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Hydro-chemical Grouping of Ground Water in Coastal Region of Cuddalore District, Tamil Nadu Using Cluster Analysis

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ABSTRACT

Hydro-chemical ground water data of coastal region of Cuddalore district was subjected to cluster analysis to group the ground water based on its homogeneity and to find out the influencing factor on ground water quality. The twenty-seven water samples were collected during summer and post monsoon season of 2007 and characterized for nine physico-chemical parameters. These physicochemical parameters were subjected to cluster analysis. From the analysis, four and five distinct clusters were identified in summer and post monsoon season respectively. The different cluster recognized in the cluster analysis differed in chemical composition. It also had significant correlation with spatial distance from the sea as well as landform.

Key words: Coastal land, ground water, hydro-chemical grouping, cluster analysis

INTRODUCTION

Groundwater in shallow aquifers is the main source of water for agriculture, industries and domestic consumption in coastal region. There is a wide variation in the chemical composition of ground water in coastal region, reflecting the diverse geo-hydrology, hydrometeorology, topography, drainage and artificially imposed conditions (Kim *et al.*, 2005). The hydrochemical differentiation of ground water in coastal areas is very complex due to influence of multitude of factors such as sea water intrusion (Morell *et al.*, 1996), rainfall, geology, topography, extent of ground water exploitation, fish farming, pollution phenomena and other local factors. But it is necessary to understand these processes in coastal land for the wise management of groundwater and its sustainable use.

Cluster analysis groups samples by linking inter-sample similarities and illustrates the overall similarity of variables in the data set (Massart and Kaufman, 1983). Cluster analysis of groundwater forms finite number of clusters among total samples and each cluster represents a specific hydrogeochemical composition of groundwater (Frapporti *et al.*, 1993; Ochsenkuhn *et al.*, 1997). Wenning and Erickson (1994) reported that application of cluster analysis was one of the unbiased methods that can help to indicate the natural association between ground water quality and variables.

Recently, many researches have adopted cluster analysis as a part of the multivariate statistical analysis for the assessment of groundwater quality (Suk and Lee, 1999; Helena *et al.*, 2000; Adams *et al.*, 2001; Lee *et al.*, 2001). Guler *et al.* (2002) concluded that combination of graphical and statistical techniques provides a consistent and objective means

to classify large number of groundwater samples. With this backdrop, cluster analysis was exploited in this experiment to group the ground water and to find out the natural association between ground water and different variables in the coastal regions of Cuddalore district, Tamil Nadu.

MATERIALS AND METHODS

Study area description: The study site, coastal region of Cuddalore district in Tamil Nadu state is situated between 11.40° and 11.25°N latitudes and 79.60° and 79.85° Longitudes. The region fall under tropical semi-arid climate, with a mean annual temperature of 27°C and a mean annual rainfall of 1150 mm. The rainy season is from October to December. Coastal aquifers in the study area are, geologically composed of Cuddalore formation belongs to tertiary age. The main landform includes seacoast, estuary, sandy plains, sand dunes and alluvial plains.

Water sampling and characterization: The hydro-geochemical information was obtained from a sampling network of 27 wells from three different zones (Zone-I<1.5 km; Zone-II 1.5 -3 km and Zone-III>3 km from sea coast) of study site. Zone I, II and III includes 7 (Well ID: 1-7), 9 (Well ID: 8-16) and 11 (Well ID: 17-27), wells, respectively. The samples were drawn as per standard procedures at tri-monthly interval from the respective wells during 2007. In this study, data pertaining to summer and post monsoon season is reported. Ground water characterized for nine variables viz., cations (Ca^{2+} , Mg^{2+} , Na^+ , K^+), anions (HCO_3^- , Cl^- , SO_4^{2-}), pH and EC.

The pH and electrical conductivity was determined by adopting US Salinity Lab. Staff (1968). Sodium and potassium was analyzed by flame photometry method (Stanford and English, 1949). Calcium and magnesium was quantified by versenate method (Diehl *et al.*, 1950). Anions viz., carbonates, bicarbonates and chloride were quantified by titration method (AOAC, 1950). Sulphate was determined by turbidity method as described by Tandon (1999). All reported values had an ionic balance within 5%.

Cluster analysis: Nine physico-chemical constituents, i.e., cations (Ca^{2+} , Mg^{2+} , Na^+ , K^+), anions (HCO_3^- , Cl^- , SO_4^{2-}), pH and EC, were used for the cluster analysis. The hierarchical clustering analysis was performed to split the water samples into a finite number of groups based on the chemical similarities in the ground water samples. Hierarchical diagram was prepared by adopting ward's method whereby well samples were formed into clusters on the x-axis and the linkage distances appear on the y-axis. The closer linkage distance indicates more similarity between the samples and wide distance indicates less similarity between the samples. Systat 11.0 package was utilized for cluster analysis.

RESULTS

Characteristics of ground water: Groundwater was alkaline (pH range: 7.19-8.48) in reaction irrespective of distance from seacoast and seasons. The degree of alkalinity decreased in post monsoon season. The mean pH value for the whole study area was 7.81 and 7.59 for summer and post monsoon season, respectively. The mean EC was 2.45 and 1.17 dS m^{-1} , respectively for the summer and post monsoon season.

Table 1: Characteristics of ground water

	pH		EC (dS m ⁻¹)		Ca (meq L ⁻¹)		Mg (meq L ⁻¹)		Na (meq L ⁻¹)		K (meq L ⁻¹)		Cl (meq L ⁻¹)		SO ₄ (meq L ⁻¹)		HCO ₃ (meq L ⁻¹)	
Well	-----		-----		-----		-----		-----		-----		-----		-----		-----	
ID	S	PM	S	PM	S	PM	S	PM	S	PM	S	PM	S	PM	S	PM	S	PM
1	7.54	7.19	3.92	1.11	3.84	1.73	4.56	2.69	8.54	3.14	0.17	0.14	8.79	3.25	2.50	1.08	2.05	1.97
2	7.79	7.76	3.67	1.44	2.99	2.69	4.87	3.89	6.84	3.98	0.34	0.28	9.18	3.64	2.42	1.23	2.73	2.52
3	7.56	7.34	5.21	2.09	4.42	2.28	5.59	3.43	9.64	3.52	0.59	0.33	8.59	3.26	1.08	0.97	2.16	1.78
4	8.01	7.58	6.98	1.21	3.87	2.68	7.21	3.26	10.44	2.98	0.45	0.38	14.58	3.46	1.28	0.67	3.26	2.38
5	7.96	7.52	3.12	0.92	4.12	1.88	4.49	3.48	6.34	3.14	0.39	0.34	5.81	3.08	1.92	0.84	2.84	2.24
6	7.65	7.64	3.60	1.94	2.38	2.17	3.30	2.94	8.84	2.92	0.26	0.22	10.19	3.22	1.67	0.82	2.63	2.48
7	7.86	7.69	1.62	1.42	2.61	2.32	2.83	2.62	4.11	2.12	0.39	0.27	2.40	1.86	1.67	1.62	2.27	2.14
8	8.01	7.64	1.65	0.78	2.87	2.42	2.96	1.94	2.64	1.42	0.31	0.25	2.12	1.83	0.93	0.58	3.33	2.77
9	7.76	7.57	2.51	1.11	4.16	2.05	5.62	2.94	9.57	3.94	0.18	0.09	4.60	2.45	2.20	1.42	2.21	2.29
10	7.74	7.66	0.95	0.52	2.22	2.06	2.62	2.54	2.46	2.08	0.43	0.29	3.20	2.16	1.04	1.10	2.59	2.57
11	7.66	7.41	1.38	0.91	2.77	2.44	4.17	3.12	2.64	2.12	0.14	0.09	1.80	1.60	0.75	0.63	3.46	3.24
12	7.74	7.64	1.98	1.14	2.40	2.22	4.31	3.58	2.76	1.68	0.09	0.08	2.40	2.51	1.34	0.98	3.23	3.17
13	7.83	7.68	2.45	1.12	4.41	4.22	5.93	3.76	3.15	2.72	0.97	0.64	4.79	2.23	1.25	1.20	3.63	3.41
14	7.84	7.58	4.97	1.86	2.38	2.21	5.09	3.12	8.26	3.89	0.30	0.20	9.77	4.12	2.21	1.64	1.52	1.51
15	8.12	7.92	1.12	0.58	2.61	2.46	2.53	2.08	1.21	0.87	0.08	0.08	1.24	0.82	1.26	0.82	4.63	4.61
16	8.48	7.92	1.44	0.68	4.81	3.29	4.36	2.88	1.49	1.16	0.22	0.16	1.46	1.32	1.04	0.98	5.23	5.14
17	8.37	7.84	1.93	1.08	3.81	3.48	2.42	2.37	1.56	1.32	0.26	0.22	1.17	0.99	0.92	0.86	5.05	4.78
18	8.25	7.68	0.83	0.54	3.41	3.28	2.62	2.52	1.69	1.24	0.16	0.13	1.46	1.22	1.36	0.92	5.07	4.99
19	7.64	7.62	1.14	0.92	4.65	3.92	3.05	2.91	1.48	1.33	0.65	0.49	1.51	1.29	1.26	0.94	4.05	3.86
20	7.54	7.58	1.11	0.94	4.21	3.84	2.62	2.53	1.19	0.98	0.87	0.61	1.03	1.14	0.88	0.90	3.95	3.87
21	7.76	7.64	1.81	1.26	3.41	3.31	2.45	2.36	1.32	1.08	0.36	0.33	1.41	1.17	1.15	1.10	5.31	4.26
22	7.52	7.36	0.98	0.72	2.68	2.44	3.12	2.28	1.94	1.08	0.22	0.17	5.79	5.12	1.37	0.92	3.59	3.09
23	7.68	7.51	3.26	1.63	2.40	2.33	2.61	1.96	2.21	1.58	0.18	0.14	7.79	6.53	1.68	1.04	3.83	3.74
24	7.78	7.64	2.09	1.54	3.01	2.81	3.44	3.36	2.81	1.92	0.52	0.42	4.79	3.46	1.08	0.82	3.45	3.57
25	7.66	7.59	2.42	1.36	2.40	2.27	3.26	3.17	1.86	1.26	0.16	0.14	2.98	2.48	1.67	0.88	3.03	3.14
26	7.53	7.31	1.64	1.02	2.14	1.98	2.65	2.22	2.94	1.62	0.24	0.18	3.00	2.60	1.25	1.20	3.63	3.61
27	7.71	7.39	2.45	1.82	2.20	1.89	2.95	1.94	2.16	1.08	0.99	0.61	2.40	1.64	1.25	0.64	2.83	2.69
M	7.81	7.59	2.45	1.17	3.23	2.62	3.76	2.81	4.08	2.08	0.37	0.27	4.60	2.53	1.42	0.99	3.39	3.18

The cation concentration in groundwater varied both spatially and temporally. The overall mean concentration of calcium, magnesium, sodium and potassium were 3.23, 3.76, 4.08, 0.37 and 2.62, 2.81, 2.08, 0.27 meq L⁻¹, respectively for summer and monsoon season. Negligible concentration of carbonate ion was noticed throughout the study area. The concentration of bicarbonate ions in the ground water samples was found to vary between 1.51 and 5.31 meq L⁻¹. The chloride ion concentration in the ground water samples was in the range of 0.82 to 14.58 meq L⁻¹ whereas sulphate ion ranged from 0.58 to 2.50 meq L⁻¹ (Table 1).

Cluster analysis: Summary statistics of the cluster analysis of the ground water samples for the different seasons were given in Table 2 and 3. In summer season, four distinct clusters were identified in summer season (Fig. 1). In group A (well ID 1, 2, 3, 4, 5, 6, 9 and 14) sodium (8.56 meq L⁻¹) was more dominant than the magnesium (5.09 meq L⁻¹), calcium (3.52 meq L⁻¹) and potassium (0.34 meq L⁻¹). In case of anions, chloride (8.94 meq L⁻¹) was the dominant anion followed by bicarbonates (2.43 meq L⁻¹) and sulphates (1.91 meq L⁻¹). The magnesium to

Table 2: Summary statistics of the chemical composition of groundwater groups in post monsoon season

	Group A			Group B			Group C			Group D			Group E		
Parameters	Min	Max	Avg.	Min	Max	Avg.	Min	Max	Avg.	Min	Max	Avg.	Min	Max	Avg.
pH	7.58	7.92	7.74	7.19	7.76	7.52	7.59	7.68	7.64	7.31	7.69	7.52	7.36	7.51	7.44
EC (dS m ⁻¹)	0.54	1.26	0.86	0.92	2.09	1.46	1.12	1.54	1.29	0.52	1.82	1.08	0.72	1.63	1.18
Ca (meq L ⁻¹)	2.46	3.92	3.37	1.73	2.69	2.21	2.22	4.22	2.88	1.89	2.44	2.19	2.33	2.44	2.39
Mg (meq L ⁻¹)	2.36	2.91	2.52	2.69	3.89	3.22	3.17	3.76	3.47	1.94	3.12	2.40	1.96	2.28	2.12
Na (meq L ⁻¹)	0.87	1.37	1.14	2.92	3.98	3.44	1.26	2.72	1.90	1.08	2.12	1.74	1.08	1.58	1.33
K (meq L ⁻¹)	0.08	0.61	0.29	0.09	0.38	0.25	0.08	0.64	0.32	0.09	0.61	0.28	0.14	0.17	0.16
HCO ₃ (meq L ⁻¹)	3.80	5.14	4.50	1.51	2.52	2.15	3.14	3.57	3.32	2.14	3.61	2.84	3.09	3.74	3.42
Cl (meq L ⁻¹)	0.82	1.32	1.14	2.45	4.12	3.31	2.23	3.46	2.67	1.64	2.60	1.95	5.12	6.53	5.82
SO ₄ (meq L ⁻¹)	0.82	1.10	0.93	0.67	1.64	1.08	0.82	1.20	0.97	0.58	1.62	0.96	0.92	1.04	0.98
Mg/HCO ₃	0.45	0.75	0.57	1.19	2.07	1.54	0.94	1.13	1.05	0.61	1.22	0.87	0.52	0.74	0.63
NaCl	0.86	1.33	1.01	0.86	1.61	1.06	0.51	1.22	0.74	0.62	1.33	0.91	0.21	0.24	0.23
HCO ₃ /Cl	2.99	5.62	4.07	0.37	0.93	0.67	1.03	1.53	1.27	1.15	2.03	1.49	0.57	0.60	0.59
Mg/Ca	1.14	1.52	1.34	0.54	0.82	0.69	0.62	1.12	0.82	0.78	1.25	0.93	1.07	1.19	1.13

Table 3: Summary statistics of the chemical composition of groundwater groups in summer season

	Group A			Group B			Group C			Group D		
Parameters	Min	Max	Avg.	Min	Max	Avg.	Min	Max	Avg.	Min	Max	Avg.
pH	7.54	8.01	7.76	7.52	7.83	7.70	7.53	8.01	7.74	7.54	8.48	8.02
EC (dS m ⁻¹)	2.51	6.98	4.25	0.98	3.26	2.20	0.95	2.45	1.76	0.83	1.93	1.34
Ca (meq L ⁻¹)	2.38	4.42	3.52	2.40	4.41	3.13	2.14	2.87	2.45	2.61	4.81	3.84
Mg (meq L ⁻¹)	3.30	7.21	5.09	2.61	5.93	3.78	2.62	4.31	3.22	2.42	4.36	2.86
Na (meq L ⁻¹)	6.34	10.44	8.56	1.94	3.15	2.53	1.86	4.11	2.70	1.19	1.69	1.42
K (meq L ⁻¹)	0.17	0.59	0.34	0.18	0.97	0.47	0.09	0.99	0.34	0.08	0.87	0.37
HCO ₃ (meq L ⁻¹)	1.52	3.26	2.43	3.45	3.83	3.63	2.27	3.63	3.05	3.95	5.31	4.76
Cl (meq L ⁻¹)	4.60	14.58	8.94	4.79	7.79	5.79	1.80	3.20	2.54	1.03	1.51	1.33
SO ₄ (meq L ⁻¹)	1.08	2.50	1.91	1.08	1.68	1.35	0.75	1.67	1.24	0.88	1.36	1.12
Mg/HCO ₃	1.25	3.35	2.19	0.68	1.63	1.05	0.73	1.33	1.07	0.46	0.83	0.61
NaCl	0.72	2.08	1.05	0.28	0.66	0.47	0.62	1.71	1.11	0.94	1.33	1.08
HCO ₃ /Cl	0.16	0.49	0.30	0.49	0.76	0.65	0.81	1.92	1.25	2.68	4.32	3.63
Mg/Ca	0.47	0.92	0.70	0.74	0.92	0.85	0.56	0.97	0.78	1.03	1.61	1.36

bicarbonate ratio (Mg/HCO₃) ranged from 1.25 to 3.35. This water was identified as Na-Mg-Cl type and all these wells were associated with sea in terms of less than 1.5 km distance from seacoast except well ID 9 and 14. The well ID 9 and 14 was located in estuary landform where brackish water comes more frequently. In group B (well ID 13, 22, 23 and 24), magnesium (3.78 meq L⁻¹), calcium (3.13 meq L⁻¹) chloride (5.79 meq L⁻¹) and bicarbonates (3.63 meq L⁻¹) was major ions. Group B was Mg-Ca-Cl-SO₄ type which was observed in four wells (well ID 13, 22, 23 and 24) located beyond 3 km distance from the sea.

No dominant (Mg-Na-Ca-Cl-SO₄) type water was noticed in group C (well ID 7, 8, 10, 11, 12, 25, 26 and 27) wells. This might be due to the partial mixing of seawater that nullifies the dominance of particular ions. Ca-Mg-HCO₃ type water was noticed in group D (well ID 15, 16, 17, 18, 19, 20 and 21). These wells were associated with alluvium lands situated away from

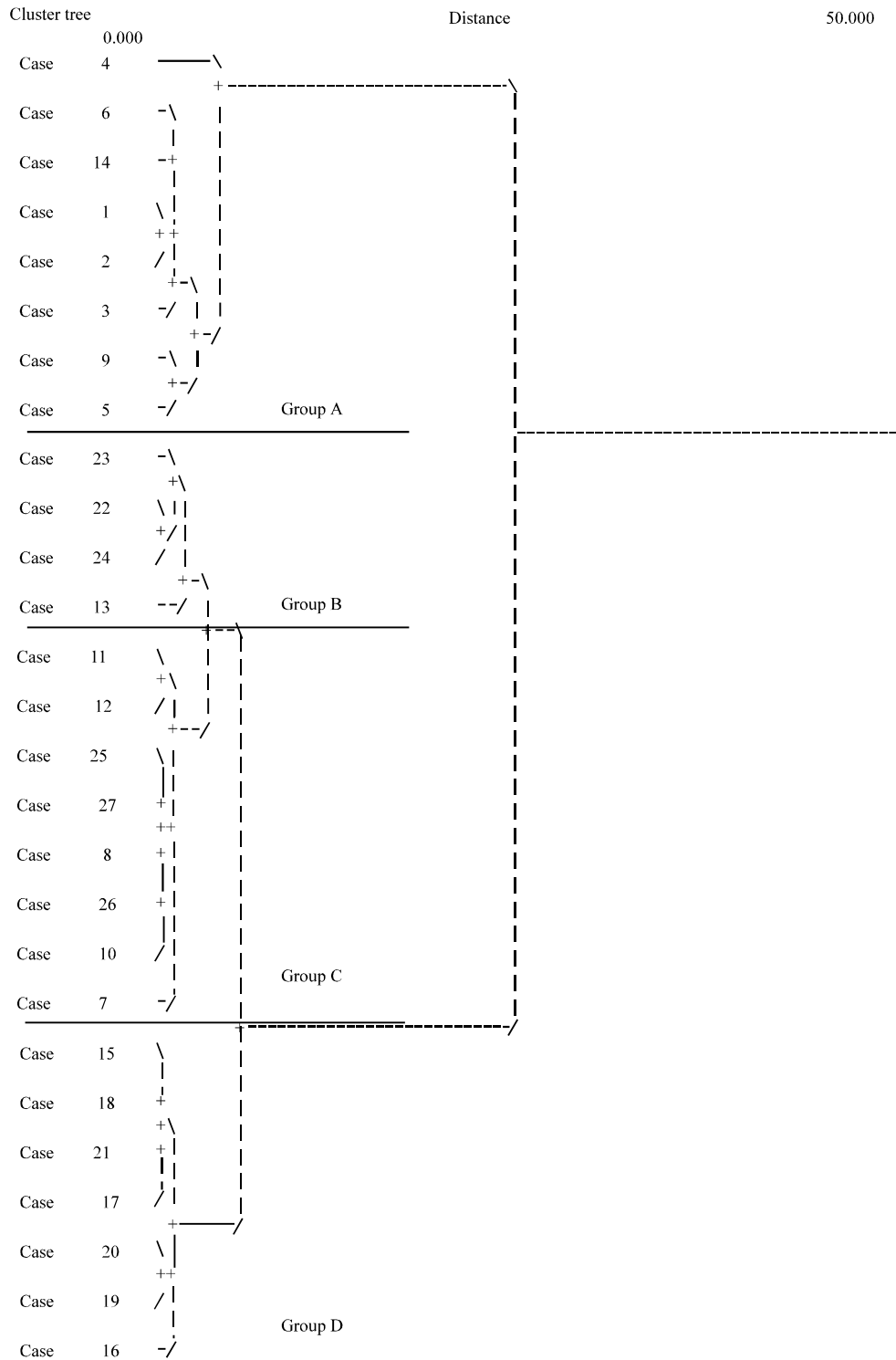


Fig. 1: Dendrogram using ward's method for summer season

seashore (zone II and III). This clearly depicted that these wells are not suffered by seawater intrusion. This was confirmed by the low value (<1) of magnesium to bicarbonates (Krishna, 1990).

In post monsoon season, group A (well ID 15, 16, 17, 18, 19, 20 and 21) noticed for CaHCO_3 type based on the ion dominance. It depicted that these well water was originated from fresh water further modified by soil and landforms. The bicarbonates to chloride ratio ranged from 2.99-5.62 which informed that there was no seawater influence in these wells. Group B wells (1, 2, 3, 4, 5, 6, 9 and 14) composed primarily of sodium (3.44 meq L^{-1}), magnesium (3.22 meq L^{-1}), chloride (3.31 meq L^{-1}) and bicarbonates (2.15 meq L^{-1}). These wells are strongly influenced by seawater based on its homogeneity with seawater composition.

In group C (Well ID 12, 13, 24 and 25) accounted to $\text{Mg-Ca-HCO}_3\text{-Cl}$ water whereas group D represented the same but with lesser ion concentration. But group E depicted Ca-Mg-Cl-HCO_3 type water. In group C, D and E, dominance of magnesium and chloride was higher that indicated the influence of seawater in these wells. But it was interpreted as partial mixing of seawater based on the less dominance of these ions.

DISCUSSION

Groundwater was alkaline irrespective of distance from seacoast and seasons. The severity of alkalinity decreased in post monsoon season due to the dilution effect brought by rain (Manikandan *et al.*, 2011). The EC of groundwater decreased spatially from seacoast to inlands and temporally from summer to post monsoon season. The spatial decrease was attributed due to the decreasing sea water intrusion (Gunnar *et al.*, 2007) whereas, post monsoon decrease was due to monsoon rainfall dilution effect (Rajasekar *et al.*, 2007).

The each group identified had specific chemical composition in water and correlated well with spatial distance from sea and landform. The Na-Mg-Cl type water (Group A) associated with sea in terms of less than 1.5 km distance from seacoast except well ID 9 and 14. But these well ID 9 and 14 was located in estuary landform where brackish water comes more frequently. The value of Mg/HCO_3 was above one which indicated seawater intrusion in this area (Edet and Okereke, 2001). It was further supported by the dominance of sodium and chloride concentration in both seasons.

Ca-Mg-HCO_3 type water was noticed in group D wells and were associated with alluvium lands situated away from seashore (zone II and III). This clearly depicted that these wells are not suffered by seawater intrusion. This was confirmed by the low value (<1) of magnesium to bicarbonates (Krishna, 1990). Group B and C had noticed for no dominance of specific ions and this might be due to the partial mixing of seawater that nullifies the dominance of particular ions.

In summer, there were only four cluster indicating the less chemical differentiation in ground water. This might be due to the concentration of ground water due to excessive evaporation and no fresh water recharge. Further seawater intrusion occurs due to less fresh water from land. All these homogenize the ground water composition leading to less groups. Post monsoon season exhibited five distinctive groups (Fig. 2) of water that was due to the dilution effect of fresh water through monsoon rainfall. The dilution rate differs with varying landform and distance from seashore which created more number of clusters in ground water.

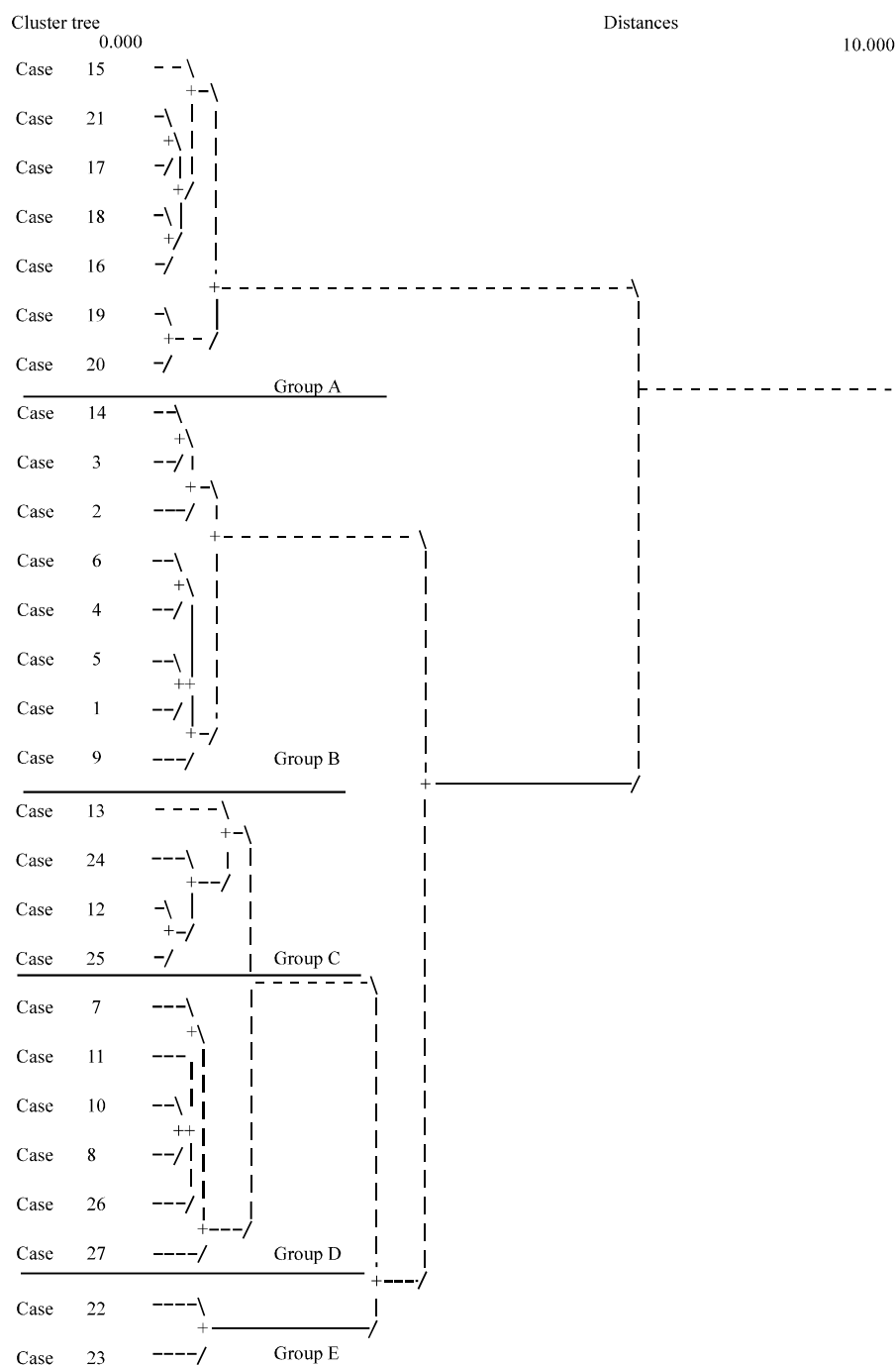


Fig. 2: Dendrogram using ward's method for post monsoon season

CONCLUSION

The hydrogeochemical system is very complex in the shallow coastal aquifers and it is difficult to group the waters based on conventional approach. Cluster analysis has the ability to utilize more number of variables in an unbiased way for the clustering of ground water. This analysis showed the similar hydro-chemical groundwater group in the study area in addition to exhibit the influence

of seawater. The temporal studies clearly identified the areas susceptible to seasonal influence of seawater intrusion. Thus cluster analysis is more useful for the wise use of ground water in the coastal region appropriate to location as well as season specific.

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