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EVALUATION OF GROUNDWATER QUALITY USING MULTIVARIATE STATISTICAL TECHNIQUES AND GIS - A CASE STUDY

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ABSTRACT

This study deals with the evaluation of spatial variations in the groundwater quality in Rajam, Srikakulam district, Andhra Pradesh, India. The significant physicochemical parameters such as pH, conductivity, total dissolved solids, chlorides, total alkalinity, calcium hardness, magnesium hardness and sulphate were assessed. Pearson's Correlation technique, box plot, multivariate statistical tools such as cluster analysis and principle component analysis were applied to groundwater quality analysis. The groundwater samples were assessed for its applicability in irrigation and drinking purposes and geographic information system techniques are used for mapping consequence. The parameters analyzed were compared with Bureau of Indian Standards (BIS) and WHO standards. Box plot analysis revealed that total dissolved solids and electrical conductivity was strongly correlated. Correlation analysis reveals that pH shows weak correlation ($r<0.5$) with chlorides ($r>0.383$). Electrical Conductivity shows strong correlation ($0.7<r<0.9$) with Alkalinity ($r>0.886$) and Total Hardness was moderately correlated ($0.5<r<0.7$) with Mg ($r>0.544$), Cl ($r>0.543$), Su ($r>0.508$), but strongly correlated with TDS ($r>0.863$). Whereas Mg ($r>0.544$), Cl ($r>0.543$) and SO_4 ($r>0.508$) was moderately correlated with Total Hardness (TH). SO_4 was moderately correlated with Mg ($r>0.664$). Water quality index (WQI) for each sample was also determined. It is found that 3,5,18,19,20,21 well point samples are fit for drinking and most samples are having poor (50-100) quality for drinking. The data was analyzed with the help of Statistical tools and found that water samples are contaminated with the weathering of metamorphic rocks (charnockite, khondalite etc.,) present in the study area. Chlorinity

Index and Salinity Index are found to be in permissible limits and hence suitable for irrigation purpose.

Key words: Groundwater, Spatial Variations, Physicochemical parameters, Pricniple Component Analysis, Water Quality Index, Chlorinity Index, Weathering.

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1. INTRODUCTION

Water is a life-preserving resource for all the living organisms and also other advancements in the world. In developing countries like India, the demand for water has increased immensely during the recent years because of population increase, urbanization, industrialization and extraordinary rural exercises. Due to the deficient supply of surface waters, the majority of the general population in India is depending primarily on groundwater assets for drinking, mechanical and water system employments. Groundwater is the principal source that is usually utilized for drinking, agriculture purposes in both rural and urban territories. Some parts of the world face serious shortage issues of groundwater because consumption rate is greater than replenishing rate. Multitudinous extensive towns and numerous urban areas in India get water supply from groundwater for various uses through municipality water networks, furthermore from a huge number of private boreholes. Around one billion people are specifically needy upon groundwater assets in Asia alone and in India, majority of the populace is dependent on groundwater as the main wellspring of drinking water supply. Groundwater is believed to be much cleaner and pollution-free when compared to surface water. But in the present scenario, due to rapid industrialization, large quantities of industrial wastes and effluents are dumped out contaminating the groundwater. The quantity of dumping pollutants by the industries, sewage waste etc., is greater than the quantity of purification of the water. According to the latest appraisal of Central Pollution Control Board, nearly 29,000 million-liters/day of wastewater is generated from Class-I and class-II cities out of which about 45% (about 13000 MLD) is generated from 35 metro-cities alone. Only about 30% of the wastewater collection system exists through sewer line and about 7000 million liter/day can be treated through treatment plants that are present until now. Therefore there is a large gap between generation, collection and treatment of wastewater. Most of the uncollected and untreated water finds its way to nearby water bodies or percolates into ground thereby polluting the groundwater resources. Hence, there is a need for better management policies to maintain the quality of groundwater which can be determined by its physicochemical parameters. The water quality appraisal gives the clear data about the sub surface geologic environment in which the water presents [1]. A lot of misuse of ground water has enormously influenced its quality and amount.

In some parts of the world, heaps of studies have been carried out to evaluate the geochemistry of groundwater [2],[3],[4]. A research on hydrochemistry and groundwater standards of Singhari river basin of Chattapur district, Madhya Pradesh was carried out by Jain [5]. Kaushik et al. assessed the groundwater quality of Ambala and Nilokheri Cities in Haryana [6]. The evaluation of groundwater quality and its expediency for drinking and agricultural use in the coastal stretch of Alappuzha district in Kerala was done by Sarath Prasanth et al. [7]. Generally, for the assessment of groundwater resources, the analysis of hydro chemical and biological characteristics of groundwater is also important

[8],[9],[10],[11]. Several researchers proposed that the best representative tool is Geographic Information System (GIS) for the mapping of spatial variations in groundwater quality and to determine its suitability for drinking, agricultural and industrial needs [12],[13],[14],[15]. Hydrologic and geologic conditions have influence on change in the groundwater quality to great extent over a period of time [16]. Improper disposal of waste and garbage is another primary factor for groundwater pollution [17]. Several studies have been carried out on the application of GIS and multivariate statistical techniques to evaluate and representation of spatial variations in groundwater quality in best possible way [18], [19]. Evaluation of quality of groundwater using several techniques has been carried out in different study areas [20],[21],[22], [23],[24]. The quality of ground water can also be interpreted in terms of Water Quality Index (WQI) [18],[19], [25],[26],[27],[28].

From the exhaustive literature survey it has been identified that the use of GIS and Multivariate Statistical Analysis techniques for interpretation of groundwater quality for various purposes is good. So the present study is carried out to apply the GIS and Multivariate Statistical Analysis techniques to assess the suitability of groundwater quality for drinking and irrigation purposes in Rajam town of Srikakulam District of Andhra Pradesh, India. The major source of drinking water in the study area is the groundwater which is suspected to be contaminated by industries in and around.

2. MATERIALS AND METHODS

Study Area: Rajam town encompassing an area of about 27.65 km² has been selected as the study area. It is situated in the Srikakulam District, Andhra Pradesh State of India between 18.27^0N & 18.28^0N Latitudes and 83.38^0E & 83.40^0E Longitudes. The study area belongs to tropical climatic zone with average annual rainfall of 1123 mm. The weather conditions of the study area are 37°C, Wind SW at 14 km/h, 33% Humidity. Paddy, Sugarcane, Ground nut are the major crops that are cultivated mostly in the area. Gneiss, Kondalite, Charnockite and other metamorphic rocks are the Geological formations in the present study area.

Sample Collection and Analysis: The samples of groundwater are collected from 30 different wells in cleaned and sterilized polythene bottles, filled without air bubbles with preeminent care at each sampling site. Map of the Study area and the sampling point details are presented in Figure1. The samples collected were labeled carefully and transported to the laboratory. Double distilled water was used to prepare the reagents that were used for the experimentation. Later, the samples were analyzed for ten parameters such as pH, Total Dissolved Solids (TDS), Total Alkalinity (TA), Electrical Conductivity (EC), Total Hardness (TH), Magnesium (Mg), Calcium (Ca), Chloride (Cl), Fluorides (F), Sulphates (SO_4). According to the standard procedures, the physicochemical parameters are estimated.

Statistical Analysis: The obtained complex data matrices are analyzed by using the application of statistical tools to obtain the groundwater quality. It gives better idea of possible sources which show predominant impact on groundwater system. It also contributes the information of reliable handling of water systems. In the present study, the statistical analysis such as Multivariate Statistical Analyses (Principle Component Analysis, Cluster Analysis), were carried out using XLSTAT software and Boxplot designs were carried out using Minitab software (Ver.14.0). Box plots help in assessing and comparing the distributions. Based on its characteristics, variables and observations are portrayed using Cluster Analysis (CA). Similarity between the samples is given by Euclidean distance and the difference between the analytical values of the samples gives the distance. The information of whole data set parameters is given by Principle Component Analysis (PCA) which explains the variances of large set of inter correlated variables and modify them into uncorrelated principal components. The Pearson's correlation was carried out for correlation matrix between the parameters. Correlation coefficient (R^2) gives the percentage of variance between the dependent and independent variables. High correlation coefficient '1' represents a good relationship between the variables and correlation coefficient value of '0' represents no relationship between the variables.

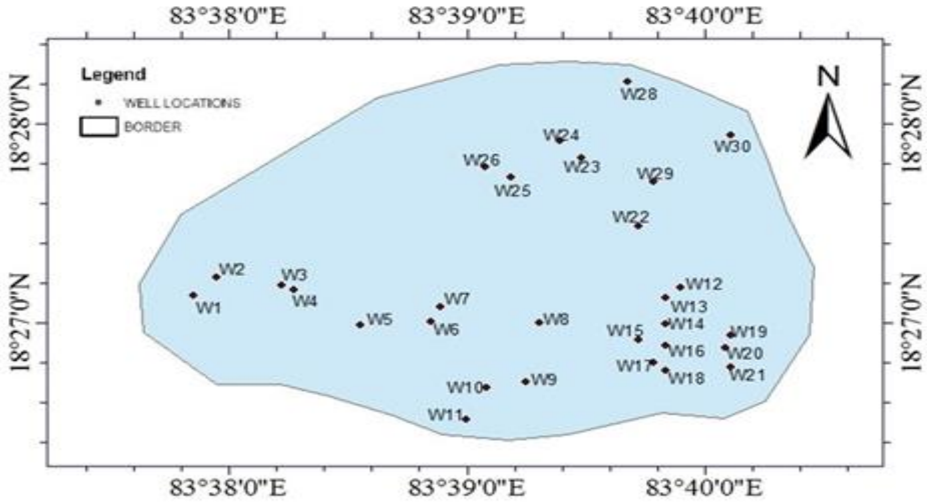

Figure 1 Map of study area

3. RESULTS AND DISCUSSION

The collected samples are analyzed for the presence of various physiochemical parameters and later they are compared with IS: 10500 (BIS-2012) [29] and WHO-2011[30] standards as shown in Table 1.

The usability of groundwater for drinking and irrigation purposes can be evaluated by comparing the obtained physicochemical parameters with the standards suggested by BIS: 10500-2012 and WHO-2011. The drinking water should be free from physical parameters such as odor, color etc. Also for irrigation purpose, the water should be free from excessive dissolved ions for the normal good growth of plants and crops.

For the low tolerant crops, the chlorine content in the water should be within the permissible limit. Hence, chlorine sensitivity is also determined by evaluating the chlorinity index. The chlorinity index for the study area is portrayed in Figure 2. All groundwater samples are found suitable for irrigation. (< 1000 mg /l).

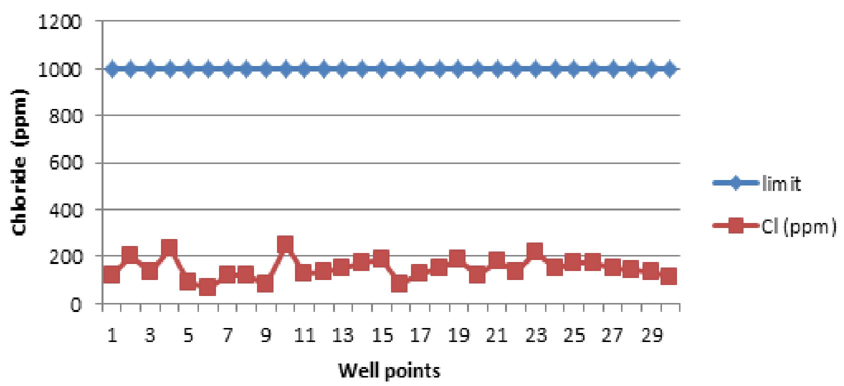

Figure 2 Chlorinity index at the study area (well points)

Table 1 Comparison of parameters with BIS (10500-2012) and WHO (2011)

Parameters	BIS (10500-2012)		WHO (2011)	Range of sample values obtained
	Acceptable Limits	Permissible Limits		
pH	6.5	8.5	7.5-8.5	7.23-8.38
Electrical Conductivity (µS/cm)	-	-	1500	537-1660
Total Dissolved Salts (ppm)	500	2000	500	225-400
Total Hardness (ppm)	200	600	200	335-585
Total Alkalinity (ppm)	-	-	120	153-299
Chlorides (ppm)	250	1000	250	67.45-244.95
Calcium (ppm)	75	200	75	23-76
Magnesium (ppm)	30	No relaxation	50	30-156
Sulphates (ppm)	200	400	250	7.15-11.84
Fluorides (ppm)	1	1.5	1.5	0.53-1.5

Similarly, salinity index is also evaluated by measuring the Electrical Conductivity (EC) values for assessing whether the water is suitable for irrigation purpose or not. Figure 3 gives the salinity index at the study area well points. According to Handa, (1969) [31], E.C values > 700 µS/cm are unsuitable for irrigation purposes. All our ground water samples are found suitable for irrigation (< 700 µS/cm) as shown in the plot. The spatial distribution of physicochemical analysis of collected groundwater samples are shown in Figure 4. Ramkumar *et al*. suggested that high concentrations of magnesium reduces the soil quality thus reducing the crops yield and also gives toxicity when it exceeds 50% of magnesium ratio [32].

Statistical Analysis: For the samples collected in study area, the box plots are drawn and are shown in Figure 5. From the figure it is observed that total hardness, total dissolved salts are dominating factors whereas magnesium, chlorides, alkalinity and calcium are observed as major ions in the sampling well points.

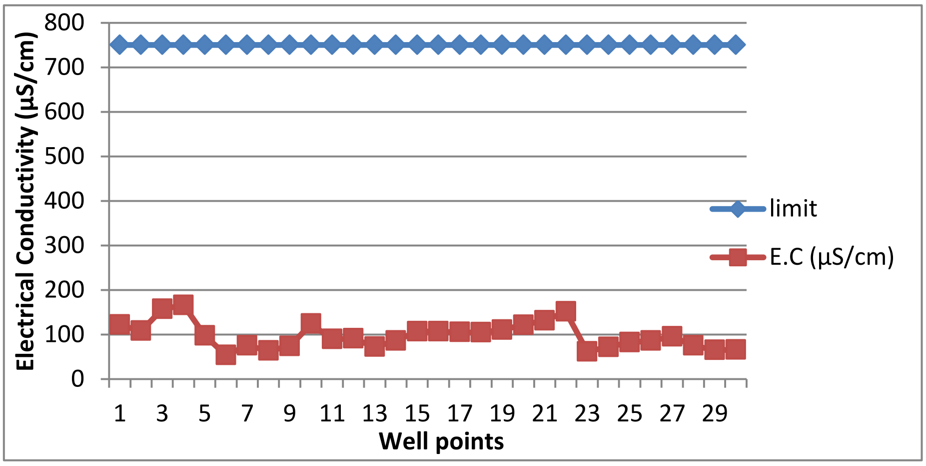

Figure 3 Salinity index at the study area (well points)

Correlation matrix: Table 2 presents the correlation values that are obtained at all the well points. The coefficient of correlation values are in the range of +1 to -1, which shows that there exists a strong relationship between the variables and near the value '0' shows that there exists no relationship between the variables. After performing PCA on all 30 samples, correlation matrix suggests that the correlation of pH shows weak correlation ($r<0.5$) with chlorides ($r>0.383$). Electrical Conductivity shows strong correlation ($0.7<r<0.9$) with Alkalinity ($r>0.886$) and Total Hardness was moderately correlated ($0.5<r<0.7$) with Mg ($r>0.544$), Cl ($r>0.543$), Su ($r>0.508$), but strongly correlated with TDS ($r>0.863$). Whereas Mg ($r>0.544$), Cl ($r>0.543$) and SO_4 ($r>0.508$) was moderately correlated with Total Hardness (TH). SO_4 was moderately correlated with Mg ($r>0.664$). According to Barr and Newland (1977) [33], three different sets of strong relationship exists between anions and cations in groundwater as follows:

(i) High competitive relationship between ions with same charge but different valence number.

(ii) High affinity between ions with same valency but different charges and

(iii) Noncompetitive relation between ions with same valency and same charge. Obtained results also demonstrate the same i.e., Magnesium is strongly correlated with sulphates and Calcium is weakly correlated with Fluorides

Multivariate analysis: Praus (2015) [34] proposed that, in order to reduce the loss of data and to reduce the data into manageable data sets, multivariate analysis like Principle Component Analysis (PCA) and Cluster Analysis can be used for monitoring of groundwater. In order to evaluate different variables and the relation between them, PCA can be done as proposed by Kuppusamy and Giridhar (2006) [35]. Eigen values are determined and are shown in Table 3. A graph of Eigen values vs cumulative variability is shown in Figure 6. In order to explain the source of variance in the data, the principal components are extracted based on the criteria, whose eigen values are greater than 1 and are given in Table 4. Principal Component PC1 alone contributed to 32.401% of total variance, PC2 contributed to 54.688% of total variance, PC3 contributed to 68.073% of total variance and PC4 contributed to 79.897% of total variance. Based on the above contributions Magnesium, Calcium, Chlorine ions are found to be predominant which may be occurred due to weathering of metamorphic rocks present in the study area.

Based on the similarity of responses to several variables, the cases are grouped using the cluster analysis. Figure 7 demonstrates the dendrogram of water quality parameters depending on the distance between the variables and their positions. The cluster analysis suggests that Total Hardness, Chloride, pH, Magnesium and TDS belong to same cluster. Whereas Mg and SO_4 are in same cluster and Chloride, Electrical Conductivity, Alkalinity belongs to same cluster of properties.

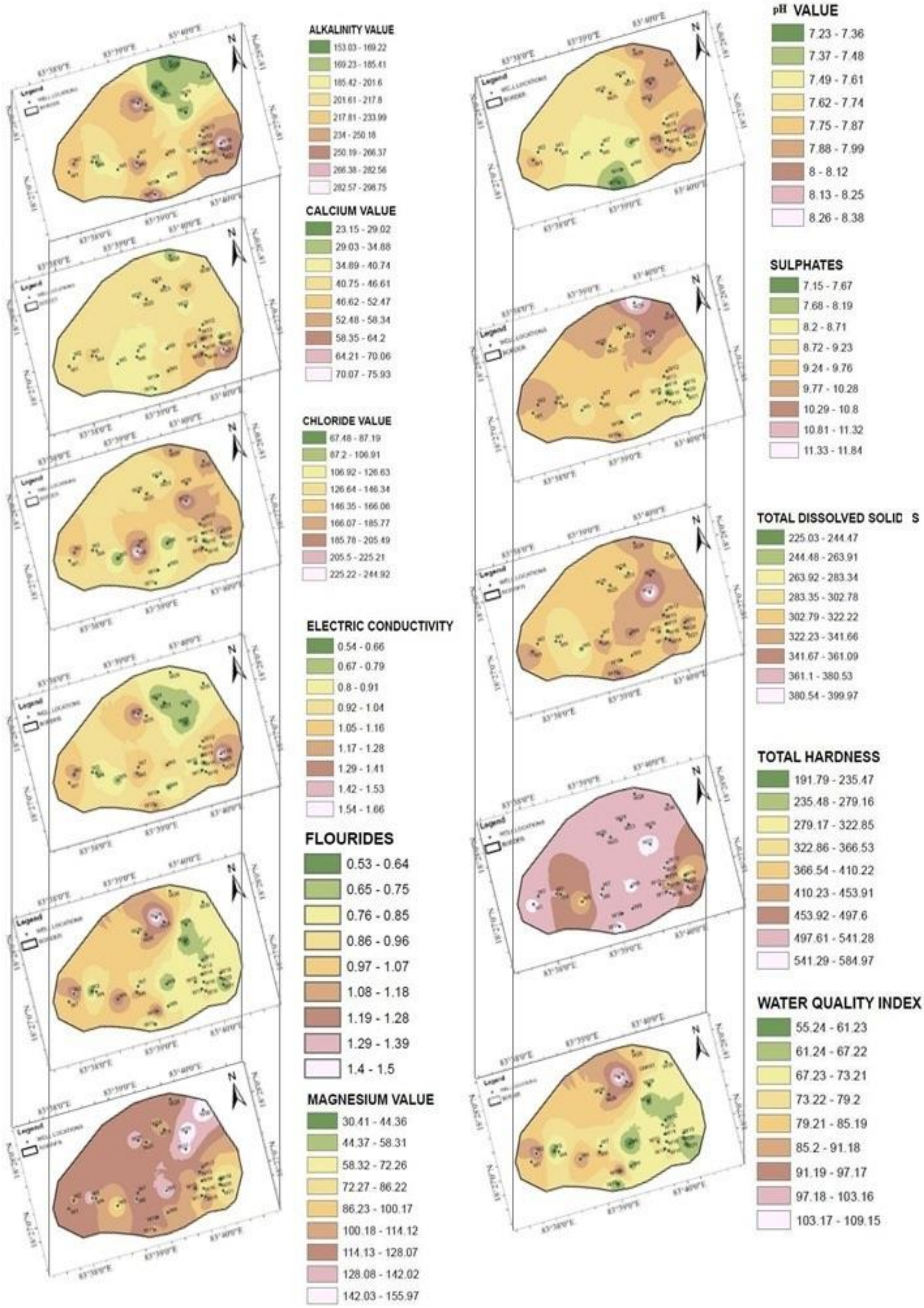

Figure 4 Spatial distribution of physicochemical analysis of collected groundwater samples and water quality index

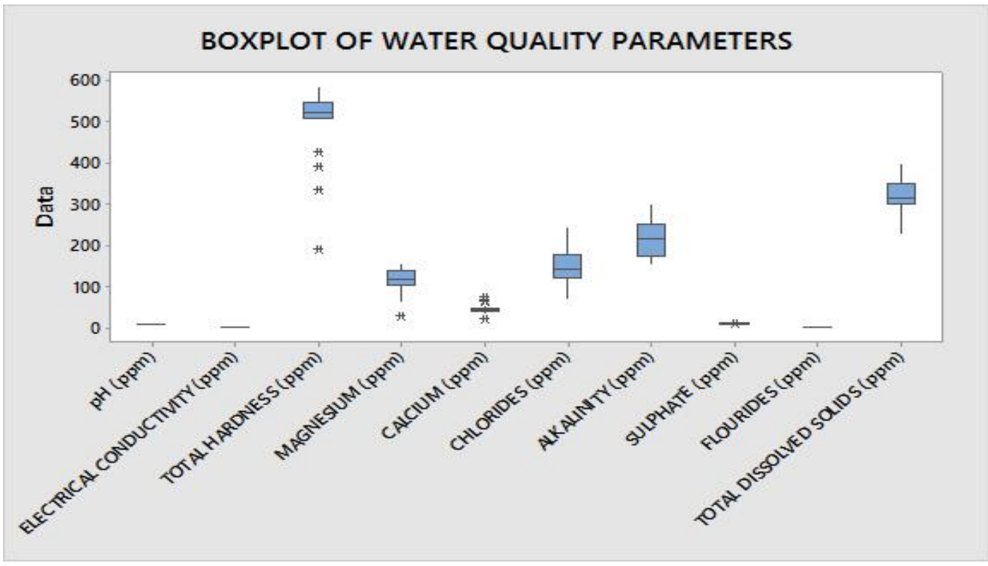

Figure 5 Box plots for physicochemical characteristics

Table 2 Correlation matrix

Variables	**pH**	**E.C (µS/cm)**	**T.H (ppm)**	**Mg (ppm)**	**Ca (ppm)**	**Cl (ppm)**	**T A (ppm)**	**So4 (ppm)**	**F (ppm)**	**TDS (ppm)**
pH	**1**	-0.022	0.162	-0.068	-0.074	0.383	-0.019	0.156	-0.179	0.220
E C (µS/cm)	-0.022	**1**	0.342	-0.165	-0.035	0.353	0.886	-0.065	-0.180	0.149
T H(ppm)	0.162	0.342	**1**	0.544	-0.173	0.543	0.280	0.508	-0.041	0.863
Mg (ppm)	-0.068	-0.165	0.544	**1**	-0.123	0.090	-0.216	0.664	-0.103	0.473
Ca(ppm)	-0.074	-0.035	-0.173	-0.123	**1**	-0.246	0.205	-0.158	-0.293	-0.013
Cl (ppm)	0.383	0.353	0.543	0.090	-0.246	**1**	0.288	0.319	-0.071	0.456
TA (ppm)	-0.019	0.886	0.280	-0.216	0.205	0.288	**1**	-0.197	-0.226	0.202
SULPHATE (ppm)	0.156	-0.065	0.508	0.664	-0.158	0.319	-0.197	**1**	-0.064	0.426
F(ppm)	-0.179	-0.180	-0.041	-0.103	-0.293	-0.071	-0.226	-0.064	**1**	-0.213
TDS (ppm)	0.220	0.149	0.863	0.473	-0.013	0.456	0.202	0.426	-0.213	**1**

Table 3 Eigen values of the variables

	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**
Eigenvalue	3.240	2.229	1.339	1.182	0.690	0.524	0.413	0.241	0.097	0.046
Variability (%)	32.401	22.287	13.386	11.824	6.901	5.239	4.132	2.405	0.969	0.457
Cumulative (%)	32.401	54.688	68.073	79.897	86.799	92.037	96.169	98.575	99.543	100.000

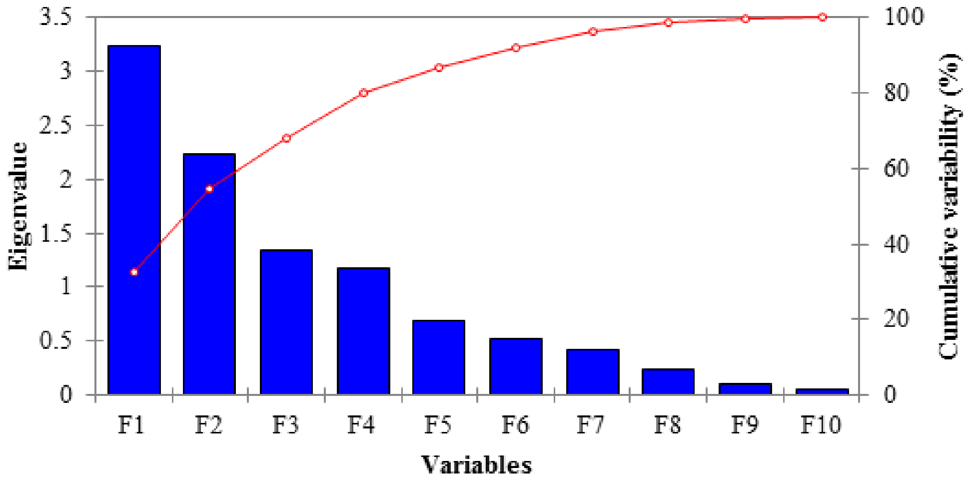

Figure 6 Graph of eigen values vs cumulative variability

Table 4 PCA for the sample data

Parameters	PC1	PC2	PC3	PC4
pH	0.174	0.001	-0.123	-0.796
E.C(µS)	0.219	0.542	-0.133	0.222
T. H(ppm)	0.512	-0.025	-0.034	0.170
Mg (ppm)	0.317	-0.386	0.252	0.279
Ca (ppm)	-0.103	0.189	0.664	-0.063
Cl (ppm)	0.387	0.122	-0.320	-0.262
TA (ppm)	0.183	0.594	0.024	0.181
SO4(ppm)	0.355	-0.342	0.087	0.037
F (ppm)	-0.128	-0.182	-0.573	0.322
TDS(ppm)	0.471	-0.046	0.153	0.009
Eigenvalue	3.240	2.229	1.339	1.182
Variability (%)	32.401	22.287	13.386	11.824
Cumulative (%)	32.401	54.688	68.073	79.897

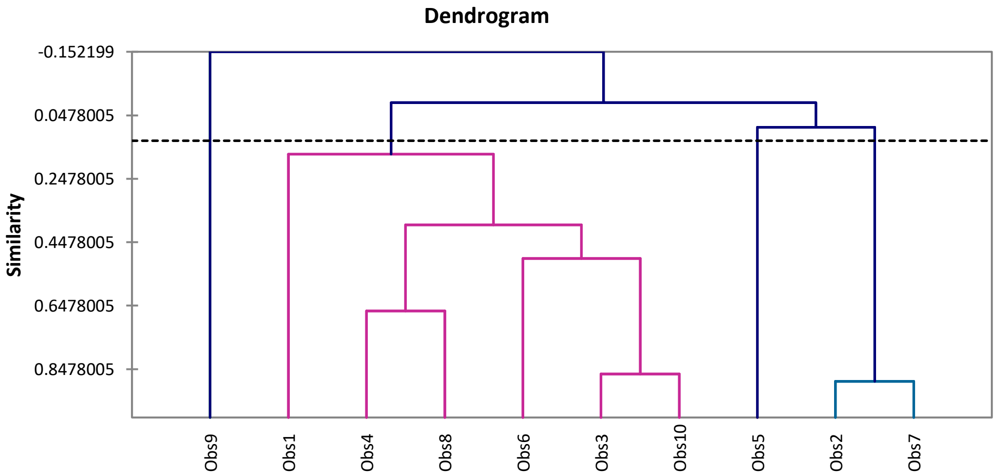

Figure 7 Dendrogram of water quality parameters

4. CONCLUSIONS

In the present study, physicochemical parameters of the samples collected from 30 well points in the town of Rajam are evaluated and compared with World Health Organization and BIS standards. It is found that Total hardness, Fluorides, Alkalinity exceeds the permissible limits. Water quality index (WQI) for each sample was also determined. It is found that 3,5,18,19,20,21 well point samples are fit for drinking and most samples are having poor (50-100) quality for drinking. The data was analyzed with the help of Statistical tools and found that water samples are contaminated with the weathering of metamorphic rocks (charnockite, khondalite etc.,) present in the study area. Chlorinity Index and Salinity Index are found to be in permissible limits and hence suitable for irrigation purpose.

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