Assessment of Groundwater Quality using Factor Analysis over Tamil Nadu, India

Anurudh R[1] and Saravanan K[2]

[1]*Student, School of Civil Engineering, Vellore Institute of Technology, Chennai, Tamil Nadu, India*
[2] *Associate Professor, School of Civil Engineering, Vellore Institute of Technology, Chennai, Tamil Nadu, India*

Abstract – *Monitoring and testing of groundwater quality is very essential as it is subjected to contamination by various natural and anthropogenic activities. The aim of this study is to evaluate of groundwater quality over northeastern part of Tamil Nadu, India. The factor analysis is used as data reduction techniques. The analysis is conducted using the groundwater quality data for the three major districts of Tamil Nadu, i.e. Vellore, Tiruvallur and Kanchipuram during the pre-monsoon and post-monsoon period of the year 2018. Thus, spatial distribution along with quantitative factor analysis of various chemical parameters or contaminants helps us to identify its possible sources and developing sustainable treatment methods for them.*

Key Words: **Groundwater quality, factor analysis. Chennai region, Groundwater mapping**

1.INTRODUCTION

Groundwater is one of the natural deposits which is highly evaluated for the development of the economy and to facilitate potable water supply in rural and urban environment as well. Assessing the quality of groundwater is vital for the socio-economic development. Analyzing physiochemical and biological parameters of groundwater helps in assessing its quality. Alteration in the quality of groundwater will be majorly based on hydrologic and geologic conditions over the timespan [1]. But presently, the quality and quantity of groundwater of being affected on large scale due to contamination by many natural and mad-made activities.

The quality being affected means chemical alteration of the groundwater which is due to various reasons like interaction with solid phases, residence time of ground water, seepage of polluted river water, mixing of groundwater with saline pockets etc [2]. The quality loss of water results in health hazards for all sort of living beings like humans, livestock etc which in turn affects the socio-economic development. Even, the improper disposal of garbage and wastes is one of the principal causes of groundwater pollution and its chemical alteration. A discernment of the groundwater's chemical quality is a requisite for determining its use for various purposes. Portraiture of groundwater with regards to geochemical type is a quintessential element for the spatial management of groundwater and its resources for the quality check and for the identification of recharge areas [3].

Geographic Information System (GIS) is one of the best mapping techniques used to represent data related to the groundwater quality and its conservative use. It is a technology that amalgamates queries and statistical analysis featuring the geographic analyze offered by maps and spatial database. GIS mapping is conceded in accosting geographical information in expansion without mislaying the spatio-temporal variability [4]. Hydro chemical characteristics of groundwater can be assessed spatially with this mapping method. While GIS mapping is used for geographical analysis, factor analysis is utilized for better understanding of correlation of underlying factor's observation which will not be directly observable. There are 3 main stages of factor analysis:

- Creating a correlation matrix for all the chemical parameters or variables.
- Based on correlation coefficients of the variables, the factors are extracted.
- The factors are being rotated to amplify the inter-connection between the factors and variables.

In this paper, the application of GIS to study the spatial distribution of chemical parameters and factor analysis to study groundwater quality in three districts of Tamil Nadu by identifying different probable sources of contamination to the local groundwater is presented. With this, the local municipal board authorities observe the trend of factors distributed in groundwater and intervene if the quality of water is very poor and implement plans and strategies to improve the local ground water sources.

2. STUDY AREA

The study area includes three major districts of Tamil Nadu, namely, Vellore, Tiruvallur, and Kancheepuram. Vellore is a city with district headquarters located in the northeastern part of Tamil Nadu near the Palar

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 08 | Aug 2021 www.irjet.net p-ISSN: 2395-0072

river with its coordinates lying at 12.92°N 79.13°E and 220 m above sea level. Low water level in phreatic aquifer in most parts of its district due to lack of rainfall.

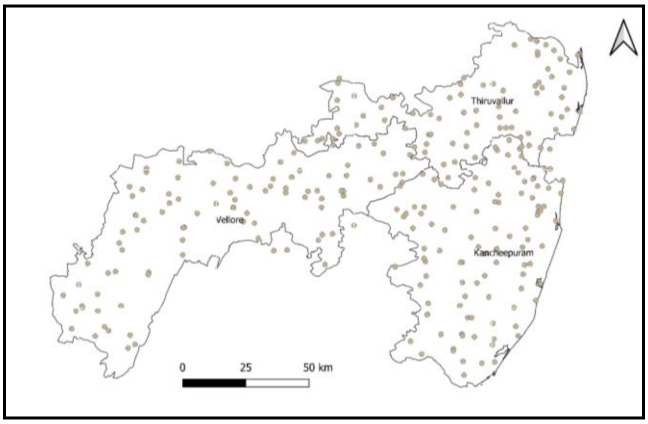

Fig -1: Study area key map

Tiruvallur is a fast-developing district located on the outskirts of Chennai in the state of Tamil Nadu with its coordinates located at 13.15°N 79.91°E. The nearest water source is Cooum river and the trend for groundwater levels is declining at a rate of 85% in the last decade. Kancheepuram, one of the oldest districts which is around 70 km away from Chennai. The coordinates of Kanchipuram are located at 12.8387°N 79.7016°E. The ground water in Kancheepuram district is developed by dug wells, dug-cum-bore wells, tube wells, bore wells and filter points.

3. METHODOLOGY

From around 600 different groundwater sampling stations (bore & dug well) in three districts, the data for various chemical parameters determined by Central Ground Water Board (CGWB) through collection of samples, testing and analyzing of parameters. The physio-chemical characterization of the groundwater samples that will be taken into account are pH, EC, TDS, major anions (CO_3^{2-}, HCO_3^-, F^-, Cl^-, NO_2^-, NO_3^-, and SO_4^{2-}), major cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+), alkalinity, and hardness for which the method of determination is presented in Table 1.

In this study, the groundwater quality data is collected from CGWB for the year 2018 which will be used to study the spatial distribution of various factors and factor analysis can be used as a quantitative tool to further infer the distribution of these factors. The data collected is categorized into pre-monsoon and post monsoon period for which the analysis was done. The three main factors for which analysis was carried out are *pH, TDS and hardness.*

Table -1: Methods of determination of chemical parameters

Parameters	Methods of determination
pH	pH meter
NO_2^-, NO_3^- (mg/l)	Chemiluminescence
Ca^{2+}, Mg^{2+} (mg/l)	Titration Method
Na^+, K^+ (mg/l)	Flame Photometer
Cl^- (mg/l)	Potentiometric Method
SO_4^{2-}, CO_3^{2-} (mg/l)	Turbidimeter Method
CO_3^{2-} (mg/l)	Turbidimeter Method
HCO_3^- (mg/l)	ABG interpretation
F^- (mg/l)	UV Spectrophotometric Method
EC (µS/cm)	Conductometer
Hardness (mg/l)	EDTA method
RSC (meq/l)	RSC index = $[HCO_3 + CO_3] - [Ca + Mg]$
TDS (mg/l)	Potentiometric Method

Note: Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Hardness (TH), Sodium (Na^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+), Fluoride(F^-), Sulphate (SO_4^{2-}), Carbonate (CO_3^{2-}), Chlorine (Cl^-), Residual sodium carbonate (RSC), Nitrite (NO_2^-), Nitrate (NO_3^-), Bicarbonate (HCO_3^-).

Spatial variation can be best studied through contour maps using Quantum GIS (QGIS) software which depicts the distribution of major parameters such as pH, hardness and TDS during pre-monsoon and post-monsoon period throughout the three major districts of Tamil Nadu. These factors are further considered for factor analysis using XLSTAT statistical software to study the predominance of various factors. The XLSTAT analyses the factors using correlation matrix, total variance and rotation principle component analysis (PCA) and then its compliance with Bureau of Indian Standards (BIS 2012) is verified for suitability of domestic uses.

Table -2: Bureau of Indian Standards - BIS 2012 for groundwater [By Central Ground Water Board (CGWB)]

Parameters	BIS 2012 (IS-10500)	
	Acceptable limit	**Permissible limit**
pH	6.5–8.5	No relaxation
EC	-	-
CO_3^{2-}	-	-
HCO_3^-	200	600
F^-	1	1.5
Cl^-	250	1000
NO_3^-	45	No relaxation
SO_4^{2-}	200	400
Na^+	–	–
Ca^{2+}	75	200
Mg^{2+}	30	100
TDS	500	2000
HAR	200	600

ALK	200	600

4. RESULTS AND DISCUSSION

The collected groundwater data which were tested for various physical and chemical parameters is presented with minimum and maximum value of occurrence along with mean values and standard deviation for the pre-monsoon and post-monsoon season of the year 2018 were reported in table 3 and 4.

Table - 3: Basic Statistics of Groundwater for Pre-Monsoon Season of year 2018

Parameters	Min	Max	Mean	Standard deviation
TDS	172	6991	838.23	708.81
NO_2^-, NO_3^-	1	68	10.96	11.01
Ca^{2+}	12	480	66.54	64.01
Mg^{2+}	4.86	267.3	51.96	37.74
Na^+	1	1944	163.51	179.31
K^+	0.1	154	8.44	14.85
Cl^-	0.73	3829	268.49	382.90
SO_4^{2-}	1	544	98.93	103.14
CO_3^{2-}	0	120	4.38	17.73
HCO_3^-	73.2	3251.3	250.91	236.61
F^-	0.05	2.94	0.73	0.56
pH	6.9	8.7	7.89	0.30
EC	330	12280	1498.23	1243.34
TH	85	2000	380.18	278.63
SAR	0.03	19.41	3.49	2.58
RSC	0	47.79	0.45	3.45
Na%	0	47.79	0.45	3.45

Table - 4: Basic Statistics of Groundwater for Post-Monsoon Season of year 2018

Parameters	Min	Max	Mean	Standard deviation
TDS	195	7015	912.87	818.29
NO_2^-, NO_3^-	0.05	63	8.83	9.28
Ca^{2+}	12	420	75.43	74.29
Mg^{2+}	2.43	364.5	55.45	43.56
Na^+	1	2042	171.23	196.84
K^+	0.1	168	6.22	18.47
Cl^-	16	3864	314.19	446.34
SO_4^{2-}	1	520	118.13	118.27
CO_3^{2-}	0	108	4.65	18.07
HCO_3^-	73.2	793	238.56	102.42
F^-	0.05	1.68	0.51	0.38
pH	6.6	8.4	7.82	0.33
EC	270	12200	1595.02	1419.27
TH	120	2550	416.76	335.20
SAR	0.03	21.88	3.48	2.55
RSC	0	5.40	0.26	0.81
Na%	1.05	77.01	41.96	16.36

4.1 Spatial distribution of groundwater data

The spatial distribution of various parameters of groundwater data of three districts in Tamil Nadu helps in assessing the usability of water for various purposes mainly for drinking. The attributes of the groundwater data such as pH, TDS and total hardness are specified with source of sample collection, well number, district, etc. These parameters vary from time to time and seasons to seasons at the same geographical location. The maps are prepared using QGIS 2.18.26 version of software. The spatial maps are interpolated for the parameters which are pH, TDS and hardness for pre-monsoon and post-monsoon season which is shown in the fig. 2-7.

One of the important indicators of groundwater is pH which chemically defines the quality of water. From the table 3 and 4, it is clear that the pH of the groundwater in most part of the study area is both alkaline and acidic in nature and it ranges more than 7 in the post monsoon season and is equivalently acidic in the pre-monsoon season of the year 2018. The pH value of all the 600 samples were within the permissible limit of drinking water quality and it ranges from minimum of 6.6 to the maximum of 8.7. The GIS mapping for pH in the Pre-Monsoon and Post-Monsoon Season is shown in Figure 2 and 3.

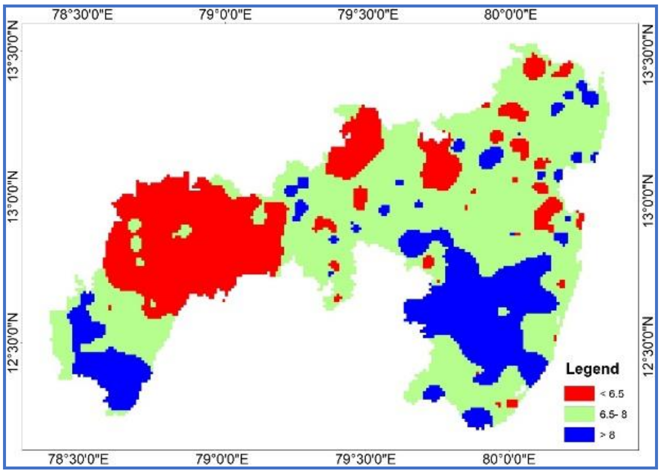

Fig -2: pH map of Pre-Monsoon Season

Another important parameter to be considered in assessing the ground water quality is TDS which depicts the mineral content in water. Higher levels of TDS in the groundwater sample may result in leaching of salts from soil when the domestic sewage may percolate into the groundwater and contaminate it [5].

Compared to pre-monsoon and post monsoon season, the TDS in pre-monsoon and post monsoon of year 2018

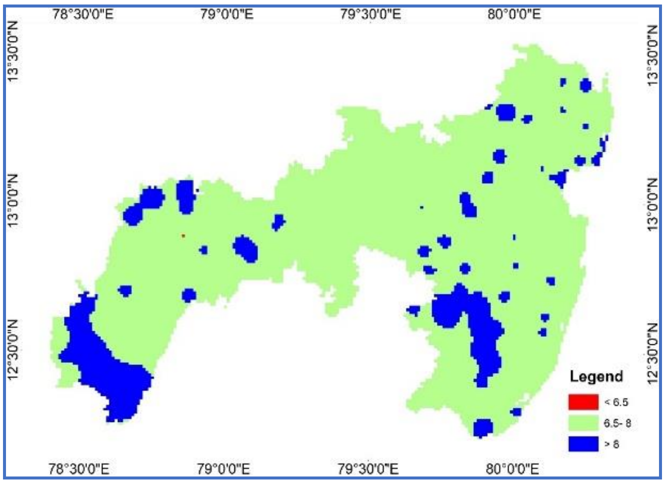

Fig -3: pH map of Post-Monsoon Season

has high level concentration which ranges 172mg/L to 7015mg/L. This shows that TDS parameter exceeds the permissible limit (2000 mg/L) as per BIS 2012 standards (IS-10500). The GIS mapping for TDS in the Pre-Monsoon and Post-Monsoon Season is shown in Figure 4 and 5.

Total hardness (TH) is another parameter which highlights the mineral content of water. If the water is too hard, it cannot be aesthetically accepted for drinking purpose and on the other hand, if it's too soft, it becomes too salty with sodium content in it. The TH in post monsoon season of year 2018 has a higher mean concentration with 416.76 mg/L in comparison to pre-monsoon season which is 380.18 mg/L which is reported in table 3 and 4. The range of TH varies between 85 mg/L to 2550 mg/L during the whole year.

Comparing with BIS 2012 (IS-10500) standards whose limit ranges between 200 mg/L to 600 mg/L, it is seen that the TH exceeds the permissible limit in most of the

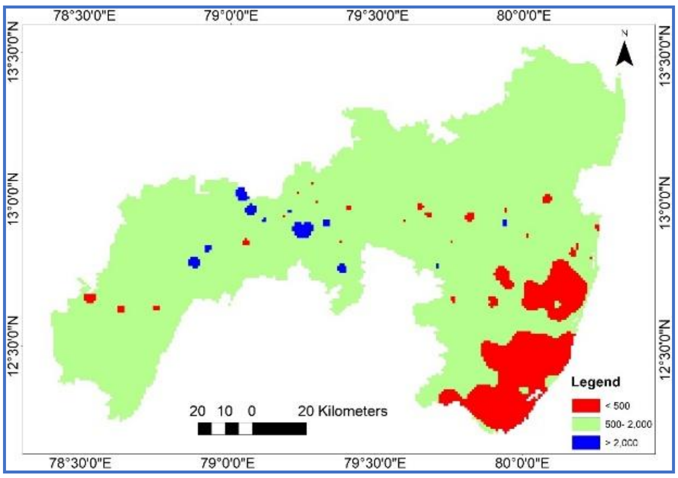

Fig -4: TDS map of Pre-Monsoon Season

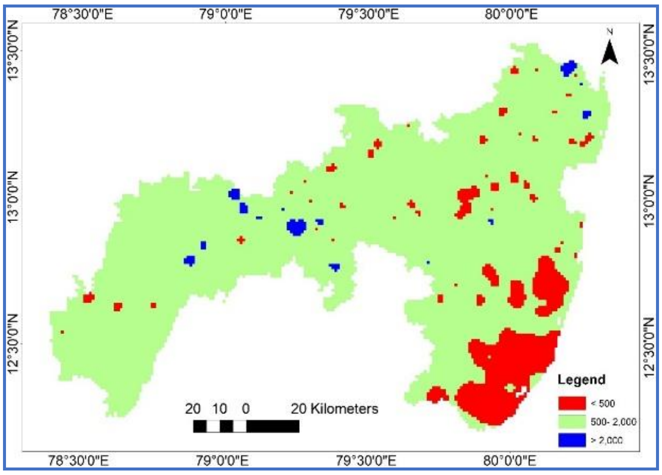

Fig -5: TDS map of Post-Monsoon Season

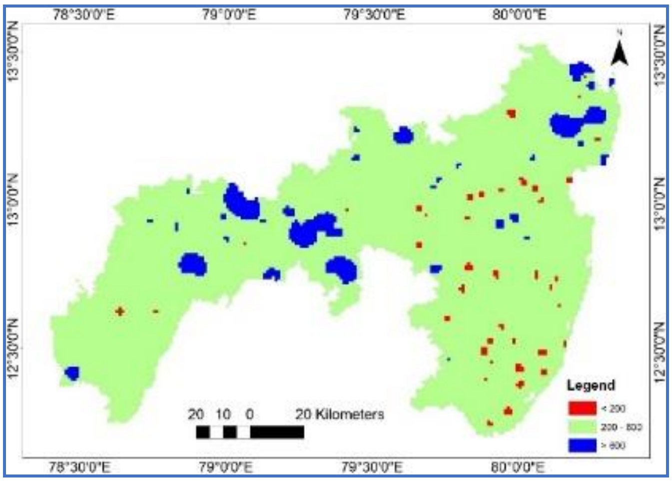

Fig -6: TH map of Pre-Monsoon Season

areas. The GIS mapping for TH in the Pre-Monsoon and Post-Monsoon Season is shown in Figure 6 and 7.

The value of other important ions in groundwater whose compliance with standards has to be checked and it is likely to vary between for the ions, Ca^{2+} (12 mg/L - 480 mg/L), Mg^{2+} (4.86 mg/L - 267.3 mg/L), Cl^- (0.73 mg/L – 3829 mg/L), SO_4^{2-} (1 mg/L - 544 mg/L), HCO_3^- (7.32 mg/l – 3251.3 mg/L), F^- (0.05 mg/L - 2.94 mg/L) for the pre-monsoon season and for the post-monsoon season, it was found to vary between for the ions, Ca^{2+} (12 mg/l -420 mg/l), Mg^{2+} (2.43 mg/l – 364.5 mg/l), Cl^- (16 mg/L – 3864 mg/L), SO_4^{2-} (1 mg/l -520 mg/l), HCO_3^- (73.2 mg/l - 793 mg/l), F^- (0.05 mg/l - 1.68mg/l) as seen in table 2 and 3 respectively.

It is evident that all these ions are highly above the concentrations of permissible limit of BIS 2012 (IS-10500) and hence, the groundwater has to be subjected

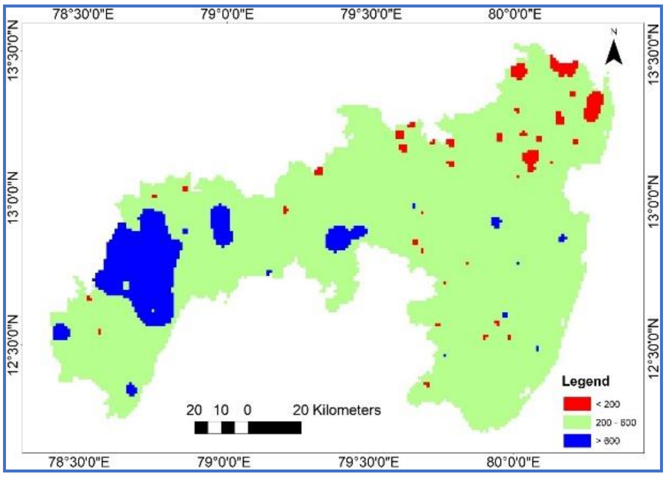

Fig -7: TH map of Post-Monsoon Season

to advanced tertiary treatment methods to be used for drinking purposes.

4.2. Pearson's correlation between variables

Pearson's correlation method was utilized in calculating the correlation coefficients (r) between the variables and the corresponding values are tabulated in table 4 - (a), (b), (c) and 5 - (a), (b), (c) for pre-monsoon and post-monsoon season of year 2018 respectively. It is noticeable from the 289 correlations for the pre-monsoon season that that electric conductivity has high positive correlation with TDS. Also, through the pre-monsoon season remarkable correlation was noted between pH, Mg^{2+}, F^-, TDS, SO_4^{2+}, CO_3^{2-}, Ca^{2+} and Na^+.

Table – 4(a): Correlation matrix for Pre-Monsoon Season (TDS, NO_2^- & NO_3^-, Ca^{2+}, Mg^{2+}, Na^+ and K^+)

Correlation	TDS	NO2+NO3	Ca	Mg	Na	K
TDS	1.00	0.29	0.77	0.77	0.95	0.08
NO_2^-, NO_3^-	0.29	1.00	0.12	0.26	0.22	0.14
Ca^{2+}	0.77	0.12	1.00	0.56	0.60	-0.04
Mg^{2+}	0.77	0.26	0.56	1.00	0.64	-0.03
Na^+	0.95	0.22	0.60	0.64	1.00	0.08
K^+	0.08	0.14	-0.04	-0.03	0.08	1.00
Cl^-	0.97	0.14	0.80	0.74	0.92	0.03
SO_4^{2-}	0.71	0.33	0.48	0.59	0.66	-0.04
CO_3^{2-}	-0.01	-0.02	-0.14	0.01	0.05	0.13
HCO_3^-	0.00	0.06	-0.04	-0.01	0.02	0.18
F^-	0.32	0.13	0.12	0.43	0.33	-0.17
pH	-0.31	-0.27	-0.46	-0.22	-0.18	0.06
EC	1.00	0.26	0.77	0.79	0.95	0.07
TH	0.87	0.22	0.89	0.88	0.70	-0.04
SAR	0.76	0.29	0.31	0.41	0.87	0.15
RSC	-0.04	-0.04	-0.04	-0.07	-0.02	0.16
Na%	0.39	0.21	-0.01	0.15	0.53	0.10

Table – 4(b): Correlation matrix for Pre-Monsoon Season (Cl^-, SO_4^{2-}, CO_3^{2-}, HCO_3^-, F^- and pH)

Correlation	Cl	SO4	CO3	HCO3	F	pH
TDS	0.97	0.71	-0.01	0.00	0.32	-0.31
NO_2^-, NO_3^-	0.14	0.33	-0.02	0.06	0.13	-0.27
Ca^{2+}	0.80	0.48	-0.14	-0.04	0.12	-0.46
Mg^{2+}	0.74	0.59	0.01	-0.01	0.43	-0.22
Na^+	0.92	0.66	0.05	0.02	0.33	-0.18
K^+	0.03	-0.04	0.13	0.18	-0.17	0.06
Cl^-	1.00	0.58	-0.06	-0.06	0.26	-0.26
SO_4^{2-}	0.58	1.00	-0.08	-0.04	0.36	-0.39
CO_3^{2-}	-0.06	-0.08	1.00	0.04	0.05	0.43
HCO_3^-	-0.06	-0.04	0.04	1.00	-0.01	-0.06
F^-	0.26	0.36	0.05	-0.01	1.00	-0.07
pH	-0.26	-0.39	0.43	-0.06	-0.07	1.00
EC	0.97	0.69	0.00	0.01	0.34	-0.30
TH	0.87	0.60	-0.08	-0.03	0.31	-0.38
SAR	0.67	0.59	0.18	0.08	0.33	-0.07
RSC	-0.05	-0.07	0.11	0.92	-0.07	0.03
Na%	0.28	0.39	0.20	0.14	0.30	0.06

Table – 4(c): Correlation matrix for Pre-Monsoon Season (EC, TH, SAR, RSC and Na%)

Correlation	EC	TH	SAR	RSC	Na%
TDS	1.00	0.87	0.76	-0.04	0.39
NO_2^-, NO_3^-	0.26	0.22	0.29	-0.04	0.21
Ca^{2+}	0.77	0.89	0.31	-0.04	-0.01
Mg^{2+}	0.79	0.88	0.41	-0.07	0.15
Na^+	0.95	0.70	0.87	-0.02	0.53
K^+	0.07	-0.04	0.15	0.16	0.10
Cl^-	0.97	0.87	0.67	-0.05	0.28
SO_4^{2-}	0.69	0.60	0.59	-0.07	0.39
CO_3^{2-}	0.00	-0.08	0.18	0.11	0.20
HCO_3^-	0.01	-0.03	0.08	0.92	0.14
F^-	0.34	0.31	0.33	-0.07	0.30
pH	-0.30	-0.38	-0.07	0.03	0.06

EC	1.00	0.88	0.75	-0.03	0.38
TH	0.88	1.00	0.41	-0.06	0.08
SAR	0.75	0.41	1.00	0.02	0.83
RSC	-0.03	-0.06	0.02	1.00	0.05
Na%	0.38	0.08	0.83	0.05	1.00

A different trend follows for the parameters in the post-monsoon season. From table 5-(c), it is notable that pH has high negative correlation with calcium and the parameters EC, TDS, TH, CO_3^{2-}, SO4, K, Mg, Na and F have significant correlation at post-monsoon season. At pre-monsoon and post-monsoon season, pH shows an inverse relation between most anions and cations for both the years.

Table – 5(a): Correlation matrix for Post-Monsoon Season (TDS, NO_2^- & NO_3^-, Ca^{2+}, Mg^{2+}, Na^+ and K^+)

Correlation	TDS	NO2+NO3	Ca	Mg	Na	K
TDS	1.00	0.29	0.85	0.80	0.95	0.07
NO_2^-, NO_3^-	0.29	1.00	0.16	0.27	0.25	0.20
Ca^{2+}	0.85	0.16	1.00	0.69	0.69	-0.07
Mg^{2+}	0.80	0.27	0.69	1.00	0.63	-0.03
Na^+	0.95	0.25	0.69	0.63	1.00	0.07
K^+	0.07	0.20	-0.07	-0.03	0.07	1.00
Cl^-	0.98	0.19	0.86	0.79	0.93	-0.01
SO_4^{2-}	0.73	0.31	0.61	0.61	0.65	0.08
CO_3^{2-}	-0.03	0.11	-0.14	-0.05	0.01	0.22
HCO_3^-	-0.07	0.06	-0.26	-0.03	0.01	0.19
F^-	0.16	0.02	-0.03	0.17	0.17	-0.09
pH	-0.11	0.04	-0.32	-0.11	-0.02	0.19
EC	1.00	0.27	0.85	0.81	0.95	0.06
TH	0.90	0.24	0.92	0.92	0.72	-0.05
SAR	0.76	0.27	0.40	0.41	0.88	0.17
RSC	-0.05	0.06	-0.21	-0.11	0.03	0.27
Na%	0.35	0.18	0.01	0.12	0.49	0.09

Table – 5(b): Correlation matrix for Post-Monsoon Season (Cl^-, SO_4^{2-}, CO_3^{2-}, HCO_3^-, F^- and pH)

Correlation	Cl	SO4	CO3	HCO3	F	pH
TDS	0.98	0.73	-0.03	-0.07	0.16	-0.11
NO_2^-, NO_3^-	0.19	0.31	0.11	0.06	0.02	0.04
Ca^{2+}	0.86	0.61	-0.14	-0.26	-0.03	-0.32
Mg^{2+}	0.79	0.61	-0.05	-0.03	0.17	-0.11
Na^+	0.93	0.65	0.01	0.01	0.17	-0.02
K^+	-0.01	0.08	0.22	0.19	-0.09	0.19
Cl^-	1.00	0.63	-0.10	-0.17	0.07	-0.17
SO_4^{2-}	0.63	1.00	-0.06	-0.15	0.38	-0.06
CO_3^{2-}	-0.10	-0.06	1.00	0.19	0.11	0.42
HCO_3^-	-0.17	-0.15	0.19	1.00	0.09	0.24
F^-	0.07	0.38	0.11	0.09	1.00	0.26
pH	-0.17	-0.06	0.42	0.24	0.26	1.00
EC	0.98	0.71	-0.04	-0.07	0.13	-0.12
TH	0.90	0.66	-0.10	-0.16	0.07	-0.24
SAR	0.68	0.61	0.13	0.22	0.28	0.15
RSC	-.119	-.081	.667	.418	.183	.403
Na%	.248	.384	.191	.373	.376	.276

Table – 5(c): Correlation matrix for Post-Monsoon Season (EC, TH, SAR, RSC and Na%)

Correlation	EC	TH	SAR	RSC	Na%
TDS	1.00	0.90	0.76	-0.05	0.35
NO_2^-, NO_3^-	0.27	0.24	0.27	0.06	0.18
Ca^{2+}	0.85	0.92	0.40	-0.21	0.01
Mg^{2+}	0.81	0.92	0.41	-0.11	0.12
Na^+	0.95	0.72	0.88	0.03	0.49
K^+	0.06	-0.05	0.17	0.27	0.09
Cl^-	0.98	0.90	0.68	-0.12	0.25
SO_4^{2-}	0.71	0.66	0.61	-0.08	0.38
CO_3^{2-}	-0.04	-0.10	0.13	0.67	0.19
HCO_3^-	-0.07	-0.16	0.22	0.42	0.37
F^-	0.13	0.07	0.28	0.18	0.38
pH	-0.12	-0.24	0.15	0.40	0.28
EC	1.00	0.91	0.74	-0.06	0.33
TH	0.91	1.00	0.44	-0.17	0.07
SAR	0.74	0.44	1.00	0.24	0.80
RSC	-0.06	-0.17	0.24	1.00	0.37
Na%	0.33	0.07	0.80	0.37	1.00

4.3 Factor Analysis using XLSTAT

Software package like XLSTAT has been used to carry out the analysis. With the help of this technique, large number of variables are deduced to fewer factors relying on the Eigen values and Eigen vectors. The clarification of data is based on rotated factors, rotated loadings and rotated Eigen values. The extraction of factor is done with the minimum acceptable Eigen value as greater than 1.

The number factors generated during the pre-monsoon season of the year 2018 was five components or factors. The variables are TDS, Na^+, Cl^- for component 1; Mg^{2+}, SO_4^{2-}, HAR for component 2; HCO_3^-, RSC, Na% for component 3; CO_3^{2-}, pH, RSC for component 4 and Ca, F^-, pH for component 5 are the loadings for corresponding components in the pre-monsoon season of the year 2018. The variance in the pre-monsoon season of the year 2018 for the five components were 37.743%, 53.320%, 64.709%, 74.534%, 81.793% with loadings TDS, EC, TH; CO_3^{2-}, pH, RSC; K, Cl^-, SO_4^{2-}; HCO_3^-, RSC, Na% for factor 1, 2, 3 and 4 respectively and it was found that there is a total variance of about 81.793% for five components as shown in Table 8.

Table – 6: Initial eigen values for Pre-Monsoon Season

Total Variance Explained			
Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	7.460	43.882	43.882
2	2.227	13.102	56.984
3	1.817	10.689	67.673
4	1.269	7.463	75.137
5	1.132	6.656	81.793
6	.907	5.334	87.127
7	.659	3.878	91.005
8	.515	3.032	94.036
9	.404	2.374	96.411
10	.278	1.635	98.046
11	.225	1.322	99.368
12	.072	.421	99.789
13	.027	.160	99.949
14	.007	.040	99.990
15	.001	.008	99.998
16	.000	.002	100.000
17	5.096E-16	2.998E-15	100.000

Table – 7: Extraction Sums of Squared Loadings for Pre-Monsoon Season

Total Variance Explained			
Component	Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %
1	7.460	43.882	43.882
2	2.227	13.102	56.984
3	1.817	10.689	67.673
4	1.269	7.463	75.137
5	1.132	6.656	81.793

Table – 8: Rotation Sums of Squared Loadings for Pre-Monsoon Season

Total Variance Explained			
Component	Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %
1	6.416	37.743	37.743
2	2.648	15.577	53.320
3	1.936	11.389	64.709
4	1.670	9.826	74.534
5	1.234	7.258	81.793

The number factors generated during the post-monsoon season of the year 2018 was four components or factors. The variables TDS, EC, HAR for factor 1; CO_3^{2-}, pH, RSC for factor 2; K, Cl^-, SO_4^{2-} for factor 3 and HCO_3^-, Na%, RSC for factor 4 are the loadings for corresponding four factors in the post monsoon season of the year 2018. The variance in the post monsoon season of the year 2018 were 42.316%, 55.627%, 68.513%, 76.013% with loadings TDS, Cl^-, EC; HCO_3^-, SAR, Na%; CO_3^{2-}, pH, RSC; K, F for factor 1, 2, 3 and 4 respectively and it was found that there is a total variance of about 76.013% for four components as shown in Table 11.

Table – 9: Initial eigen values for Post-monsoon Season

Total Variance Explained			
Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	7.467	43.921	43.921
2	3.097	18.216	62.137
3	1.304	7.669	69.806
4	1.055	6.207	76.013
5	.974	5.729	81.742
6	.785	4.617	86.359

7	.703	4.137	90.496
8	.611	3.596	94.092
9	.313	1.841	95.932
10	.273	1.605	97.537
11	.236	1.387	98.924
12	.160	.942	99.866
13	.018	.104	99.970
14	.004	.023	99.993
15	.001	.007	100.000
16	5.958E-5	.000	100.000
17	2.704E-16	1.591E-15	100.000

Table – 10: Extraction Sums of Squared Loadings for Post-Monsoon Season

Total Variance Explained			
Component	Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %
1	7.467	43.921	43.921
2	3.097	18.216	62.137
3	1.304	7.669	69.806
4	1.055	6.207	76.013

Table – 11: Rotation Sums of Squared Loadings for Post-Monsoon Season

Total Variance Explained			
Component	Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %
1	7.194	42.316	42.316
2	2.263	13.311	55.627
3	2.191	12.886	68.513
4	1.275	7.500	76.013

The factor loadings obtained after varimax orthogonal rotation using XLSTAT software for the groundwater quality data of pre-monsoon and post-monsoon seasons are given in Tables 12 and 13, respectively. These factor loadings are either positive or negative in magnitude ranging between 0 to 1. Loadings which are having a magnitude greater than 0.75 are having strong correlation, the ones between 0.5 and 0.75 have moderate correlation and the ones approaching zero have a weak correlation.

Table – 12: Rotation PCA Loading Matrix for Pre-Monsoon Season

Parameters	Component				
	1	2	3	4	5
TDS	**.930**	.348	-.007	-.070	.010
NO_2^-, NO_3^-	.078	.534	-.026	-.478	.180
Ca^{2+}	**.874**	-.148	-.010	-.239	.040
Mg^{2+}	**.806**	.124	-.005	-.066	-.214
Na^+	**.820**	.489	-.001	.073	.003
K^+	.028	.210	.136	.076	**.796**
Cl^-	**.957**	.173	-.039	-.005	.007
SO_4^{2-}	.580	.472	-.046	-.291	-.182
CO_3^{2-}	-.001	.185	.064	**.721**	.086
HCO_3^-	-.027	.083	**.976**	-.039	.055
F^-	.230	.381	.014	.019	-.676
pH	-.279	-.015	-.057	**.813**	.022
EC	**.941**	.322	-.002	-.043	-.012
TH	**.951**	-.016	-.009	-.174	-.097
SAR	.520	**.790**	.033	.156	.022
RSC	-.021	-.023	**.973**	.066	.074
Na%	.123	**.868**	.076	.192	-.064

All major high factor loadings explained in pre-monsoon of year 2018 are having positive values except for pH in factor 1, NO_2^- and NO_3^- in factor 4 and F in factor 5. In the case of post-monsoon of year 2018, all major high factor loadings are having positive values except for HCO_3^- in factor 1, Ca^{2+} in factor 2 and predominantly F^- in factor 4.

Table – 13: Rotation PCA Loading Matrix for Post-monsoon Season

Parameters	Component			
	1	2	3	4
TDS	**.972**	.191	-.036	.074
NO_2^-, NO_3^-	.285	.141	.097	.423
Ca^{2+}	**.896**	-.191	-.174	.044
Mg^{2+}	**.858**	-.065	.011	-.017
Na^+	**.866**	.384	-.011	.074
K^+	-.001	.152	.251	.688
Cl^-	**.960**	.081	-.110	.039

SO_4^{2-}	**.751**	.257	-.011	-.147
CO_3^{2-}	-.003	-.052	**.886**	.145
HCO_3^-	-.205	.571	.208	.296
F^-	.158	.379	.332	-.646
pH	-.143	.241	.670	-.101
EC	.973	.170	-.041	.078
TH	**.955**	-.141	-.091	.015
SAR	.626	.716	.118	.083
RSC	-.087	.259	**.788**	.183
Na%	.214	**.874**	.203	-.063

When the rotation PCA loading matrix is observed for the pre-monsoon season, factor 1 is strongly correlated with TDS, Ca^{2+}, Mg^{2+}, Na^+, Cl^- and hardness with variability of 37.7% shows that intrusion of sea water into the sources of groundwater is possible. Factor 2 and 5 is strongly correlated with Na+ and K ions with a variability of 15.6% and 7.2% respectively which can be due to cation exchange effect. Factor 3 is strongly correlated with HCO_3^- with a variability of 10.69% which were responsible for turning the water alkaline in nature. Finally, factor 4 suggests that its high correlation with CO_3^{2-} and pH with a variability of 9.83% depicts that mineral precipitation may have occurred in the aquifer.

In the post-monsoon season, Factor 1 is strongly loaded with TDS, Ca^{2+}, Mg^{2+}, Na^+, Cl^-, SO_4^{2-} and hardness which explains for the variability of 42.3% in the data set. This can be due to dilution of groundwater as water recharges with rain and the concentrations of chloride, calcium, magnesium and sodium ions are very much reduced in the samples. Factor 2 is strongly correlated with Na^+ ions with a variability of 13.3% which can be due to mineral dissolution effect. And finally, factor 3 accounts for 12.9% of variability which includes parameters CO_3^{2-} and RSC shows the occurrence of moderate alkalinity as well mineral precipitation in water.

5. CONCLUSIONS

Statistic analytical methods like factor analysis is an effective tool for manipulation, interpretation and representation of data with respect to the quality of groundwater. It helped in identifying the natural grouping interpretation of these analytical data that showed the variance in groundwater quality.
The outcome is that there is a total variance of around 81.79% during the pre-monsoon season and around 76.01% during post-monsoon season. This analysis helped in figuring out that the most influential cation was Ca and the anion was HCO_3^-. The ratio of Cl^- by HCO_3^- was more than 2 while the ratio of Mg^{2+} by Ca^{2+} was less than 1 indicating there is interruption of sea water in pre-monsoon season. The ratio of corrosivity was greater than 1 for every sample symbolizing that metal ion being the main reason for corrosion.

R-mode factor analysis is one of the reliable tools for the studies relating to groundwater quality but in some cases, it doesn't present a definite answer. Thus, multivariate statistical method like factor analysis shall be a supplement method but not a replacement of conventional groundwater quality data handling methods.

ACKNOWLEDGEMENT

The author is grateful for the groundwater quality data provided by Central Ground Water Board (CGWB), Chennai, Tamil Nadu and also their support and permission to publish the results.

REFERENCES

[1] Pandey, S.K. and S. Tiwari, "Physico-chemical analysis of ground water of selected area of Ghazipur city-A case study", Nature and Science, 2009;7(1).

[2] Stallard R.F. and Edmond, J.M., "Geochemistry of the Amazon river: 2. The influence of the geology and weathering environment on the dissolved load", J Geophys Res., v.88, Nov. 1983, pp.9671-9688.

[3] Arveti Nagaraju, P. Muralidhar, Y. Sreedhar, "Hydro geochemistry and Groundwater Quality Assessment of Rapur Area, Andhra Pradesh, South India", Journal of Geoscience and Environment Protection, Vol.4 No.4, April 27, 2016, doi: 10.4236/gep.2016.44012.

[4] Mtetwa S., Kusangaya S. and Schutte C.F, "The application of geographic information system (GIS) in the analysis of nutrient loadings from an agro-rural catchment", Water SA, v.29(2), Apr. 2003, pp.189-193.

[5] Sarath Prasanth S.V., Magesh N.S., Jitheshlal K.V. et al., "Evaluation of groundwater quality and its suitability for drinking and agricultural use in the coastal stretch of Alappuzha District, Kerala, India", Appl Water Sci 2, 165–175 (2012), doi: 10.1007/s13201-012-0042-5.

[6] Yu S., Shang J., Zhao J. et al. "Factor Analysis and Dynamics of Water Quality of the Songhua River,

Northeast China", Water, Air, & Soil Pollution 144, 159–169, (2003), doi: 10.1023/A:1022960300693.

[7] S. Venkateswarana and S. Deepa, "Assessment of Groundwater Quality using GIS Techniques in Vaniyar Watershed, Ponnaiyar River, Tamil Nadu", Aquatic Procedia 4, 2015, 1283–1290, doi: 10.1016/j.aqpro.2015.02.167.

[8] J. Umamaheswari, R. Anjali, S. Abinandan, 1S. Shanthakumar, G.P. Ganapathy and M. Kirubakaran "Assessment of Groundwater Quality Using GIS and Statistical Approaches", Asian Journal of Earth Sciences 8 (4): 97-113, 2015

[9] H Boyacioglu "Surface water quality assessment using factor analysis" Water SA Vol.32 (3) 2006: pp.389-393, doi: 10.4314/wsa.v32i3.5264

[10] S. Krishnaraj, Sanjiv Kumar and K. P. Elango, "Factor analysis as a tool for evaluation of spatial and temporal variations in groundwater quality: A case study", IOSR-JAC, Volume 5, Issue 5, Sep. – Oct. 2013, PP 13-16.

[11] Rubia Khan and D. C. Jhariya "Groundwater Quality Assessment for Drinking Purpose in Raipur City, Chhattisgarh Using Water Quality Index and Geographic Information System", Journal Geological Society of India, Vol.90, July 2017, pp.69-76.

[12] Pande C.B., Moharir, K. "Spatial analysis of groundwater quality mapping in hard rock area in the Akola and Buldhana districts of Maharashtra, India", Appl Water Sci 8, 106 (2018), doi: 10.1007/s13201-018-0754-2.