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GROUNDWATER CHEMICAL STUDIES USING STATISTICAL ANALYSIS IN COIMBATORE CORPORATION, TAMIL NADU, INDIA

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ABSTRACT

In place with comprehend the hydrochemistry and the probable contamination of groundwater for drinking and irrigation purposes, 60 groundwater samples have been collected from Coimbatore Corporation region in march 2014 and various physicochemical parameters (pH, EC, TDS, Alkalinity, TH, Ca2+, Mg2+, Na+, K+, Fe2+, NH3, NO2-, NO3-, Cl-, F-, SO42- and PO42-) were analysed. The concentrations of physiochemical parameters in the studied samples were compared with the WHO standards to study the suitability of water for drinking purpose. The statistical analysis "Q-mode factor" and "cluster analyses" were carried out and found that geology and exchange between the river water and the groundwater plays a dominant role in the hydro chemical evolution of groundwater. Cluster tree diagram reveals that 41.67% of the study area comes under cluster I, II and III classification. Cluster tree clearly reveals that elevation high automatically geochemical concentration is low. The geochemical concentration is inversely proposed to elevation. A long term management strategy should be formulated for the protection of groundwater resources for drinking and agricultural activities.

Keywords

Coimbatore Corporation, factor, cluster, drinking, agricultural activities.

Academic Discipline And Sub-Disciplines

Environmental Engineering

SUBJECT CLASSIFICATION

Environmental Chemistry , Water Quality

TYPE (METHOD/APPROACH)

Groundwater Chemical Studies Using Statistical Analysis.

INTRODUCTION

Natural water is never pure they always contain at least small amount of dissolved gases and solids. The quality of water that we ingest as well as the quality of water in our lakes, streams, river and oceans in a critical parameter in determining the overall quality of our lives. Water quality is determined by the solutes and gases dissolve in the water, as well as the matter suspended in and floating on the water, the quality is a consequence of the natural physical and chemical state of the water as well as any alteration that may have occurred as a consequence of human activity. The usefulness of water for a particular purpose is determined by the water quality (Maheswaran et al, 2015) . If human activity alters the natural water quality so that it's no longer fit for a use for which it had previously been suited, the water is said to be polluted or contaminated (Arumugam and Elangovan, 2009).

Multivariate statistical analysis like factor and cluster, interpretation shows that inter relationship of groundwater chemistry. Factor and cluster results are widely applied to spatial distribution map of the geochemistry (Papatheodorou et al., 1999, Geetha Selvarani and Elangovan,2008; Hydrochemistry (Voudouris et al., 2000); Mineralogy (Seymour et al., 2004) the groundwater and source of soil/rocks (Papatheodorou et al., 2002, Vega et al., 1998; helena et al., 2000; Lambrakis et al., 2004), Kavidha and Elangovan, 2010,

Generally used to describe Also assess surface waters (Reisenhofer et al., 1995; mill operator et al., 1997; de Ceballos et al., 1998; Momen et al., 1999; Perona et al., 1999; Lau Also Lane, 2002; Simeonov et al., 2003; Yu et al., 2003; Vengosh What's more Keren, 1996; Suk and Lee, 1999; Panagopoulos et al., 2004; Vincent Cloutier et al., 2008), Samson and Elangovan, 2011

In the present study, groundwater samples in the proximity of Coimbatore Corporation, Coimbatore district, Tamil Nadu, India have been analyze in order to determine the effect of the industrial waste and man-made impact. The suitability of groundwater for Drinking and Irrigation purpose has been proposed based on WHO standards.

Study area

Coimbatore is a one of the largest city (Second position) of Tamil Nadu. It is also the most important commercial and industrial centre in our state. Ever since 1932 when power from Pykara was made available the Coimbatore Corporation and its surrounding have been population growing is rapidly. Coimbatore Corporation covers an area about 257.06 sq.km, out of 7575.20 sq.km 17.70% is the developed area. The gross density of the local planning area is work out of 37.26 persons/sq.km. The study area is located in part of Coimbatore district of Tamil Nadu, India. It is lies between the latitudes 10°54′45” N and 11°6’12” N and longitudes 76°52′14” E and 77°3′52” E. It is surrounded by mountains on the west and with reserve forests and river basin on the northern side, whereas the eastern part of the district starting from the city is predominantly dry. Due to the presence of the mountain pass, most parts of the district benefit for rainfall from the southwest monsoon season. After a pleasant September, regular monsoon starts from October lasting till early November. These rainfall are not enough for the entire year.

A geological study shows that the fissured zones and the age group of Pre-Cambrian group. The lithological characteristics include gneiss and other basic intrusive. The ground water is restricted to a depth of around up to 20 m in the study area. The water table is at a depth of 400 m above Mean Sea Level. The aquifer of the area is discontinuous with secondary inter-granular porosity and fractures. (Central Ground Water Board).

Coimbatore district, called as Manchester of South India is situated on the banks of River Noyyal, a part of Cauvery basin and various tanks fed by Noyyal river, Singanallur tank is one of the biggest and most polluted tanks. It is situated in western corner of Tamil Nadu and is bounded by Erode on the east, Dindigul on the southeast direction, Teni and Idukki on the south direction, Eranakulam (Kerala) on the south west direction, Palakkad (Kerala) on the west direction and Nilgiri district on the North side of the study area.

MATERIALS AND METHODS

The water samples were collected (figure 1) during March 2014 (pre-monsoon season) in various location of the study area. A total of 60groundwater samples were collected from bore and dug wells. In pre-monsoon, 26 groundwater samples were collected from the geological rock types of Hornblende biotite gneiss, 17 groundwater samples from Fissile hornblende biotite gneiss, 17 groundwater samples from Fluvial (Black cotton soil with Gypsum) and twelve surface water samples from tank areas. The parameters like pH, Electrical Conductivity (EC) were measured on the spot during the sample collected and stored in plastic containers and further laboratory analysis as recommended by American Public Health Association (APHA, 1995).

The analysed parameters includes hydrogen ion concentration (pH), Turbidity, electrical conductivity (EC), Total Dissolved Solids (TDS), Alkalinity (Alk), Total hardness (TH) and important cations like Sodium(Na^+), Potassium (K^+), Magnesium (Mg^{2+}), Calcium (Ca^{2+}), and as iron (Fe^{2+}) as well as anions such, Ammonia (NH_3), Nitrite (NO_2^-), Nitrate (NO_3^-), Chloride (Cl^-), Fluoride (F^-), Sulphate(SO_4^{2-}) and Phosphate (PO_4^{2-}). The base map was prepared using corporation map on 1:7,500 scales.

Multivariate techniques can help to simplify and organize large data sets and to make useful overview that can be lead to significant insight (Laaksoharju et al., 1999). Cluster and factor analyses are efficient ways of displaying complex relationships among many objects (Davis et al., 1973). Q-mode cluster and R-factor analyses have been done it for the data generated. R-mode analysis reveals the inter-relations among the variables studied and the Q-mode analysis reveals the interrelation among the samples studied. The STATISTICA software has been used to carry out the analysis. The data have been standardized by using standard statistical procedures.

Geological Investigation

District resource maps were collected from Geological Survey of India (GSI). The collected maps were digitised in Geographic Information System (GIS) with help of georeferencing tool and digitized in the study area geology.

RESULTS AND DISCUSSION

The analysis of Physicochemical parameters shows that there is significant variation of ionic concentrations. Minimum, maximum, average, median, mode and standard deviation values of the chemical composition for groundwater are presented in different formations are given in Tables 1.

The total cations (TZ^+) and total anions (TZ^-) balance (Freeze and Cherry 1979) was considered to show the charge balance error percentage. The error percentage in the groundwater samples of the present study ranged between ±2% and ±8%. Occurrence of errors in chemical analysis of groundwater and surface water is also due to the reagents employed, limitations of the methods, the instruments used and the presence of impurities in distilled water, etc. The TDS/EC ratio was in the range of 0.5–0.9. The role played by other ions than those considered in the study for the major elements charge balance is less significant. In the study area was generally odourless and colourless in most of the places. But tank water in the study area was collared with odour.

Alkalinity in groundwater is the measure of its capacity of neutralization. It is formed mainly due to the action of atmospheric CO_2 and CO_2 released from organic decomposition. Sodium is the important and most abundant alkali metal which is highly mobile and soluble in groundwater. Potassium in groundwater is generally lesser due to its higher solubility Groundwater quality.

In Hornblende biotite gneiss formation, Cl was the dominant anion followed by HCO_3, CO_3, SO_4 and NO_3, F and NH_3during pre-monsoon season. In Fissile Hornblende biotite gneiss formation, HCO_3 was the dominant anion followed by CO_3, Cl, SO_4, NO_3, F and NH_3 during study period. In Fluvial (Black cotton soil with Gypsum) formation, Cl, HCO_3 was the dominant anion followed by CO_3, SO4, NO_3, F and NH_3 during above mentioned period. In tank water, Cl was the dominant anion followed by HCO_3, SO_4 and NO_3, F and NH_3 irrespective of the seasons. Na was the dominant cation followed by Ca, K and Mg irrespective of the seasons.

Geology

The district resources map was collected from Geological Survey of India (GSI). The map was scanned, digitized and then taken to GIS. In the field, the rock samples were collected and identified to assess groundwater chemistry. The study area lies mainly over the Archaean crystalline rocks (Fig. 2), and the groundwater occur under phreatic conditions of the hard-rock aquifers. The study area is made up of high-grade metamorphic rocks Hornblende biotite gneiss, Fissile Hornblende biotite gneiss and Fluvial (Black cotton soil with Gypsum) deposits. The Fissile hornblende biotite gneiss occupied in north-eastern part of the study area. The rocks of Fluvial (Black cotton soil with Gypsum) occur in north-western part of the study area. Majority of the lower portion are occupied in Hornblende biotite gneiss with trending towards southeast direction. The other types of rocks are present in very small portion of the study area. The Fissile hornblende biotite gneiss (90.22 km^2) occupies in more or less one third out of the entire portion. Next dominated group of rocks followed by hornblende biotite gneiss (59.95 km^2) and Fluvial (Black cotton soil with Gypsum-85.90 km^2).The development of drainage networks mainly depends on the underlying geology, precipitation, exogenic and endogenic processes of the area.

Hydrogeochemical facies

The Piper (1983) Trilinear Diagram is the most useful tool to understand the chemical relationships among groundwater. The evolution of hydrochemical parameters on the basis of chemical analysis, groundwater is divided into six facies (Fig. 3). The plot shows that the groundwater samples fall in the field of CaCl and mixed $CaNaHCO_3$ respectively, according to the order of their dominance. From the plot, it is observed that $CaNaHCO_3$ and alkalis (Na^+) exceed the alkaline earths (Ca^{2+}) and Cl^- exceeds the other anions. The hydrochemical facies of groundwater is summarised in Table 2. Lithology wise groundwater chemical facies reveals that hornblende biotite gneissic formation water samples fall within Mixed $CaNaHCO_3$, because rate of weathering and underground flow is low or short time compare with other formations. Rest of two formations water samples fell in Mixed $CaNaHCO_3$ and NaCl class. The NaCl type of samples occur in lower part of the river side and influence of external polluted area, this is conformed to at the time of field validation.

Factor analysis

Factor analysis the interrelationships within a set of variables by reducing the complex data to an easily interpretable form (Suresh et al., 2010). In this work, R-mode (Relation between the element concentrations) factor analysis is chosen, which allows interpretation of the data more scientifically. Cations and Anions, TDS, EC, pH and Total Hardness have been considered for the present analysis. The pre-monsoon groundwater chemistry data analysis generated 3 factors which together account for 80.56% of variance. The rotated loadings, Eigen values, percentage of variance and cumulative percentage of variance of all 3 factors are given in Table 3. The first Eigen value is 13.35 which accounts for 66.74% of the total variance and this constitutes the first and main factor. The second Eigen values are 1.59 and these account for 7.93% respectively, of the total variance. The rest of the Eigen values each constitute less than 5.58% of the total variance. The first factor (which accounts for 66.74% of the total variance) is characterized by very high loadings of EC, TDS, TH, CO_3, HCO_3, Ca, and NO_3 and moderate to high loadings of Na, Mg, Fe, Mn, SO_4, and Cl. This factor reveals that the high concentration EC, TDS, TH, CO_3, HCO_3, Ca, and NO_3 in the study area are is mainly due to Na, Mg, Fe, Mn though SO_4 and Cl also plays a substantial role in determining EC and TDS. This factor accounts for the permanent hardness of the water. The second factor (which accounts for 7.93% of the total variance) is mainly associated with very high loading of NH_3 and PO_4 and also with moderate loading of K. This factor accounts for the polluted water. The loading of bicarbonate is same as it is in the first factor. The third factor (which accounts for 5.88% of the total variance) is mainly associated with very high loading of F and Alkalinity also with moderate loading of Mg and Na. This factor accounts for the permanent hardness of the water.

Cluster analysis

Q-mode cluster analysis

In pre-monsoon (Fig. 3) Q-mode cluster (Relation between the samples) four major clusters groups are obtain from the data. Second and third major group was subdivided into two minor clusters. This dendogram shows that the station 1 presents the first cluster (Fig. 3) in pre-monsoon season.

Cluster 1 (Stations 1,2,7,15,20,34,43,44 and 60) of the pre-monsoon season is characterized by polluted region. This area lies in nearby highly polluted water bodies, so that the groundwater is polluted. Cluster 2 (Stations 3,5,6,8,12,13,17,18,19,21,22,24,28, 31,32,33, 35,36,38,39,40,41,42,45,46,47,49,50,51,53,55,56,57,58 and 59) of the samples could be categorized as good to very less polluted, as these show high HCO_3. Cluster 3 (Stations 4,26,48,30,54,16,25,27 and 37) of the pre-monsoon season is a typical grouping. Cluster 4 (Stations 9,10,11,14,29,23 and 52) of the pre-monsoon season were related to highly rack-water interaction station, as these are near to the downstream, showing a high TDS value as well as high concentrations of Ca, Mg, K, SO_4, Na, and Cl.

CONCLUSION

The physical appearance of the water is colourless which is also supported by the turbidity. The pH of the studied samples was almost neutral. The EC and TDS in majority of the samples were very high and indicate that it is not suitable for drinking purpose. The hardness in all the studied samples falls in the category of hard to very hard due to the dissolution from the rocks. The Ca^{2+} and Mg^{2+} concentration in most of the samples were within the WHO standards. The most of the locations were not safe for drinking with respect to Na^+, whereas 73.33% of the samples exceed the permissible limits of groundwater. The concentrations of Fe^{2+}, Cl-, NO_3^-, $SO_4^{2-}$and $F^-$are few samples fall in undesirable limit.

The factor analysis of the major ion chemistry of the groundwater reveals three factors operating in this groundwater. The major factors which explain the various loadings are precipitation and chemical weathering and anthropogenic activities. The Q-mode factor and cluster analyses indicate that geology and exchange between the river water and the groundwater plays a dominant role in the hydrochemical evolution of groundwater. Cluster tree diagram reveals that 41.67% of the study area comes under cluster I classification. Cluster tree clearly reveals that elevation high automatically geochemical concentration is low. The geochemical concentration is inversely proposed to elevation. A long term management strategy should be formulated for the protection of groundwater resources for drinking and agricultural activities

TABLE CAPTIONS

Table. 1. Lithology wise Minimum and Maximum values of physical and chemical parameters of groundwater with statistical parameters. These result of the various location groundwater chemical concentration are given in the table.

Hornblende biotite gneiss – 26 Samples					
Parameters	**Units**	**Maximum**	**Minimum**	**Average**	**Standard deviation**
Ca^{2+}	mg/l	224.00	48.00	130.62	40.22
Mg^{2+}	mg/l	88.00	20.00	55.31	16.85
Na^+	mg/l	396.00	68.00	200.38	75.76
K^+	mg/l	58.00	8.00	29.81	13.65
$Fe^{2+ \text{ or } 3+}$	mg/l	1.8	0	0.3	0.64
HCO_3^-	mg/l	533.00	97.00	332.35	95.98
CO_3^{2-}	mg/l	516.00	94.00	321.46	92.78
SO_4^{2-}	mg/l	200.00	38.00	93.46	40.77
Cl^-	mg/l	640.00	72.00	308.31	150.28
F^-	mg/l	2.8	0.2	1.52	0.72
NO_3^-	mg/l	112	1	50.31	29.53
NO_2^-	mg/l	0.8	0.00	0.11	0.21
NH_3	mg/l	3	0.00	0.61	0.82

PO_4	mg/l	3	0.00	0.45	0.67
pH	-	8	7.06	7.54	0.28
EC*	µS/cm	3092	665	1945.54	625.041
TDS	mg/l	2072	446	1303.51	418.78
K. Ratio	meq/l	1.26	0.58	0.78	0.15
RSC*	meq/l	8.92	-1.83	5.10	2.28
SAR*	-	6.59	2.08	3.65	0.98
Na%	%	57.63	38.80	45.55	4.13
Mg ratio	meq/l	47.02	32.54	41.18	3.07
TH	mg/l	1620	20	653.23	347.69
Alk	mg/l	620	28	431.77	129.20
Fissile Hornblende biotite gneiss – 17 Samples					
Ca^{2+}	mg/l	420.00	80.00	201.88	88.76
Mg^{2+}	mg/l	168.00	28.00	85.35	36.20
Na^{+}	mg/l	624.00	108.00	362.88	160.63
K^{+}	mg/l	92.00	12.00	49.88	22.68
$Fe^{2+ \text{ or } 3+}$	mg/l	1.8	0	0.35	0.67
HCO_3^{-}	mg/l	1252.00	226.00	580.29	293.36
CO_3^{2-}	mg/l	1212.00	218.00	549.76	286.99
SO_4^{2-}	mg/l	412.00	54.00	171.12	98.59
Cl^{-}	mg/l	1160.00	116.00	664.94	352.02
F^{-}	mg/l	2.8	0.2	1.7	0.81
NO_3^{-}	mg/l	96	1	49	30.86
NO_2^{-}	mg/l	0.6	0	0.12	0.19
NH_3	mg/l	2.00	0	0.53	0.70
PO_4	mg/l	1.00	5.00	0.45	0.43
pH	-	7.82	7	7	0.18
EC*	µS/cm	6090	1065	3310.24	1362.3
TDS	mg/l	4080.30	714	2218	912.74
K. Ratio	meq/l	1.52	0.66	0.93	0.26
RSC*	meq/l	29.10	2.57	10.74	8.12
SAR*	-	8.66	2.65	5.32	1.73
Na%	%	61.60	42.35	49.40	5.90
Mg ratio	meq/l	51.04	30.39	41.06	5.52
TH	mg/l	1620.00	20.00	629.88	381.40
Alk	mg/l	524.00	28.00	398.94	138.07
Fluvial (Black cotton soil with Gypsum) – 17 Samples					

Ca^{2+}	mg/l	244.00	6.00	131.65	58.91
Mg^{2+}	mg/l	124.00	2.00	61.88	35.39
Na^{+}	mg/l	384.00	10.00	213.53	112.91
K^{+}	mg/l	96.00	2.00	34.00	24.46
$Fe^{2+ \text{ or } 3+}$	mg/l	1.8	0	0.35	0.67
HCO_3^{-}	mg/l	570.00	14.00	315.06	126.59
CO_3^{2-}	mg/l	552.00	12.00	288.71	125.40
SO_4^{2-}	mg/l	280.00	3.00	118.24	82.24
Cl^{-}	mg/l	736.00	12.00	350.59	236.73
F^{-}	mg/l	2.80	0.20	1.70	0.81
NO_3^{-}	mg/l	96.00	1.00	49.00	30.86
NO_2^{-}	mg/l	0.60	0.00	0.12	0.19
NH_3	mg/l	2.00	0.00	0.53	0.70
PO_4	mg/l	1.00	0.00	0.45	0.43
pH	-	8.08	7.11	7.46	0.24
EC*	µS/cm	3670.00	93.00	2052.82	1027.93
TDS	mg/l	2458.9	62.31	1375.39	688.72
K. Ratio	meq/l	0.96	0.62	0.79	0.12
RSC*	meq/l	9.95	-6.28	3.13	3.69
SAR*	-	5.57	0.90	3.68	1.29
Na%	%	51.16	40.02	46.12	3.72
Mg ratio	meq/l	51.76	33.84	41.98	5.27
TH	mg/l	1620	20	629.88	381.40
Alk	mg/l	524.00	28.00	398.94	138.07

Table. 2. Results of the Hydrochemical Facies of Piper Trilinear Diagram result based on chemical concentration as well as type of groundwater

Facies	**Pre-Monsoon**		
	Sample Numbers	**Total No. of Samples**	**Percentage of Samples**
$CaHCO_3$	Nil	-	-
NaCl	Fissile hornblende biotite gneiss – 5,9,10,11,17,23,29,37,46,58	10	16.67%
	Fluvial (Black cotton soil with Gypsum) – 4,16,18,25,27,38,53,57	8	13.33%
Mixed $CaNaHCO_3$	Hornblende biotite gneiss - 2,3,6,7,12,13,19,21,24,26,30,31,32,33,35,39,40,42,44,45,48,49,51,55,56,60.	26	43.33%
	Fissile hornblende biotite gneiss – 8,14,20,22,41,52,54	7	11.67%

	Fluvial (Black cotton soil with Gypsum) – 1,15,28,34,36,43,47,50,59.	9	15%
Mixed CaMgCl	Nil	-	-
CaCl	Nil	-	-
$NaHCO_3$	Nil	-	-

Table 3. Interrelationship of element concentration - Result of R-Mode Factor Analysis of groundwater

Variable	**Factor-1**	**Factor-2**	**Factor-3**
EC	0.94	0.25	0.15
TDS	0.94	0.25	0.15
pH	-0.19	-0.08	-0.70
Alk	0.69	-0.13	0.32
TH	0.95	0.17	0.00
CO3	0.93	0.14	0.00
HCO3	0.95	0.17	0.00
Ca	0.95	0.15	0.10
Mg	0.84	0.28	0.17
Na	0.89	0.28	0.17
K	0.77	0.39	0.13
Fe	0.80	0.10	-0.23
Mn	0.87	-0.06	-0.09
NH3	0.38	0.84	0.04
NO2	0.75	-0.17	-0.26
NO3	0.91	0.29	0.11
Cl	0.89	0.34	0.09
F	0.07	-0.07	0.63
SO4	0.89	0.15	0.09
PO4	0.20	0.89	-0.03
Eigen value	13.35	1.59	1.18
% Total variance	66.74	7.93	5.88
Cumulative Eigen value	13.35	14.94	16.11
Cumulative %	66.74	74.68	80.56

FIGURES/CAPTIONS

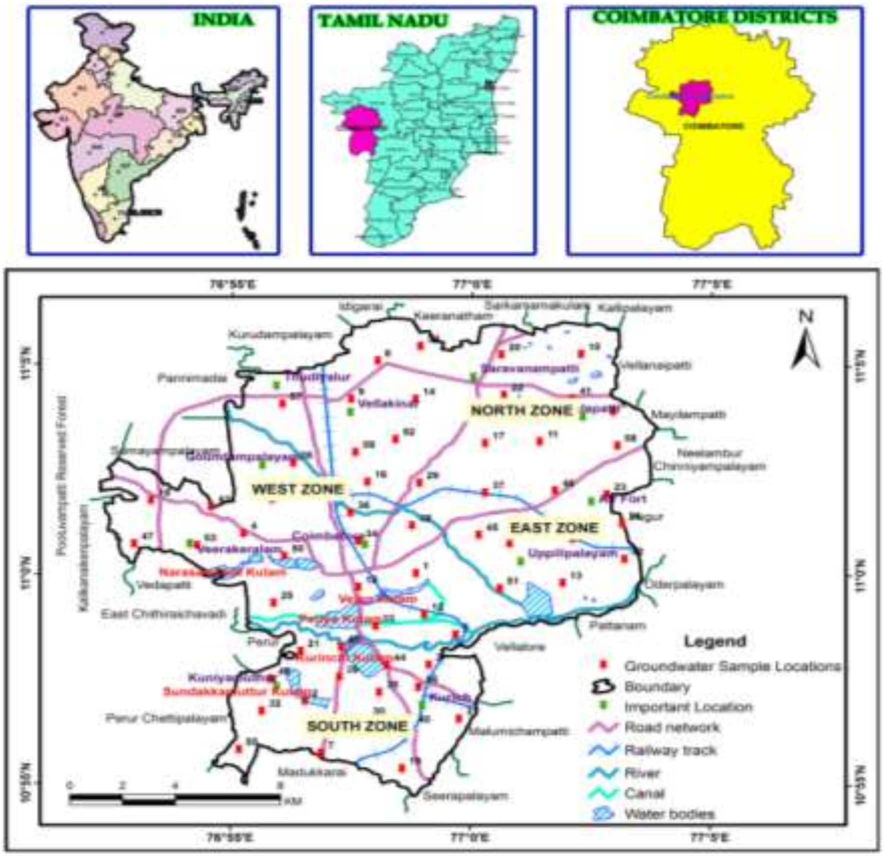

Fig. 1 Location of the Coimbatore Corporation map with groundwater sample locations marked in points and study area details are given in figure.

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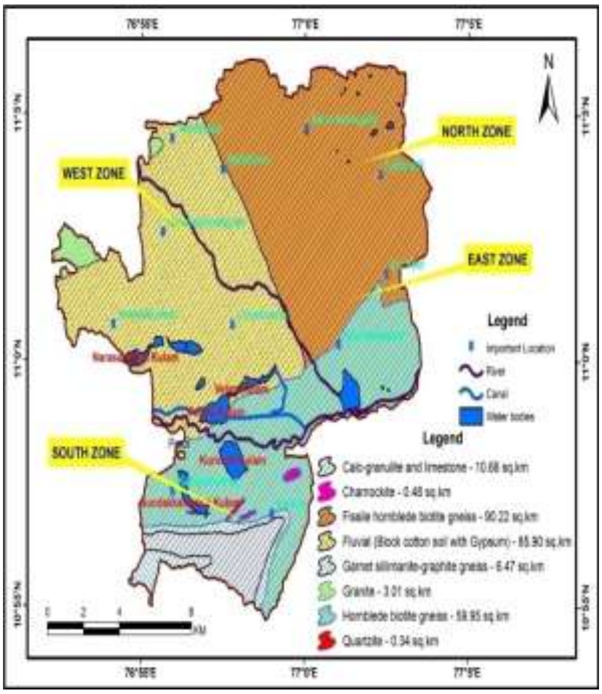

Fig. 3 Geology of the study area with spatially represented and land marks.

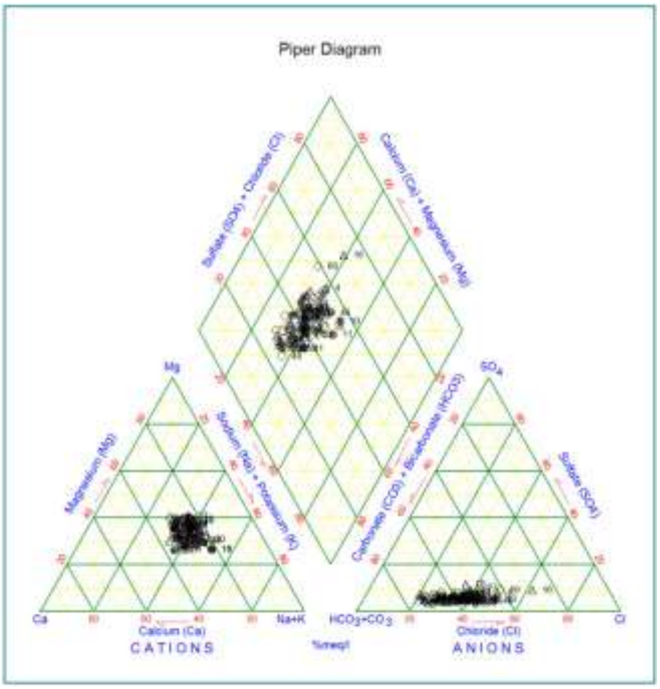

Fig. 2 Piper Trilinear Diagram reveals that the groundwater samples which are the type with respect to cations and anions concentration

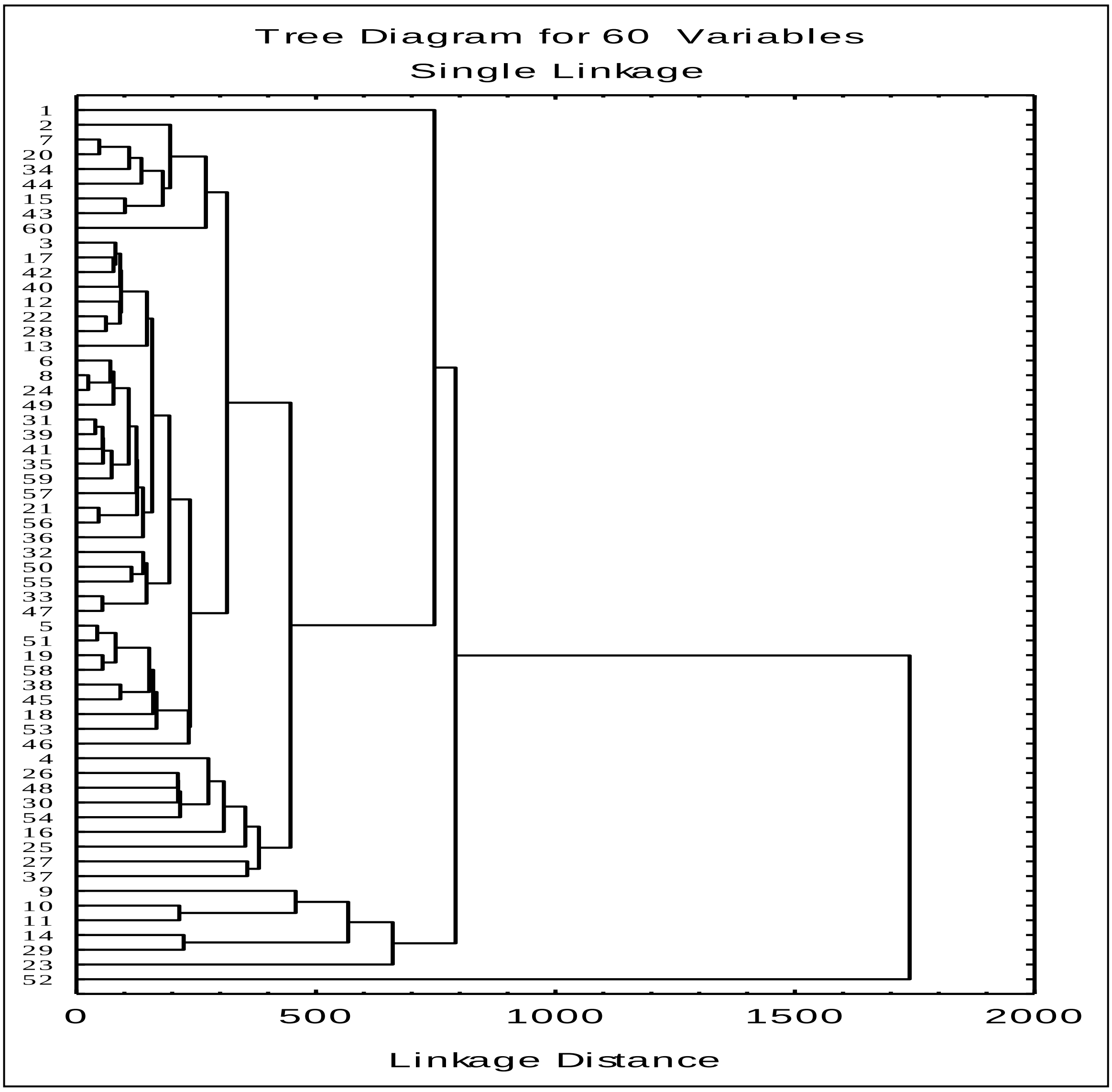

Fig. 4 Pre-Monsoon dendrogram of the Q-mode cluster analysis (Dendrogram of the Q-mode cluster analysis (The axis shown at the top indicates the relative similarity of different cluster groups. Lesser the distance, greater the similarity between objects).

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Author' biography with Photo

I am working as an associate professor in Department of Civil Engineering at PSG College of Technology, Coimbatore, Tamil Nadu, India. And also, Academic and Research experienced for 20 years, and Guided for 8 Ph.D., scholars was Completed and ongoing 11 Ph.D., Research Scholars under Anna University, Chennai. More than 75 Research papers published in national and International reputed journals. Principal Investigator for an AICTE project on Seismic Microzonation of Coimbatore Corporation (Rs. 16.5 Lakhs) sanctioned during 2013 and Three AICTE project handled as Co-Investigator for Rs. 25 Lakhs, One TNSCST student project. I have published Book named as Geographic Information System, during 2006. I have joined as a Life Memberships in many associations like ISTE, ISRS, IAH, AHI, ISRS, INCA, ISG, IAEM, ISET, FGSI, FMSI, Indian Geotechnical Society, International Association of Hydrologists etc.,. Included in Biography of IBC, ABI, and Marquis Who's Who and nominated for several awards.

I am working as an assistant professor in Department of Civil Engineering at Mahendra Engineering College, Namakkal, Tamil Nadu, India. And also, Academic and Research experienced for 07 years and Guided for 15 PG and 56 UG students. I have joined as a Life Memberships in many associations like ISTE, IEI and delivered the special lecture and presented papers at national and international conferences at various Engineering Colleges in around the Tamil Nadu. Real-time Research project proposals submitted by various funding agencies like MSME, UGC, DST, MOFE, DRDO, etc.