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Evaluation of Groundwater Chemistry of a Central Kerala River Basin, India using Multivariate Analysis

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Abstract

Statistical processing of data was necessary to arrive at a reasonable conclusion regarding the chemical behavior of groundwater in a river basin. Multivariate analysis was done to elucidate the groundwater chemistry of a Central Kerala River basin. Hydrochemical parameters like EC, pH, TDS, TH, Ca, Mg, Na, K, Cl, F, HCO_3+CO_3, SO_4, total Fe were estimated in the pre-monsoon and post-monsoon seasons. Factor and cluster analysis differentiated two distinct contributing components to the groundwater in the basin indicating that there is considerable mixing of the groundwater and surface water in the post-monsoon season whereas such a process is not significant during the pre-monsoon period. Different geochemical controls of the investigated parameters were also assessed.

Keywords: *Muvattupuzha river basin, Central Kerala, Groundwater chemistry, Multivariate analysis, Groundwater mixing.*

1. Introduction

The quality of groundwater is of nearly equal importance as its quantity; a fact which has been recognized in recent years. At the outset it is important to know the changes in mineral characters that will vary from place to place depending upon the geology of the terrain. The natural chemistry can often have an important bearing on human health or on livestock. A detailed analysis of major, minor, and trace constituents (including organics) of groundwater is a prerequisite for commissioning public supplies in developing countries. Various international bodies such as the World Health Organization (WHO), European Economic Community (EEC) and Indian Standard Institution (ISI) have given certain standards for drinking water supplies. For the hydrogeologist, an understanding of the geochemical characteristics of groundwater systems can be an important aid in determining the physical properties of flow systems. Hydrochemical data can be used to help estimate such properties as the amount of recharge, the extent of mixing, the circulation pathways, maximum circulation depths, the temperatures at depth, as well as residence time [1]. Statistical tools such as factor and cluster analysis have been widely used to decipher groundwater recharge, mixing, geochemical process and characterization [2, 3 and 4]. The present investigation is aimed to study the groundwater chemistry in hard rock crystalline terrains of the Muvattupuzha River basin, central Kerala through a statistical approach.

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2. Experimental

2.1 Environmental Settings

Muvattupuzha River is one of the major perennial rivers in the central Kerala. It originates from the Western Ghats and drains mainly through highly lateritised crystalline rocks. It debouches into the Vembanad estuary near Vaikom. The Muvattupuzha River basin is bounded by the Periyar River basin in the north and the Meenachil River basin in the south. The interbasin transfer of surface water from Periyar River basin situated on the northern part of the Muvattupuzha basin is a unique feature in the entire state of Kerala. For this study, the Muvattupuzha River basin lying between latitudes 9^0 40′ and 10^0 10′ N and longitudes 76^0 20′ and 77^0 00′ E has been selected (Fig. 1). Before joining the Vembanad Lake at Vettikattumukku towards the western margin of the basin it bifurcates into Ittupuzha and Murinjapuzha. The present work is confined to the river course of almost 116 km up to Vettikattumukku, and thus the area of the river basin covered is only about 1488 km^2.

The basin consists of highly varied geological formations such as Pre- Cambrian crystallines, laterites and Tertiary sedimentary rocks (Fig. 2). Charnockites, hornblende-biotite gneisses and other unclassified gneisses cover a major portion (~85%) of the drainage basin. These rock types are often intruded by rocks of acidic (granite, pegmatite and quartz vein) and basic (gabbro and dolerite) types. Laterite is seen almost in the entire basin as a cap rock and Tertiary Warkallai beds are found near the mouth of the river. The basin is also characterized by more than 70% of lateritic soil, the remaining being riverine alluvium and brown hydromorphic soil.

2.2 Sampling and analysis

Groundwater samples have been collected from 55 dug wells from Muvattupuzha River basin during pre-monsoon (April to May) and post-monsoon (December) periods. The pH and electrical conductivity (EC) were measured at the sampling location, whereas the major cations and anions were estimated in the laboratory, following standard analytical procedures [5]. Na^+ and K^+ were analyzed using flame photometry (Systronics FPM digital Flame Photometer). Ca^{2+} and Mg^{2+} were analyzed by ethylene diaminetetraacetic acid (EDTA) titrimetric method, whereas Cl^- was determined by argentometric titration using standard silver nitrate. The CO_3^{2-} and HCO_3^- concentrations of groundwater were determined titrimetrically [5]. The total iron in samples was analyzed by colorimetric method (Hitachi Model 2000, double beam UV-Visible Spectrophotometer) and sulphate in samples was analyzed by the nephelo-turbidimetry method. Fluoride concentrations in the samples were measured by colorimetric methods using SPADNS reagent [5]. Analytical reproducibility was checked by performing triplicate analyses for each sample; thus final analytical data are presented as the average of triplicate values.

2.3 Statistical analyses

The analytical data for the pre-monsoon and post-monsoon seasons were subjected to factor and cluster analysis using the software, Statistica Ver.5.0. Statistical processing of the data was absolutely necessary to arrive at a reasonable conclusion regarding the chemical behavior of this complex Muvattupuzha river basin. Since inter-basin transfer occurs in the study area, the chemical indicators may also get modified. Hence, factor analysis was chosen to get a clear picture of the processes that are taking place in the region and to reduce the dimensionality of the problem.

3. Results and Discussion

The results of chemical analysis of groundwater samples for 13 parameters in 55 locations of the Muvattupuzha River Basin in the pre-monsoon and post-monsoon seasons are summarized in Tables 1 and 2.

3.1 Factor analysis

Factor analysis assumes that relationships within a set of variables reflect correlations with a smaller number of underlying factors [6]. The main applications of factor analytical techniques are to reduce the number of variables and to detect structure in the relationships between variables, or to classify them. A special feature of this technique is that it extracts factors or principal components which are linear combinations of all variables that can explain the maximum of total variance successively. Thus the first factor explains the maximum variance; the remaining factors define the maximum of the residual variability. The factors extracted are uncorrelated or orthogonal to each other. The variances extracted by the factors are called the eigen values. Since the first factor explains maximum variance it has the highest eigen value. The sum of eigen values of all factors will be equal to the total number of variables. In this study we have selected only those factors which have eigen values greater than one. The correlations of the original variables in the factors extracted are termed as 'factor loadings'. To obtain a clear pattern of loadings and to maximize the variance on the first extracted principal axes, the Varimax normalized rotation was applied [7, 8, 9 and 10].

Three main factors with eigen value greater than 1 were extracted using this technique in each season from the original 13 variables of more than 100 samples. The 'loadings' of variables in these factors were analysed in order to get the variations in geochemical behavior of the groundwater in the Muvattupuzha basin. A graphical representation of the analysis was also given to get a better visual perception of the grouping variables. The 13 variables were distributed in each of these factors in a distinct manner in the two seasons and are discussed in detail below. The factor loadings and eigen values with cumulative variance are given in Tables 3 to 6.

3.2 Factor analysis: Pre-monsoon season

In the pre-monsoon season, factor analysis displayed most of the variables loadings in the first factor itself (EC, Ca, Na, K, HCO_3, SO_4, Cl, TDS and TH). This factor could alone explain 53.27% of the total variance and the second and third factors showed significant loading of pH and Mg respectively (Table 3). These three factors explained 73% of the total variance (Table 4). Since the first factor exhibited significantly high loadings (>0.7) for almost all ions and moderate loading for K and total Fe, it can be concluded that there may be a single source for all the ionic species. The less significant loading of total Fe in the pre-monsoon indicates that this ion was probably derived from the leaching of lateritic soil, a process which might have diminished in the lean flow period. Graphical representations of the factors are depicted in Figure 3.

The scatter diagram of factor 1 with factor 3 clearly displayed the association of variables in a distinct manner.

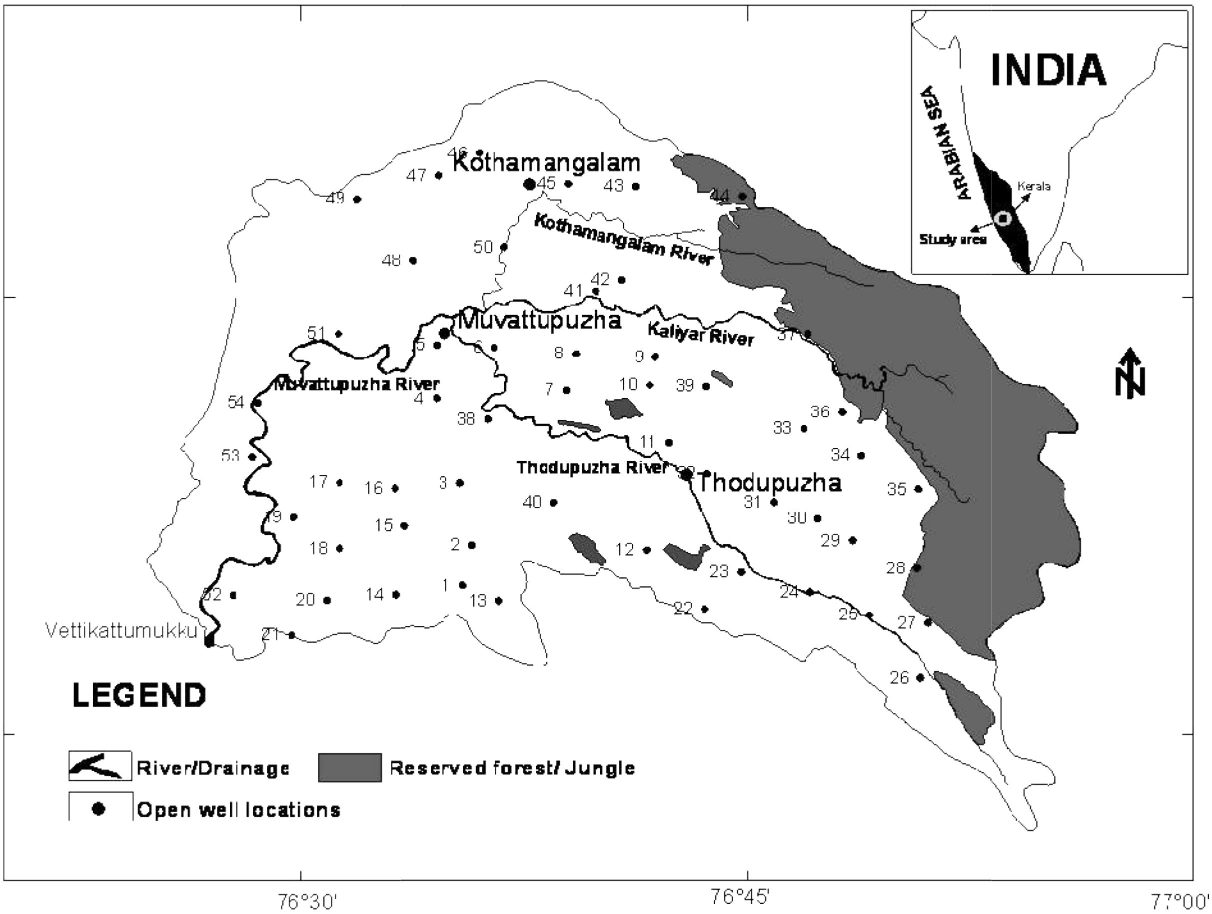

Fig. 1. Base map and open well locations of the Muvattupuzha river basin.

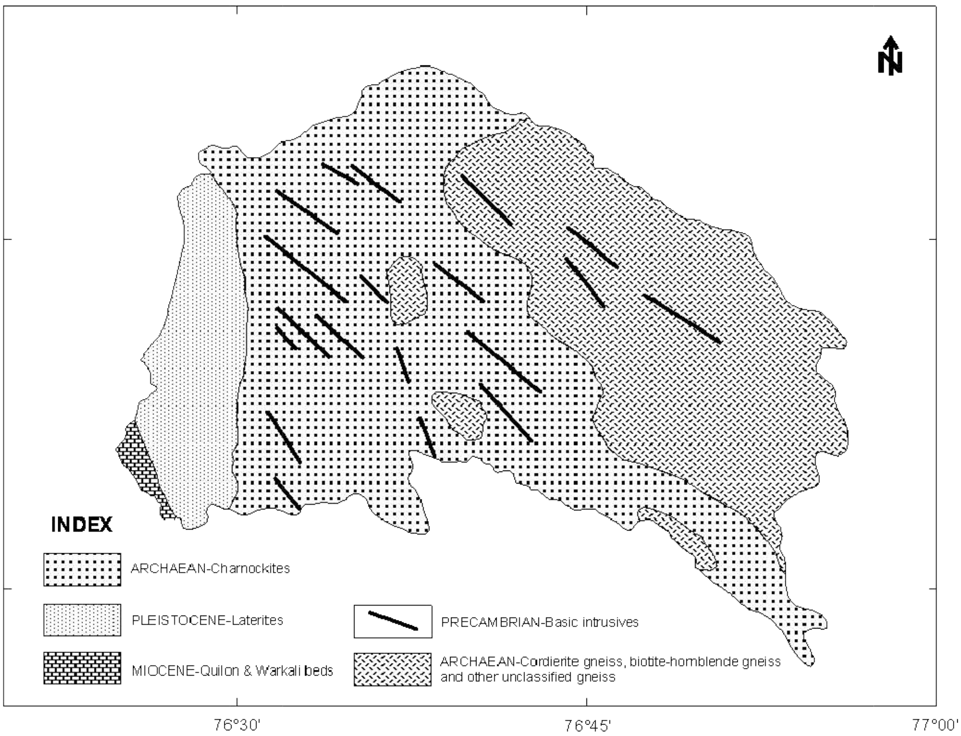

Fig. 2. Geology of the Muvattupuzha river basin (Source: GSI. 1995).

Table 1. Results of chemical analysis of groundwater from Muvattupuzha River Basin for the pre-monsoon season.

Well No.	EC	pH	Ca	Mg	Na	K	HCO_3+CO_3	SO_4	Cl	F	T. Fe	TDS	TH
1	166	6.5	9.6	3.37	9.3	1.1	22.0	6.9	14.9	0.34	ND	70	38
2	210	7.5	20.8	4.00	19.0	9.0	31.9	9.1	32.9	0.10	ND	130	68
3	55	8.0	4.0	1.07	4.2	1.0	15.4	3.4	5.0	0.07	ND	35	14
4	137	6.5	16.8	0.73	7.4	2.9	30.8	5.6	15.9	0.15	ND	87	45
5	112	6.3	6.4	5.32	13.0	1.2	17.6	5.6	18.9	0.22	0.20	71	38
6	64	6.6	4.0	0.20	7.7	1.0	23.1	5.6	6.0	ND	0.39	41	11
7	73	7.5	4.0	1.95	5.9	1.0	23.1	4.9	13.9	0.17	ND	47	18
8	68	6.7	6.4	0.49	5.1	0.7	24.2	4.9	8.0	ND	ND	43	18
9	72	6.8	0.8	3.90	5.5	1.3	17.6	4.9	10.0	0.17	ND	48	18
10	54	6.4	0.8	2.15	4.9	1.3	9.9	4.9	9.0	ND	ND	34	11
11	57	7.3	4.8	1.46	3.4	1.2	22.0	4.9	5.0	ND	ND	36	18
12	271	6.8	12.0	4.98	18.0	16.5	92.4	7.8	29.9	0.08	ND	173	50
13	153	7.3	8.0	2.15	21.0	3.5	60.5	5.8	8.0	0.31	0.39	99	29
14	142	7.3	20.8	2.24	3.0	1.9	48.4	9.2	6.0	0.11	ND	90	61
15	52	6.6	4.0	1.51	3.2	0.7	15.4	6.2	7.0	0.07	ND	33	16
16	52	6.3	0.8	3.02	3.8	0.9	20.9	5.6	9.0	ND	ND	35	14
17	53	7.1	6.4	0.05	4.9	1.1	17.6	7.3	5.0	0.04	N.D.	34	16
18	40	5.9	1.6	0.78	4.1	0.7	14.3	6.4	8.0	N.D.	0.14	25	7
19	55	5.7	3.2	0.68	5.2	0.4	12.1	5.6	7.0	0.24	N.D.	35	11
20	56	6.7	4.0	1.51	4.2	1.1	16.5	4.9	5.0	0.12	ND	36	16
21	124	7.2	14.4	0.44	5.2	5.5	59.4	4.9	5.0	ND	ND	80	38
22	45	6.3	1.6	1.22	2.3	0.7	11.0	6.4	2.0	0.04	ND	28	9
23	55	6.2	4.0	0.63	3.4	1.0	13.2	4.4	7.0	N.D.	ND	35	13
24	47	6.1	3.2	1.12	3.8	0.9	16.5	6.4	6.0	N.D.	ND	30	13
25	59	6.7	5.6	0.54	3.7	1.3	12.1	4.5	4.0	0.18	ND	37	16
26	119	6.7	11.2	0.20	9.7	3.6	23.1	6.2	15.9	0.08	0.08	76	29
27	79	6.4	4.0	0.20	2.9	1.4	30.8	6.9	1.0	0.08	2.40	50	11
28	67	6.8	6.4	2.68	3.6	1.6	26.4	6.2	2.0	0.09	0.08	42	27
29	98	6.3	8.0	0.39	7.6	2.7	11.0	5.6	12.9	0.17	N.D.	62	22
30	78	6.7	4.8	1.46	5.5	3.4	18.7	5.6	10.0	ND	0.08	49	18
31	99	6.7	0.8	7.41	8.0	1.6	23.1	5.8	10.0	0.04	0.76	63	32
32	156	6.6	11.2	3.27	11.4	7.9	59.4	9.0	9.0	0.04	ND	99	41
33	53	7.6	4.8	0.15	4.6	1.4	12.1	4.1	9.0	N.D.	ND	33	13
34	49	6.3	2.4	1.17	4.5	0.9	22.0	3.4	9.0	0.18	ND	31	11
35	61	6.3	5.6	0.98	5.6	2.5	19.8	5.2	10.0	N.D.	0.14	39	18
36	103	6.6	3.2	0.24	6.2	6.8	22.0	6.9	12.0	0.08	0.39	66	9
37	124	6.5	6.4	1.37	13.8	7.0	14.3	6.4	25.9	0.22	0.24	78	22
38	69	7.3	5.6	0.54	3.2	0.8	22.0	5.6	6.0	0.35	0.14	43	16
39	94	6.0	6.4	0.93	5.8	6.7	6.6	7.3	13.9	0.31	N.D.	60	20
40	40	6.0	3.2	1.56	2.5	0.7	16.5	5.8	8.0	0.29	N.D.	26	14
41	46	6.7	1.6	0.78	2.8	1.5	27.5	5.6	2.0	0.15	1.76	30	7
42	170	6.1	16.8	0.29	12.0	4.3	24.2	6.7	22.9	0.02	ND	108	43
43	57	6.1	1.6	2.98	3.2	1.0	13.2	7.4	9.0	ND	ND	37	16
44	136	6.3	1.6	0.78	3.1	1.5	61.6	6.9	8.0	0.10	0.14	87	7
45	161	6.3	16.0	1.66	19.0	8.2	34.1	6.9	29.9	ND	ND	103	47
46	89	6.1	8.0	0.83	11.8	3.0	15.4	5.6	9.0	ND	ND	56	23
47	121	7.0	9.6	1.61	9.7	7.3	11.0	7.3	17.9	0.08	0.18	77	31
48	134	6.6	7.2	0.44	16.0	1.4	12.1	6.9	11.0	0.03	0.08	85	20
49	356	7.3	38.5	0.29	27.0	3.9	128	13.6	38.9	0.07	4.74	227	97
50	107	6.3	6.4	0.05	8.6	5.6	13.2	7.3	12.0	0.36	0.40	68	16
51	80	6.1	5.6	0.10	6.8	2.3	9.9	6.9	10.0	ND	ND	51	14
52	186	7.4	16.0	2.98	6.0	0.7	62.7	8.0	11.0	0.09	1.02	119	52
53	44	7.0	1.6	0.78	3.6	1.3	19.8	5.8	5.0	0.05	1.33	28	7
54	87	6.6	1.6	0.34	7.6	3.5	12.1	6.4	17.9	0.04	0.39	55	5
55	52	6.2	4.1	1.50	6.8	1.0	25.1	4.1	24.8	0.40	N.D.	33	16

T.Fe- Total Iron, TH- Total Hardness * Except EC and pH, all others are expressed in mg/l N.D. not Detected

Table 2. Results of chemical analysis of groundwater from Muvattupuzha River Basin for the post-monsoon season.

Well No.	EC	pH	Ca	Mg	Na	K	HCO_3+CO_3	SO_4	Cl	F	T.Fe	TDS	TH
1	77	6.4	6.53	1.00	7.00	1.48	33.95	6.84	5.00	0.24	0.66	49	20
2	139	6.9	16.32	N.D.	12.00	8.58	33.95	8.39	15.00	0.09	0.18	88	40
3	42	6.4	1.63	1.50	5.00	2.01	38.80	N.D.	5.00	0.07	0.06	26	10
4	95	6.7	10.61	2.00	5.50	6.55	48.95	4.65	10.00	0.11	N.D.	60	34
5	87	6.8	5.71	1.00	11.50	2.20	29.10	2.75	16.99	0.19	0.07	55	18
6	44	6.2	3.26	0.50	5.80	1.12	19.40	2.90	4.00	N.D.	N.D.	28	10
7	52	6.4	4.08	1.50	6.80	0.93	29.10	2.75	8.00	0.15	N.D.	33	16
8	48	6.4	4.90	1.00	5.10	1.48	24.25	3.29	6.00	N.D.	0.07	30	16
9	30	6.4	2.45	2.50	2.80	0.93	29.10	2.60	2.00	0.16	N.D.	19	16
10	41	6.1	4.08	0.50	5.90	1.83	19.40	3.29	8.00	N.D.	0.19	26	12
11	42	7.0	3.26	0.50	2.10	0.90	10.00	3.15	4.00	N.D.	N.D.	27	10
12	125	7.1	11.42	0.50	8.20	7.65	43.65	3.59	9.00	N.D.	0.28	80	30
13	29	6.4	4.90	0.50	4.80	1.48	29.10	2.60	8.00	0.30	0.13	19	14
14	86	7.4	13.87	1.00	5.20	1.48	53.35	2.60	3.00	0.09	N.D.	54	38
15	45	6.6	4.08	1.00	5.00	0.58	24.25	2.60	4.00	0.05	0.07	27	14
16	43	6.4	3.26	1.00	5.00	1.12	33.95	N.D.	6.00	N.D.	N.D.	28	12
17	46	6.6	4.08	1.50	6.50	1.31	33.95	3.29	6.00	N.D.	0.35	29	16
18	41	5.9	2.45	0.50	6.20	2.20	29.10	2.90	12.00	N.D.	N.D.	26	8
19	54	5.6	3.26	0.50	6.40	1.12	24.25	2.75	11.00	0.19	N.D.	35	10
20	45	7.1	3.26	0.50	5.80	1.68	29.10	2.60	5.00	0.10	0.67	28	10
21	55	6.8	4.08	1.50	7.40	2.54	33.95	2.75	9.00	N.D.	0.06	35	16
22	25	6.1	2.45	1.00	3.40	0.93	29.10	3.82	5.00	N.D.	0.13	16	10
23	39	6.2	1.63	2.00	5.20	2.01	24.25	N.D.	4.00	N.D.	0.07	24	12
24	32	6.5	2.45	0.50	4.30	1.48	24.25	2.60	6.00	N.D.	N.D.	20	8
25	46	6.0	4.08	3.00	5.00	1.12	33.95	2.60	5.00	0.11	N.D.	30	22
26	56	6.8	6.53	0.50	5.20	2.39	29.10	3.52	4.00	N.D.	N.D.	35	18
27	29	6.6	1.63	0.50	3.90	1.83	29.10	2.75	3.00	N.D.	N.D.	18	6
28	27	6.2	2.45	1.00	2.60	0.93	33.95	3.29	2.00	N.D.	0.28	17	10
29	74	6.4	1.63	0.50	8.30	3.64	24.25	3.06	8.00	0.06	N.D.	47	6
30	73	6.1	6.53	0.50	7.80	4.76	24.25	2.75	10.00	N.D.	N.D.	46	18
31	48	6.6	5.71	0.50	4.50	1.31	29.10	5.42	6.00	N.D.	N.D.	30	16
32	128	6.8	12.24	0.50	12.20	10.17	63.05	2.90	12.00	N.D.	N.D.	82	32
33	36	6.6	2.45	0.50	4.60	3.30	29.10	2.60	3.00	N.D.	0.35	24	8
34	41	6.4	2.45	1.00	5.10	2.01	24.25	2.75	7.00	0.09	0.18	27	10
35	71	6.3	5.71	0.50	8.50	5.84	24.25	2.60	12.00	N.D.	0.11	45	16
36	94	6.9	8.16	1.50	8.60	10.53	33.95	2.75	13.00	N.D.	0.26	60	26
37	138	6.4	10.61	1.50	13.80	7.81	19.40	2.75	22.99	0.21	N.D.	88	32
38	61	7.0	7.34	0.50	4.60	2.01	38.80	2.75	6.00	0.31	0.19	39	20
39	86	6.2	2.45	0.60	1.40	0.60	14.10	2.90	10.18	0.31	N.D.	55	12
40	34	6.2	2.45	0.50	3.20	0.76	33.95	3.06	3.00	0.25	0.06	22	8
41	40	6.7	4.90	1.00	4.20	0.76	29.10	2.60	2.00	0.15	0.28	26	16
42	88	6.1	8.98	1.00	7.60	4.57	24.25	3.52	11.00	N.D.	0.28	57	26
43	49	7.4	6.53	0.50	4.00	4.76	29.10	2.75	5.00	N.D.	N.D.	32	14
44	55	6.4	4.08	1.50	5.30	2.20	29.10	3.29	6.00	0.10	0.06	36	16
45	180	6.4	17.95	1.50	15.40	7.29	24.25	9.16	21.99	N.D.	0.06	115	50
46	71	6.5	6.53	1.00	12.00	4.03	29.10	2.60	16.99	N.D.	0.06	45	20
47	48	6.7	2.45	1.50	5.20	2.20	29.10	3.59	4.00	N.D.	0.14	31	12
48	114	6.3	5.71	1.50	13.70	2.20	24.25	8.70	16.00	N.D.	0.13	72	20
49	254	8.1	34.27	9.50	16.00	4.91	155.2	3.52	15.00	N.D.	1.00	162	122
50	137	7.0	2.45	0.50	14.40	10.03	38.80	3.52	22.99	0.33	0.11	87	8
51	50	6.3	2.45	1.50	5.50	10.01	24.25	3.06	9.00	N.D.	N.D.	32	12
52	97	7.4	16.32	1.50	5.70	0.58	63.05	2.75	5.00	0.09	1.20	63	46
53	37	6.6	3.26	0.50	4.80	1.48	29.10	4.21	5.00	N.D.	N.D.	23	10
54	110	6.2	3.26	3.00	13.40	5.32	24.25	2.90	22.99	N.D.	0.11	70	20
55	72	6.1	3.26	0.50	7.90	2.20	19.40	3.29	10.00	0.35	N.D.	46	10

T.Fe- Total Iron, TH- Total Hardness * Except EC and pH, all others are expressed in mg/l N.D. not Detected

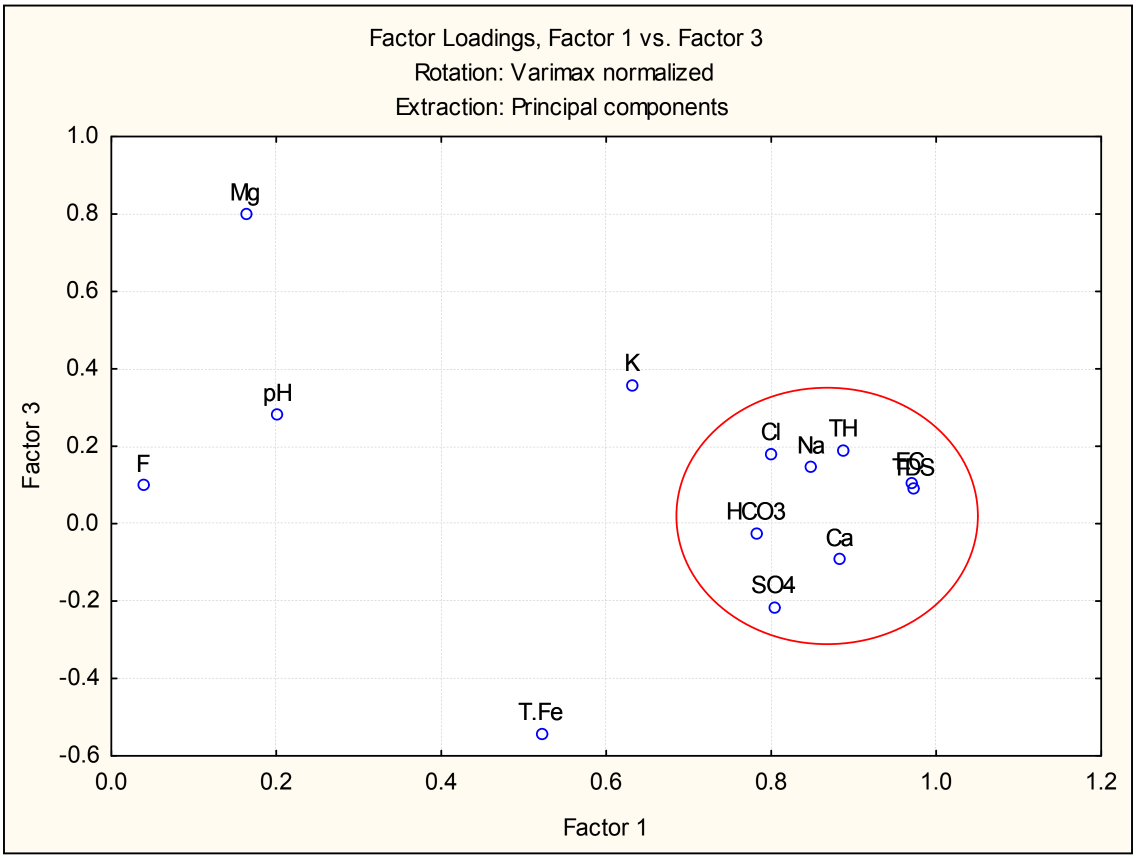

Fig. 3. Scatter diagram of Factor 1 vs Factor 3 for the pre-monsoon season. (Please note the grouping of most of the parameters into one group).

Table 3. Factor loadings for the pre-monsoon season (loadings > 0.7 are given in red).

	Factor 1	Factor 2	Factor 3
EC	0.97	0.06	0.10
pH	0.20	0.77	0.28
Ca	0.88	0.20	-0.09
Mg	0.16	0.09	0.79
Na	0.85	-0.17	0.15
K	0.63	-0.31	0.36
HCO_3	0.78	0.37	-0.0254
SO_4	0.80	0.09	-0.22
Cl	0.80	-0.34	0.18
F	0.04	-0.38	0.09
T.Fe	0.52	0.36	-0.54
TDS	0.97	0.08	0.09
TH	0.89	0.22	0.19
Expl.Var	6.82	1.36	1.31
Prp.Totl	0.53	0.10	0.10

Table 4. Eigen values for the pre-monsoon season.

	Eigen value	% Total Variance	Cumulative Eigen Value	Cumulative Total Variance
Factor 1	6.93	53.27	6.93	53.27
Factor 2	1.47	11.30	8.39	64.57
Factor 3	1.10	8.46	9.49	73.02

Table 5. Factor loadings for the post-monsoon season (loadings > 0.7 are given in red).

	Factor 1	Factor 2	Factor 3
EC	0.58	0.79	0.06
pH	0.74	0.05	-0.06
Ca	0.82	0.46	-0.05
Mg	0.78	0.14	-0.10
Na	0.25	0.89	-0.02
K	0.046	0.77	-0.23
HCO_3	0.93	0.11	-0.05
SO_4	0.03	0.55	0.06
Cl	-0.01	0.92	0.09
F	-0.07	0.03	0.97
T.Fe	0.75	-0.08	0.15
TDS	0.58	0.79	0.06
TH	0.88	0.40	-0.06
Expl.Var	4.76	4.23	1.06
Prp.Totl	0.37	0.33	0.08

Table 6. Eigen values for the post-monsoon season.

	Eigen value	% Total Variance	Cumulative Eigen Value	Cumulative Total Variance
Factor 1	6.00	50.78	6.60	50.78
Factor 2	2.40	18.47	9.00	69.24
Factor 3	1.055	8.12	10.057	77.36

Only pH and Mg had high loadings in the rest of the factors; this indicates some external influence for them. Perhaps the carbonate dissolution- precipitation reaction alone cannot explain the variation of pH. In the humid tropics, the influence of organic acids (e.g. humic and fulvic acids) is magnified in the pre-monsoon periods; this might have contributed significantly in determining the pH of the system.

It should be noted that individual concentrations of all the ions in this season were higher than the post-monsoon period. In the pre-monsoon period, the groundwater of this hard rock basin may have undergone a concentration effect during the summer time when inflow is greatly reduced which elevates the individual ionic concentrations. Thus occurrence of major ions in a single factor in the summer periods indicates that the flow direction is towards the running stream and that no mixing with river water is taking place in this season.

3.3 Factor analysis: Post-monsoon season

The Muvattupuzha River basin presented a completely different picture of geochemical processing in the post-monsoon season. Here again three factors were extracted with eigen value >1. However, the loadings of the variables in these three factors were astonishingly different from that of the pre-monsoon season; pH, Ca, Mg and HCO_3, total Hardness and total Fe correlated positively in the first factor along with moderate loading of TDS and EC. The second factor had significant correlations for Na, K, Cl, TDS and moderate loading for Ca and SO_4 (Table 5). Thus, it is possible to separate the two factors as 'ground water component' and 'stream water component'. Only fluoride was loaded in the third factor indicating an anthropogenic source for it. The association of components causing hardness in the first factor could explain 51% of total variance, whereas the second and third factor could explain 18.5% and 8.1% of variance respectively. All together, 77.4% of the variance is explained by these three factors (Table 6).

Although, EC and TDS were highly loaded in the second factor, they were moderately loaded in the first factor also. This can be expected, since the conducting ions were equally distributed in the first two factors. From the analysis, it can be concluded that Ca may have been present either as carbonates or sulphates. Scatter diagram of factor 1 with factor 3 is given in Figure 4.

Factor analysis revealed two distinct components for the post- monsoon season, namely, the groundwater component and the stream water component; it can be concluded that fair mixing of the two water bodies was taking place in this season.

3.4 Cluster analysis

Cluster analysis is an assortment of techniques designed to perform classification by assigning observations to groups so that each group is more or less homogeneous and distinct from other groups [11]. In clustering, the objects are grouped in such a manner that similar objects fall into the same class [12]. As an exploratory technique with graphical output (dendrogram), cluster analysis does not require many of the assumptions that other statistical methods do. The Ward's Method, using squared Euclidian distances as a measure of similarity, possesses a small space distorting effect, uses more information about cluster contents than other methods and has been proved to be an extremely powerful grouping mechanism [13, 14 and 15]. This method was selected for the present study using the statistical package, *Statistica, Version 5.0*.

Cluster analysis using Ward's method and squared Euclidean distance as the linkage criteria was applied to the data set (Figs. 5 & 6). From the analysis in the two seasons a clear pattern of clusters could not be discerned. However, in the pre-monsoon season, two distinct clusters were obtained. This distribution is totally disturbed in the post-monsoon season even though two clusters can be identified in this season also. No clear pattern of distribution of sampling points could be observed which may be a reflection of the human intervention in this basin. Huge amount of water from the adjacent Periyar River is discharged to the Muvattupuzha River after power generation at the largest power station of the State, the Idukki hydroelectric project. This inter-basin transfer might have modified the geochemistry of the groundwater of the basin causing a mixed nature.

4. Conclusions

- An examination of the geochemical processing of groundwater of Muvattupuzha River Basin was attempted with the aid of multivariate statistical tools such as factor and cluster analysis.
- Results of factor analysis have shown that in the post-monsoon season the groundwater is well connected to the river water whereas in the lean flow period, such an exchange between two water bodies is not significant. Separate clusters of downstream sampling locations were clearly visible in the cluster analysis.

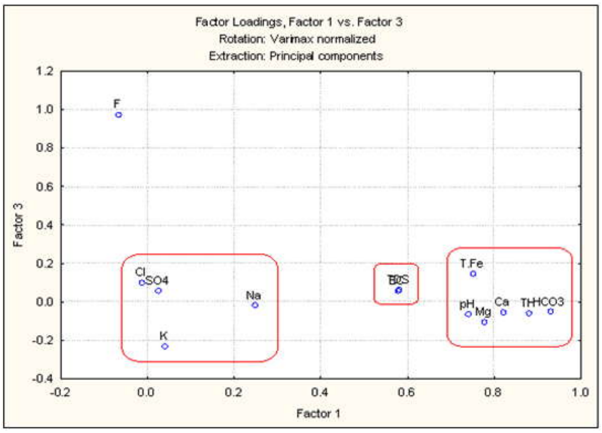

Fig. 4. Scatter diagram of Factor 1 vs Factor 3 for the post-monsoon season. Two groups of parameters (streamwater component and groundwater component) are clearly seen.

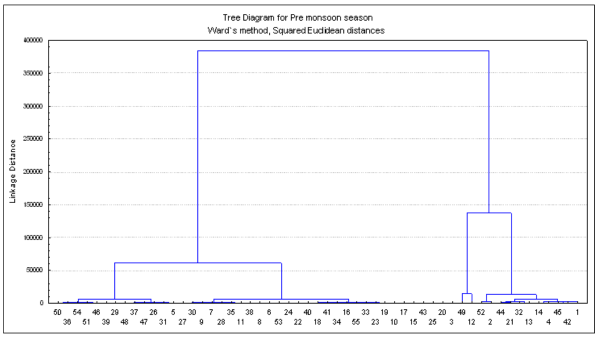

Fig. 5. Dendrogram of sampling points for the pre-monsoon season. Two clusters are obtained.

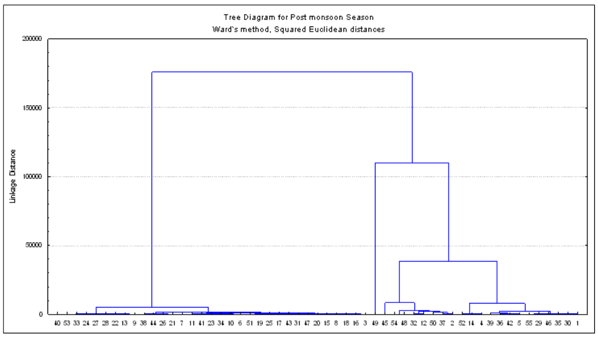

Fig. 6. Dendrogram of sampling points for the post-monsoon season with two clusters.

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