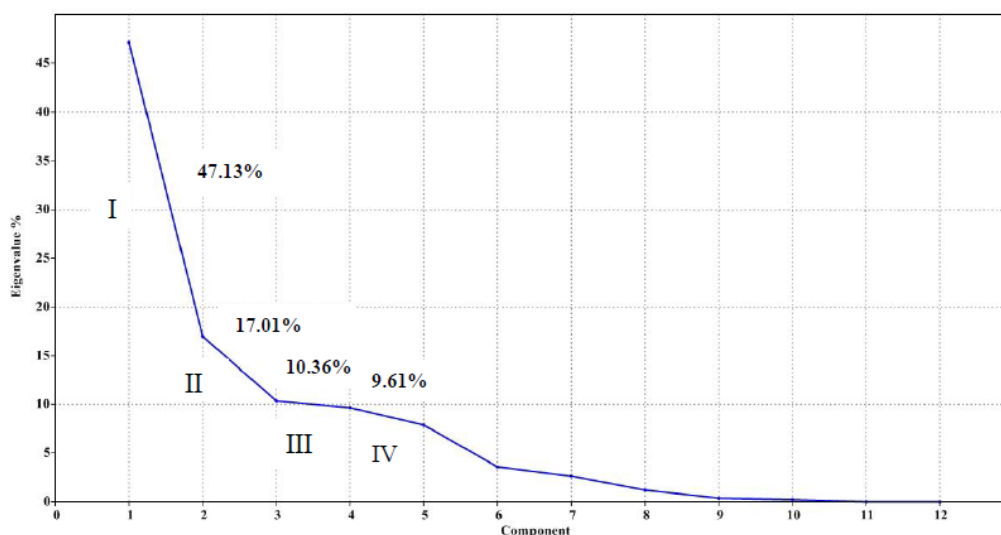


Fig3. Scree plot of PCA components

4.3. Cluster Analysis

Cluster analysis is a statistical technique which is used to classify cases of groups that are relatively homogenous within themselves and heterogeneous between each other, on the basis of a defined set of variables. These groups are called as clusters. When compared to principal component analysis, it is observed that PCA loading gradually decrease in each component and does not provide a direct relation to any other ion or two set of individual families. But cluster analysis points out a direct relation between parameters. Using diagonally symmetrical correlation matrices and arithmetic averaging of correlation coefficient, cluster analysis has been performed using the methodology by (Davis 1973). Many subsequent researchers discussed the cluster analysis of geochemical parameters of groundwater's in 21st century (Usman Nasiru Usman et al, 2014; Yehia Ahmed Idris, 2013; Prashant K. Srivastave et al, 2015; Petr Praus, 2007; Gomaa et al, 2014; Alhassan H. Ismail et al, 2015). The cluster analyses of geochemical parameters of the study area are performed for 2 purposes of study, such as;

1. Ionic clusters concentration on the elements of geochemistry of groundwater
2. Aerial grouping of cluster of concentration of elements of the groundwater samples in the study area.

The following average parried groups of ionic clusters of geochemical parameters is obtained in the present studies

Ionic cluster	Similarity or correlation coefficient of cluster
1. SO_4^- , F, K^+ , Na^+	- 0.20
2. TDS, EC, Mg^{2+} , Ca^{2+} , Cl^-	- 0.90
3. NO_3^- , HCO_3^-	- 0.50
4. pH	- 0.05

The hierarchical tree cluster or dendrogram of ionic concentration of geochemistry of groundwater is shown in the diagram (Fig. 4a) and the degree of similarity or significance is established as the low negative values of -0.44. The aerial grouping distribution of elemental concentration of geochemical parameters of groundwater samples of the study area is shown in the dendrogram, through Ward's minimum variance method or Euclidean method (Fig. 4b). The aerial distribution dendrogram shows the following four kinds of cluster which are as follows;

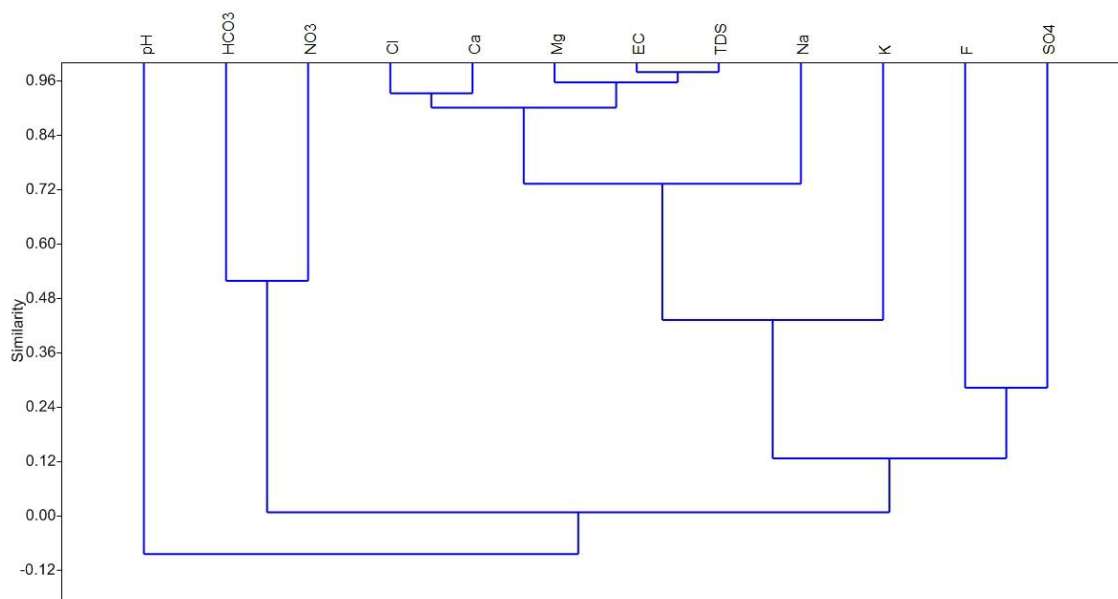


Fig4a. Dendrogram of ionic concentration of groundwater of the study area

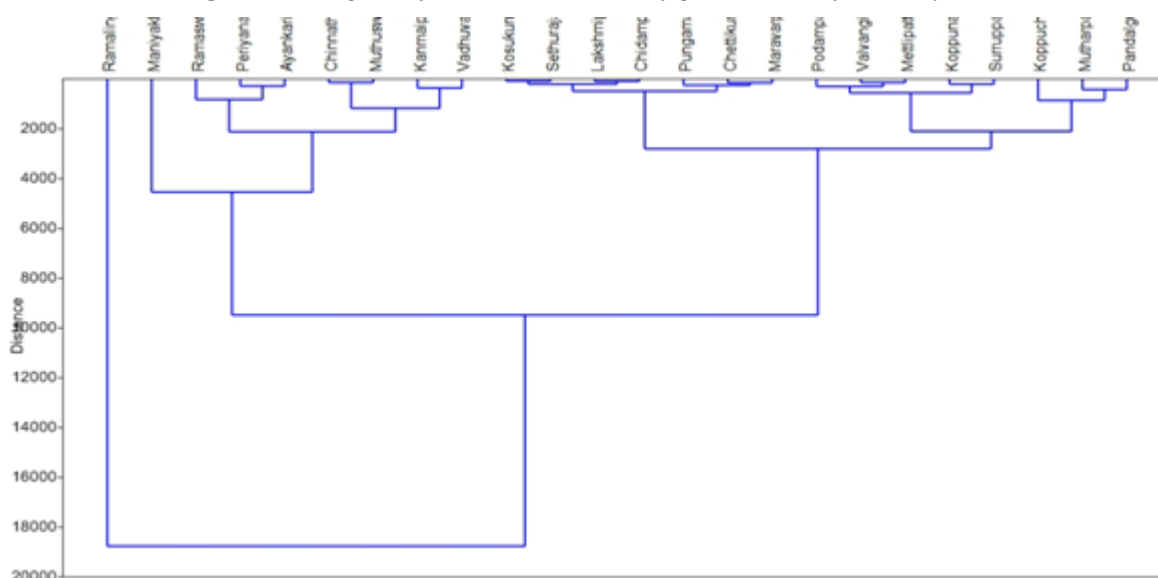


Fig4b. Aerial distribution of dendrogram cluster of geochemistry of groundwater

First cluster includes the sample locations of Koppuchittampatti, Mutharupatti and Pandalgudi villages. The second cluster consists of the sample locations of Podampatti, Valvangi, Mettlipatti, Koppunayakanpatti, Soruppanayakanpatti. The third cluster involves the sample locations such as Kosukundu, Sethurajapuram, Lakshmipuram, Chidambarapuram, Pungamarathupatti, Chettikurchichi and Maravarpaerungudi. The fourth cluster consists of the sample locations of Ramalingapuram, Maniyakaranpatti, Ramaswamipuram, Periyanaayagipuram, Ayankarisalkulam, Chinnathummakundu, Muthuswamipuram, Kanmaipatti and Vaduvarpatti villages.

4.4. Gibbs Mechanism

The mechanism controlling groundwater chemistry proposed by Gibbs (1970), established the close relationship between aquifer and water composition. This is established with cations and anions of groundwater such as $Cl/Cl^- + HCO_3^-$ vs TDS and $Na^+ + K^+/Na^+ + K^+ + Ca^{2+}$ vs TDS. The cations and

anions Gibbs diagram (Fig. 5a-b), for the average value of two seasons indicates the combined rock dominance and evaporation and crystallization dominance characters of mechanism that control the groundwater chemistry.

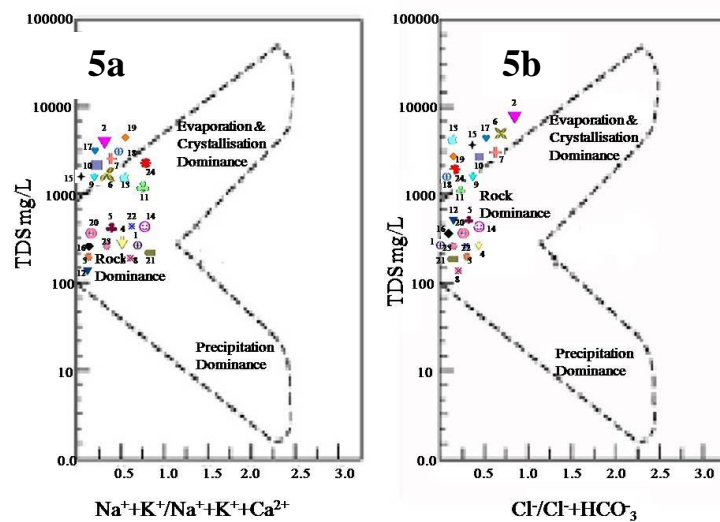


Fig5(a-b). Gibbs plots cations and anions for the average values of two seasons

Numerous researchers have observed such illustration of Gibbs mechanism from various regions (Masoud Eid AL-Ahmadi 2013; Srinivas et al., 2014; Ramesh and Thirumangai 2014; Senthilkumar et al., 2014; Udayanapillai et al., 2012 and 2014). The high TDS concentration indicates that there is a limited dilution process by soil leaching by surface water or meteoric water. The presence of more thickness of regolith calcrete profile in the study area also proves that evapo-transpiration and evaporation of groundwater is activity involved under tropical climate condition.

4.5. Piper Diagram

Piper diagram is widely used to understand problem of the geochemical faces of groundwater chemistry. The average values of cation and anions for two seasons plotted on the respective triangle field (Fig.6) are projected in the diamond shaped field by using the software (AquaChem 4.0)..

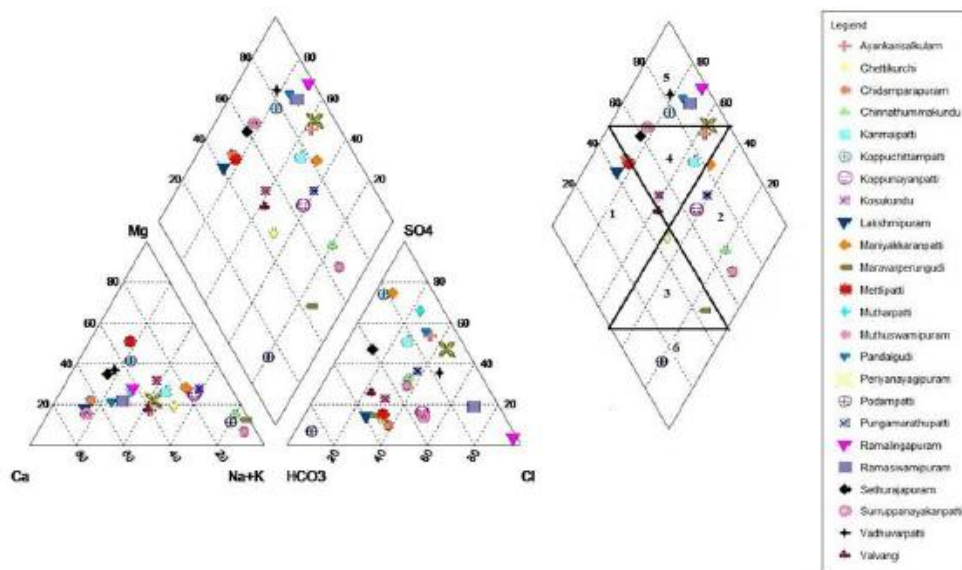


Fig6. Piper plots diagram in average value of the two seasons

The early researchers categorized the diamond shaped piper diagram into 9 geochemical facias (Hill 1999; Piper 1944; Walton 1970 and Dinesh Kumar and Singh 2010). Later, it is modified into 6 geochemical facias (Vasantha Vihar et al., 2010; Ahmed Al-ameri et al., 2012; Ghoraba and Khan 2013; Jafar Ahamed 2013 and Senthilkumar et al., 2014). The geochemistry of groundwater of the

study area falls on the sub division of 5, 4, 2, 1,3 and 6 of diamond field indicates that CaCl (29%), Mixed CaMgCl (20%), NaCl (20%), CaHCO₃ (16%), Mixed CaNaHCO₃ (8%) and NaHCO₃ (4%) are important geochemical facias. Among the above 6 sub divisions, the predominance facias of groundwater of the study area are CaCl (29%), Mixed CaMgCl (20%) and NaCl (20%) types.

4.6. Groundwater Quality Assessment

Early researchers discussed the chemical quality standards for drinking, (BIS 1991; WHO 1973), livestock uses (Ramakrishna 1998) and irrigation uses (USDA diagram-Todd 1959). Subsequent research on the chemical quality of the study area is discussed related to the drinking water qualities standard (WHO, 2011; BIS, 2012) livestock standard (Ramakrishna 1998) and irrigation standard (Richards, 1954 and Wilcox, 1995 and Saharam Ashraf et al., 2011). Drinking water qualities of groundwater of the study area generally show within permissible limit of BIS and WHO, except serial number (1, 3, 4, 5, 7, 8, 9, 12, 13, 14, 15, 16, 17, 18, 20, 21, 22 and 23) which shows higher concentration than the permissible limit of WHO standard. Livestock use of water quality based on TDS (Ramakrishna 1998) is given as follows, Below 2500mg/l TDS – Fair; Below 3500 mg/L TDS – Poor; Above 4500 mg/L TDS – Not satisfactory, As per the above classification, 75% of the study area is having low TDS which shows more suitable for live stock uses.

4.7. Irrigation and Agricultural Quality

The concentration of Na⁺ is very important to classify the irrigation purpose. If the water rich in sodium is applied to soils, some of the sodium is taken up by clay which is in exchange gives up calcium and magnesium, thereby decreasing the permeability of the soil and it has a great effect of on plant growth (Shahidullah et al., 2000; Sadashivaiah 2008; Pradhan and Chandrasekharan 2009; Prabakaran et al., 2012; Erum Bashir et al., 2013; Shah and Mistry 2013) Sodium Adsorption Ratio (SAR) gives a clear idea about the adsorption of sodium by soil and the same has been calculated by using the following formula

$$SAR = \frac{Na}{[(Ca + Mg)/2]^{1/2}} \tag{1}$$

Where all ion concentration is expressed in EPM.

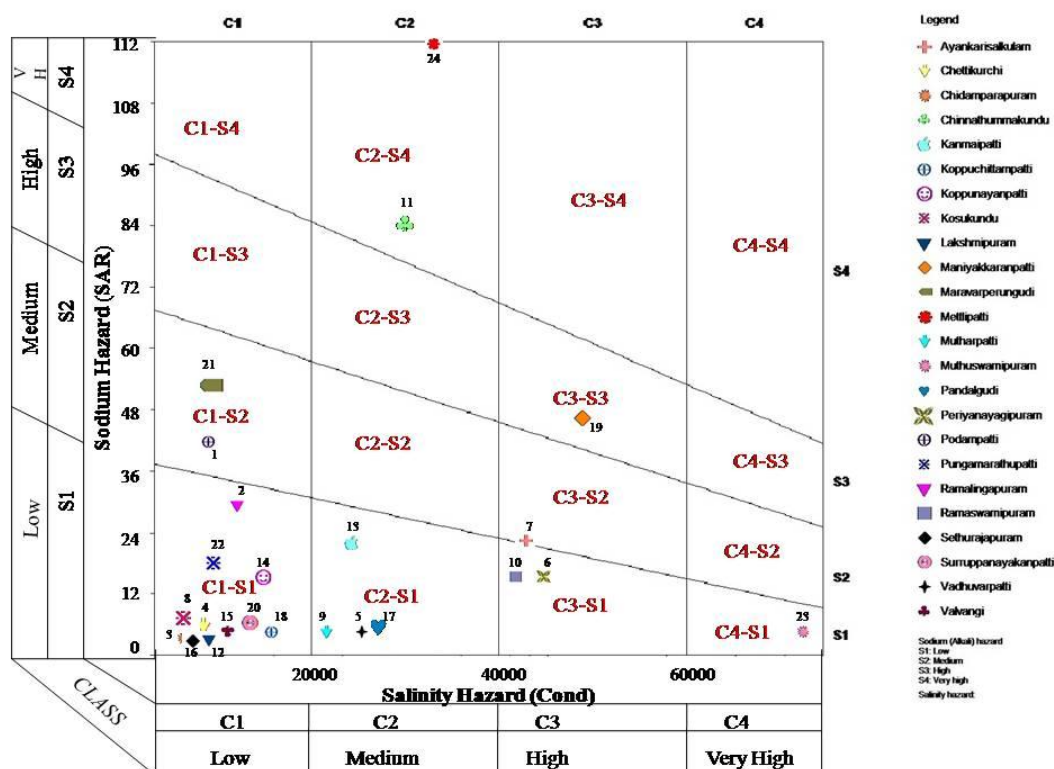


Fig7. USDA diagram plots in average value of the two seasons (Richard 1954)

The Sodium Adsorption Ratio (SAR) parameter evaluates the Sodium hazard in relation to Calcium and Magnesium concentration. SAR values ranges of 2.13 to 112.2, in the study area. The values greater than two indicate that ground water is unsuitable for irrigation purpose (Tatawat and Singh Chandel 2007; Rosalin Das et al., 2012; Ayuba et al., 2013). Only 9 ground water samples of this study area are showing higher SAR values, which are unsuitable as sources of water for irrigation. The utility of U.S Salinity diagram for (Fig. 7) irrigation is discussed by numerous researchers (USSL 1954; Sharaky et al., 2007; Umopathy 2011; Tripathi et al., 2012; Ahmed Al-ameri 2012; Kaveh Pazand and Ardeshir Hezarkhani 2012; Ikbal Husain et al., 2013). The average data plotted for two seasons of the study area indicate that 11 wells fall in C₁-S₁ and 2 wells fall in C₁-S₂ – excellent water quality, 4 wells in C₂-S₁ and 2 wells in C₂-S₄ – good water quality, 3 wells in C₃-S₁ and 1 well in C₃-S₃ – fair water quality and 1 wells in C₄-S₁ – bad water quality. The data plotted for the study area indicates that maximum water samples of the study area have excellent to good quality water for irrigation.

4.8. Sodium Percentage

Sodium in soil is considered as vital for determining groundwater suitability for irrigation purpose, because sodium reacts with soil to reduce its permeability and support little or no growth (Ayuba et al. 2013). Sodium salts in soil, besides affecting the growth of plants directly, also affect soil structure, permeability and aeration which directly assail plant growth (Singh et al. 2008).

The sodium in irrigation waters is usually denoted as percent sodium (Kumaresan and Riyazuddin 2006; Dinesh Kumar Tank and Singh Chandel 2010; Prabaharan et al., 2012; Rosalin Das et al., 2012; Erum Bashir et al., 2013) and can be determined using the following formula

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

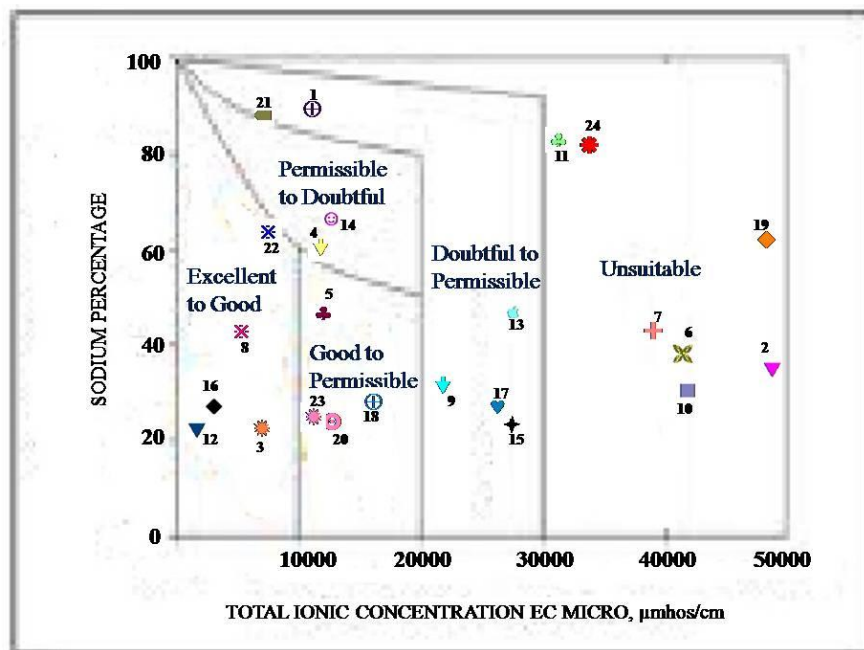


Fig8. Plot of the Sodium percentage and EC average value of the two seasons

The Na percentage of the study area ranges (Fig. 8) from 21.57% to 92.08%. Na percentage greater than 35% in ground water is unsuitable for irrigation (Ayuba et al. 2013). Ground water samples 3, 12, 15, 16, 17, 18, 20 and 23 of the study area are unsuitable for irrigation purpose, whereas all other samples are suitable for irrigation purposes. In general, 67% of samples are suitable for irrigation purposes.

4.9. Wilcox Diagram Result

In the WILCOX diagram 1955, Electrical Conductivity and Sodium Percentage are used to classify the water for agricultural utility. Agricultural utility of groundwater sample based on Wilcox diagram plot, in various areas are discussed by numerous researchers (Kumaresan and Riyazuddin 2006;

Sharaky et al., 2007; Sadashivaiah et al., 2008; Tatawat and Singh Chandel 2008; Dinesh Kumar Tank and Singh Chandel 2010; Umopathy 2011; Kaveh Pazand and Ardeshir Hezarkhani 2012; Rosalin Das et al., 2012; Ahmed Al-ameri et al., 2012; Tripathi et al., 2012; Ayyandurai et al., 2013; Iqbal Husain et al., 2013; Sridhar et al., 2013; Srinivas et al., 2014). This average data plot of study area for two seasons reveals that out of 24 samples, 5 water samples falling on the excellent to good, 4 Samples are falling on good to permissible, 3 samples are falling on permissible to doubtful limit, 5 samples fall in doubtful to permissible limit and 7 samples fall in unsuitable field to permissible. In general, all the samples are suitable for agricultural utility. Groundwater quality can be more enhanced for livestock and irrigation and drinking water uses by river basin recharge, land use pattern plan for impounding of water in ayacuts, construction of percolation ponds and canals making from major rivers, constructions of series of check dams in the major drainages and rainwater harvesting.

5. CONCLUSIONS

The study area is a hard rock crystalline terrain which consists of calc alkaline group of rocks such as Hornblende-biotite gneiss, charnockite, granite and per alkaline group of rocks such as crystalline limestone and calc granulites. The GIS based evaluation of geochemistry of groundwater illustrated groundwater quality distribution of the study area. Statistical evaluated through correlation, PCA and cluster analysis illustrates the association of geochemical parameters and its areal distribution concentration in the study area. Gibbs mechanism reveals evaporation and rock dominance character controlling water chemistry. Geochemical evaluation through Piper analysis shows the predominance of CaCl (24%), mixed CaMgCl (20%) and NaCl (20%) rich faces. Groundwater samples generally show within the permissible limit of BIS and WHO drinking water standard except pH and Cl⁻. Based on USDA standard 67% of samples are suitable for irrigation purposes. Groundwater quality may be enhanced by river basin recharge land use pattern plan, construction of check dam in river, construction of percolation ponds and rain water harvesting in the weathered zone of hard rocks.

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