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Geochemical Modelling of Ground Water by Cluster Analysis in Hard Rock Area of Kadiri Schist Belt, Anantapur District, Andhra Pradesh (India)

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Abstract: An assessment of the quality of ground water for the Kadiri schist belt of Anantapur district has been carried out with an objective to determine the hydrochemical variability. A total of 41 representative samples from different geological formations were collected in both pre- and post-monsoon seasons and analyzed for the major chemical constituents, viz. Ca, Mg, Na, K, CO_3, HCO_3, SO_4, Cl, F, pH and EC. Cluster analysis, a multivariate statistical tool, has been used in the study as qualitative means for differentiating ground waters into distinctive types. Based on hydrochemistry, chemical variability deciphered from cluster analysis suggests three distinct types of ground waters, viz. mixed type (Si-Ec-**Ca**-Cl-SO_4-Mg or **Ca**-Cl-EC-Si-Mg) and **Na**-HCO_3 type in both pre- and post-monsoon, whereas in post-monsoon in addition to these two types one more type has been formed in the form of SO_4. Sulphate type occurs only in the post-monsoon season due to the use of excessive sulfate fertilizers to improve the yield of the crops. Ground water of the study area is (except fluorine) within the permissible limits for domestic and irrigation purposes.

Key words: Groundwater, modelling, hard rock, cluster analysis.

Introduction

Groundwater quality is mainly a function of the rock types and the residence time with which it is associated besides the role played by altitude, soils, climate and weathered mantle. Hence the variable amounts of the principal ions in ground water at different depths can be attributed to variation in lithology. It is not possible to prevent dissolution of undesirable constituents once the water enters the ground surface (Pojasek, 1977). The usual procedure of interpretation of chemical quality of ground water with the help of plots of different ions and pairs of ions do not define simultaneously, the similarity or other rapid and simultaneous comparison among all the ions. As numerical and statistical computations of the hydrochemical data are very useful and handy, modelling task was performed in the above study area.

Cluster analysis reduces and organizes a large data set into groups with similar characteristics. It provides a straightforward logical and pair-by-pair comparison between various chemical constituents (variables). The results of cluster analysis are presented in an easily understandable two-dimensional hierarchical diagram, on which the natural breaks between the groups become obvious. The observer can also pickup groups at any desired level of similarity/dissimilarity (Robert and James, 1962; George et al., 1970; Roger, 1974). Ramachandran (1989), Ratha et al. (1992), Reddy and Reddy (1989), Lingeswara Rao (2003), and Hussain et al. (2005) adopted cluster analysis in their studies.

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Multivariate statistical methods such as cluster analysis and factor analysis have been used for groundwater quality by several researchers (Ballukraya and Ravi, 1999; Subba Rao et al., 2001; Janardhana Raju, 2006; Chidambaram et al., 2008; Pathak et al., 2008).

Study Area

The area under study is a part of Kadiri schist belt in Anantapur district, Andhra Pradesh. It lies in between North latitude 14°-14° 10′ and East longitude 78° 05′-78° 15′ in the Survey of India toposheet No. 57 J/4. The area consists of a number of isolated clusters of hillocks amidst an otherwise gently undulating plateau. The schist belt is a plain area dotted with occasional hills. On either side of the schist belt, granitic rocks form high hills. The elevation in the area ranges between 265 and 1500 ft. The soil is coarse grained over granitic terrain and fine- to medium-grained over schist belt rocks. Sandy soil occurs along the river course.

Kadiri schist belt, which forms a part in the area, is a linear greenstone belt situated in the eastern part of the Dharwar Craton and southwestern part of the Cuddapah Basin. The schist belt comprises predominantly acid volcanics, with minor basic volcanics, belonging to the Dharwar Supergroup. It is enveloped on all sides by migmatites and granites of Peninsular Gneiss Complex. Rhyolite, rhyodacite, quartz porphyry, quartz-feldspar porphyry, muscovite-sericite schist and quartz-sericite schist represent acid volcanics. Metabasalt and metagbbro (amphibolite) constitute the basic volcanics. Besides, impersistent bands of Banded Iron Formation (BIF) are found in acid volcanics. Impersistent, but conspicuous autoclastic conglomerate horizon, occurs in conformable relationship, with acid volcanics of the belt. The lithounits are traversed by pegmatite veins, quartz reefs, calcite veins and dolerite dykes (Figure 1).

In the central portion of the area, granodiorite-tonalite suite runs parallel to the rocks of the schist belt, occupying the plains in the eastern part. The strike of foliation of

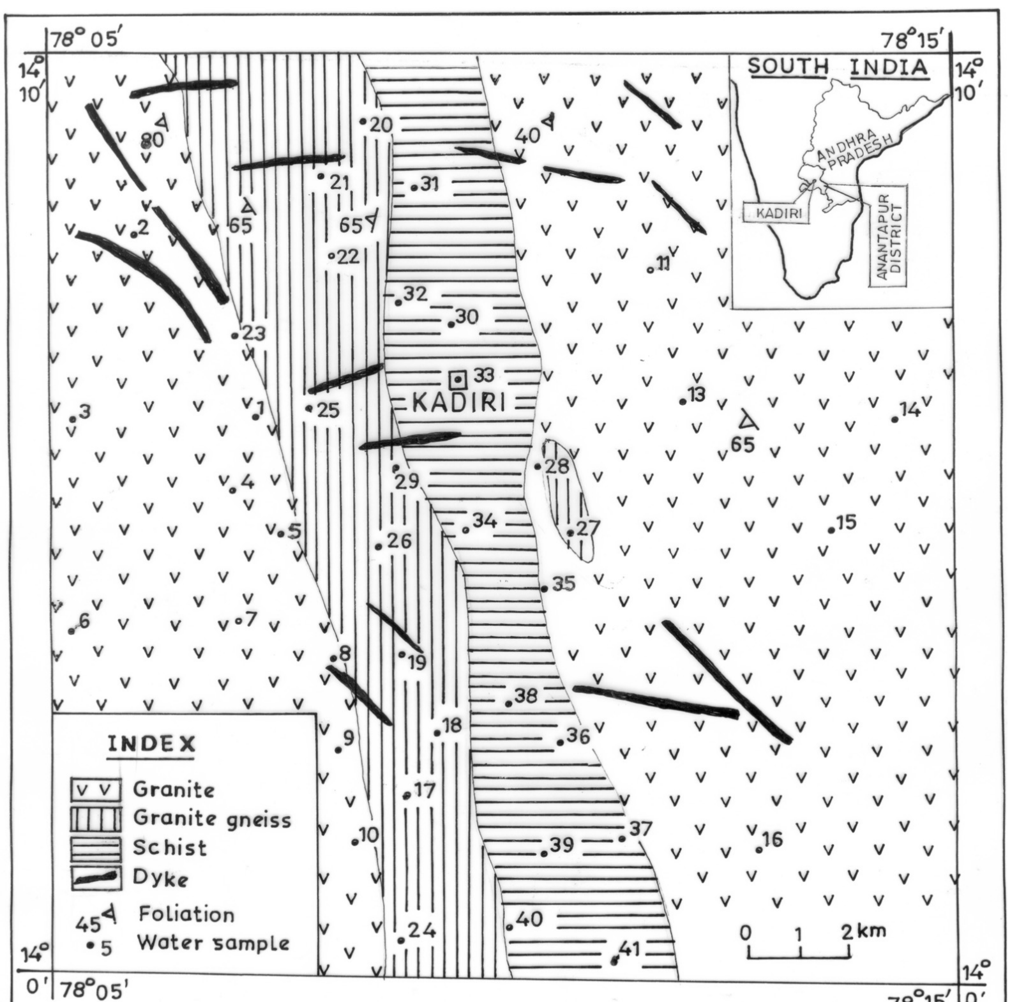

Figure 1: Geology with water sample location map of the study area.

Table 1: Chemical analysis data of groundwater samples (mg/l)

S.No.	Ca	Mg	Na+K	SiO_2	CO_3	HCO_3	SO_4	Cl	F	EC μS/cm	pH	TDS (mg/l)
	←mg/l								→			
a. Pre-monsoon												
1	66	13	88	05	32	332	10	50	1.6	618	8.2	428
2	76	27	80	10	24	432	15	48	1.5	756	8.3	493
3	76	14	95	10	55	304	20	66	1.8	785	8.3	426
4	32	07	57	05	Nil	192	10	46	1.6	436	7.7	257
5	68	11	105	10	24	400	10	46	0.9	724	8.3	471
6	22	04	177	20	51	392	10	28	2.0	810	8.4	503
7	76	21	182	28	24	488	25	148	1.8	1210	8.4	547
8	60	15	99	10	39	336	15	50	1.5	756	8.3	454
9	42	23	147	15	24	344	25	122	1.5	926	8.4	560
10	76	16	133	10	16	384	20	52	1.2	724	8.2	462
11	78	15	137	20	47	416	15	84	1.2	972	8.4	601
12	80	20	121	18	32	448	15	76	1.8	867	8.3	583
13	40	15	143	15	47	310	60	15	1.8	837	8.4	512
14	64	08	117	25	63	240	25	84	1.8	1020	8.8	626
15	72	14	109	15	24	392	15	68	1.7	860	8.3	510
16	48	12	124	10	43	376	10	34	2.2	726	8.3	466
17	108	23	49	05	43	348	15	70	1.0	734	8.2	485
18	144	32	46	18	51	408	25	104	1.0	952	8.3	621
19	152	37	85	28	12	384	50	234	1.8	1367	8.2	787
20	84	17	117	15	39	432	10	74	1.8	956	8.4	569
21	84	03	62	28	Nil	204	25	80	0.8	652	7.8	389
22	104	07	105	10	24	444	10	71	0.8	880	8.3	551
23	72	19	113	15	24	376	15	98	0.8	857	8.3	541
24	84	29	76	15	59	360	10	64	0.7	820	8.3	514
25	100	15	51	05	39	368	10	32	0.9	690	8.3	433
26	80	31	35	10	Nil	300	10	104	0.8	671	7.5	418
27	96	04	72	10	24	344	15	54	0.9	643	8.3	443
28	72	08	107	15	Nil	152	100	152	1.5	814	7.5	529
29	122	29	131	28	39	344	100	182	1.5	1295	8.2	740
30	104	19	137	25	63	344	20	160	1.2	1145	8.3	698
31	30	18	59	10	Nil	260	05	42	1.2	429	7.8	287
32	68	05	109	10	20	400	05	44	1.8	792	8.4	458
33	120	04	90	10	39	364	05	100	2.6	900	8.2	552
34	44	14	96	10	12	320	15	56	2.4	672	8.3	405
35	66	29	76	10	24	376	10	60	2.0	720	7.8	463
36	10	46	55	10	Nil	328	25	28	1.8	521	7.7	336
37	125	04	100	12	Nil	400	20	140	1.9	910	7.4	598
38	50	09	79	05	16	280	05	52	2.0	560	8.2	324
39	60	17	136	15	24	428	15	78	2.6	912	8.3	556
40	68	37	106	20	35	456	15	72	2.0	910	8.3	578
41	52	35	85	10	32	416	15	36	1.8	683	8.2	470

(*Contd.*)

(Table 1 *contd.*)

S.No.	Ca	Mg	Na+K	SiO_2	CO_3	HCO_3	SO_4	Cl	F	EC µS/cm	pH	TDS (mg/l)
	←mg/l→											
					b. Post-monsoon							
1	100	11	27	5	Nil	336	15	44	0.9	578	7.5	368
2	52	17	78	5	Nil	256	15	44	1.2	532	7.4	337
3	48	10	72	10	Nil	296	15	44	1.4	556	7.7	345
4	42	20	31	5	Nil	224	5	44	1.2	405	7.7	257
5	92	22	45	10	Nil	400	15	60	0.8	712	7.2	441
6	16	10	143	18	31	399	10	20	1.6	655	8.4	429
7	68	36	102	25	24	416	25	118	1.6	915	8.2	591
8	80	6	56	10	Nil	328	15	44	1.2	583	7.7	373
9	98	16	75	15	Nil	408	15	88	1.5	816	7.4	508
10	92	20	23	5	Nil	352	20	44	0.9	596	7.4	378
11	58	23	75	15	Nil	368	15	60	1.2	693	7.4	624
12	94	3	10	10	Nil	272	5	20	1.5	409	7.7	276
13	48	20	46	10	Nil	312	5	60	1.2	612	7.8	363
14	164	2	21	20	Nil	248	30	162	1.8	816	7.5	521
15	90	25	53	12	Nil	408	5	60	1.6	695	7.4	446
16	48	12	67	5	Nil	312	5	40	1.8	519	7.8	331
17	128	2	32	5	Nil	336	25	68	0.8	715	7.4	426
18	100	2	45	15	Nil	360	5	40	1.0	621	7.8	384
19	130	16	23	18	Nil	380	5	88	2.0	695	8	467
20	100	15	57	10	Nil	408	5	68	1.6	692	7.9	456
21	100	3	5	5	Nil	208	5	68	0.8	428	7.6	259
22	183	5	70	5	Nil	416	30	182	1.2	1020	7.4	680
23	82	32	44	10	Nil	344	20	92	0.9	723	7.4	450
24	104	18	43	15	Nil	404	5	64	0.8	710	7.8	448
25	100	5	9	5	Nil	332	5	24	0.9	482	7.5	312
26	104	15	7	10	Nil	264	5	82	1.2	546	7.3	353
27	90	8	50	10	Nil	328	30	44	1.4	651	7.7	394
28	94	13	24	10	Nil	120	30	150	1.8	567	7.5	380
29	238	1	8	25	Nil	384	40	184	1.2	1127	7.6	685
30	46	15	42	5	12	236	20	32	1.4	416	8.1	276
31	120	32	40	25	Nil	352	25	144	1.0	892	7.4	560
32	60	18	52	10	Nil	344	5	38	1.4	537	7.7	353
33	72	38	55	10	24	360	25	68	1.8	732	7.9	469
34	66	16	66	10	Nil	344	5	62	2.0	637	7.7	405
35	84	47	62	12	Nil	289	5	56	2.5	1100	7.5	700
36	10	46	55	5	Nil	328	25	28	2.0	521	7.8	336
37	125	4	100	12	Nil	400	20	140	2.0	910	7.4	598
38	72	13	14	5	Nil	220	5	56	1.6	426	8.1	273
39	90	22	75	12	Nil	432	10	80	2.0	791	7.9	502
40	108	10	44	15	Nil	368	20	60	1.8	732	7.5	448
41	64	5	95	5	Nil	384	5	48	1.8	627	7.7	411

the suite is in conformity, with that of the schist belt rocks. Granite suite is the dominant rock type among the granitoids. A faint foliation is observed in granite due to the alignment of feldspars and mafic minerals. The trend of foliation veers from NNW to NNE with easterly to westerly dips. Dolerites that cut across all the formations represent the last phase of igneous activity in the area.

Sampling and Methods of Analysis

Water samples from 41 bore wells, covering different formations, were collected both in pre-monsoon (May 2002) and post-monsoon (Jan. 2003) seasons to assess the quality variation (Figure 1). Water samples are analyzed and interpreted, using standard methods (Rainwater and Thatcher, 1960; Brown et al., 1970; Hem, 1985; APHA-AWWA-WEF, 1996. Silica (Si) is determined by spectrophotometer, while sodium (Na) and potassium (K) by flamephotometer. Calcium (Ca) and total hardness (TH) as $CaCO_3$ are estimated by complexometric titration methods; magnesium (Mg) is calculated from estimated amounts of TH; $CaCO_3$ and HCO_3 are estimated by potentiometric method; chloride (Cl) by argentometric method and sulfate (SO_4) by turbidimetric method. Fluoride (F) is determined spectrophotometrically, using SPANDS reagents and retested by Ionic Fluoride Meter. Total dissolved solids (TDS) are estimated on residue on evaporation and also by calculation. Specific conductance at 25^{o}C is determined by specific conductivity bridge and hydrogen ion concentration (pH) by pH Meter. All the dissolved constituents are expressed in milligrams per litre. The analysis results are given in Table 1.

Cluster Analysis

Cluster analysis is the generic name for variety of procedure that can be used to create a classification. These procedures empirically form 'Clusters' or 'Groups' with highly similar entities. More specifically, a clustering method is a multivariate statistical procedure that starts with a data set containing information about a sample of entities and attempts to reorganize these entities into relatively homogeneous groups.

Cluster analysis, which is a useful tool for analyzing the large data in reducing form as groups or pairs or types with similar characteristics of chemical constituents of groundwater quality, was used in the present work for understanding the interrelations among the chemical constituents. Summary of the chemical constituents of ground waters of the area is shown in Table 2. The correlation coefficients of the chemical constituents (8 × 8 matrices) of the groundwater samples were compared using 'Stastica' statistical software presented in Table 3. The chemical constituents were subjected to cluster analysis on the basis of distance correlation coefficients for possible zonation of ground water. Based on the correlation coefficients, the matrix was

Table 2: Correlation co-efficient values

	Ca	*Mg*	*Na*	*Si*	*HCO_3*	*SO_4*	*Cl*	*EC*
a. Pre-monsoon								
Ca	1.00	0.06	-0.17	0.30	0.28	0.22	0.65	**0.56**
Mg	0.06	1.00	-0.23	0.16	0.27	0.15	0.19	0.22
Na	-0.17	-0.23	1.00	0.51	0.40	0.22	0.21	**0.56**
Si	0.30	0.16	**0.51**	1.00	0.15	0.46	**0.64**	**0.78**
HCO_3	0.28	0.27	0.40	0.15	1.00	-0.31	-0.00	0.46
SO_4	0.22	0.15	0.22	0.46	-0.31	1.00	**0.54**	0.45
Cl	**0.65**	0.19	0.21	**0.64**	-0.00	**0.54**	1.00	**0.74**
EC	0.56	0.22	**0.56**	**0.78**	0.46	0.45	**0.74**	1.00
b. Post-monsoon								
Ca	1.00	-0.42	-0.41	0.38	0.19	0.45	0.75	**0.60**
Mg	-0.42	1.00	0.20	0.12	0.12	0.00	-0.09	0.20
Na	-0.41	0.20	1.00	0.16	**0.50**	-0.01	-0.08	0.28
Si	0.38	0.12	0.16	1.00	0.37	0.30	0.51	**0.62**
HCO_3	0.19	0.12	**0.50**	0.37	1.00	0.02	0.09	**0.55**
SO_4	0.45	0.00	-0.01	0.30	0.02	1.00	**0.62**	0.48
Cl	**0.75**	-0.09	-0.08	**0.51**	0.09	**0.62**	1.00	**0.69**
EC	**0.60**	0.20	0.28	0.62	0.55	0.48	**0.69**	1.00

Table 3: Different steps of correlation matrix

Pre-monsoon

(a) First Step

	Ca	*Mg*	*Na*	SiO_2	HCO_3	SO_4	*Cl*	*EC*
Ca	1.00	0.06	-0.17	0.30	0.28	0.22	0.65	0.56
Mg	0.06	1.00	-0.23	0.16	0.27	0.15	0.19	0.22
Na	-0.17	-0.23	1.00	0.51	0.40	0.22	0.21	0.56
SiO_2	0.30	0.16	0.51	1.00	0.15	0.46	0.64	**0.78**
HCO_3	0.28	**0.27**	0.40	0.15	1.00	-0.31	-0.00	0.46
SO_4	0.22	0.15	0.22	0.46	-0.31	1.00	0.54	0.45
Cl	**0.65**	0.19	0.21	0.64	-0.00	**0.54**	1.00	0.74
EC	0.56	0.22	**0.56**	**0.78**	**0.46**	0.45	**0.74**	1.00

(b) Second Step

	SiO_2-EC	*Ca*	*Mg*	*Na*	HCO_3	SO_4	*Cl*
SiO_2-EC	1.00	0.43	0.19	**0.54**	**0.32**	0.46	**0.69**
Ca	0.43	1.00	0.06	-0.17	0.28	0.22	0.65
Mg	0.19	0.06	1.00	-0.23	0.27	0.15	0.19
Na	0.54	-0.17	-0.23	1.00	0.40	0.22	0.21
HCO_3	0.32	0.28	**0.27**	0.40	1.00	-0.31	-0.00
SO_4	0.46	0.22	0.15	0.22	-0.31	1.00	0.54
Cl	**0.69**	**0.65**	0.19	0.21	-0.00	**0.54**	1.00

(c) Third Step

	SiO_2-EC-Cl	*Ca*	*Mg*	*Na*	HCO_3	SO_4
SiO_2-Ec-Cl	1.00	**0.54**	0.19	**0.47**	0.16	**0.50**
Ca	**0.54**	1.00	0.06	-0.17	0.28	0.22
Mg	0.19	0.06	1.00	-0.23	0.27	0.15
Na	0.47	-0.17	-0.23	1.00	**0.40**	0.22
HCO_3	0.16	0.28	**0.27**	0.40	1.00	0.31
SO_4	0.50	0.22	0.15	0.22	-0.31	1.00

(d) Fourth Step

	SiO_2-EC-Cl-Ca	*Mg*	*Na*	HCO_3	SO_4
SiO_2-EC-Cl-Ca	1.00	0.12	0.15	0.22	**0.36**
Mg	0.12	1.00	-0.23	0.27	0.15
Na	0.15	-0.23	1.00	**0.40**	0.22
HCO_3	0.22	**0.27**	**0.40**	1.00	-0.31
SO_4	**0.36**	0.15	0.22	-0.37	1.00

(e) Fifth Step

	SiO_2-EC-Cl -Ca-SO_4	*Na-HCO_3*	*Mg*
SiO_2-EC-Cl-Ca-SO_4	1.00	**0.13**	**0.14**
Na-HCO_3	0.13	1.00	0.02
Mg	**0.14**	0.02	1.00

(f) Sixth Step

	SiO_2-EC-Cl-Ca-SO_4-Mg	*Na-HCO_3*
SiO_2-EC-Cl-Ca- SO_4-Mg	1.00	**0.08**
Na-HCO_3	**0.08**	1.00

Post-monsoon

(a) First Step

	Ca	*Mg*	*Na*	SiO_2	HCO_3	SO_4	*Cl*	*EC*
Ca	1.00	-0.42	-0.41	0.38	0.19	0.45	**0.75**	0.60
Mg	-0.42	1.00	0.20	0.12	0.12	0.00	-0.09	0.20
Na	-.0.41	0.20	1.00	0.16	0.50	-0.01	-0.08	0.28
SiO_2	0.38	0.12	0.16	1.00	0.37	0.30	0.51	0.62
HCO_3	0.19	0.12	**0.50**	0.37	1.00	0.02	0.09	0.55
SO_4	0.45	0.00	-0.01	0.30	0.02	1.00	0.62	0.48
Cl	**0.75**	-0.09	-0.08	0.51	0.09	**0.62**	1.00	**0.69**
EC	0.60	**0.20**	0.28	**0.62**	**0.55**	0.48	0.69	1.00

(b) Second Step

	Ca-Cl	*Mg*	*Na*	SiO_2	HCO_3	SO_4	*EC*
Ca-Cl	1.00	-0.26	-0.25	0.45	0.14	**0.54**	**0.65**
Mg	-0.26	1.00	0.20	0.12	0.12	0.00	0.20
Na	-0.25	0.20	1.00	0.16	0.50	-0.01	0.28
SiO_2	0.45	0.12	0.16	1.00	0.37	0.30	0.62
HCO_3	0.14	0.12	**0.50**	0.37	1.00	0.02	0.55
SO_4	0.54	0.00	-0.01	0.50	0.02	1.00	0.48
EC	**0.65**	**0.20**	0.28	**0.62**	**0.55**	0.48	1.00

(c) Third Step

	Ca-Cl-EC	*Mg*	*Na*	SiO_2	HCO_3	SO_4
Ca-Cl-EC	1.00	-0.30	-0.02	**0.54**	0.35	**0.51**
Mg	-0.30	1.00	0.20	0.12	0.12	0.00
Na	-0.02	**0.20**	1.00	0.16	**0.50**	-0.01
SiO_2	**0.54**	0.12	0.16	1.00	0.37	0.30
HCO_3	0.35	0.12	**0.50**	0.37	1.00	0.02
SO_4	0.51	0.00	-0.01	0.50	0.02	1.00

(d) Fourth Step

	Ca-Cl-EC-SiO_2	*Mg*	*NaHCO_3*	SO_4
Ca-Cl-EC-SiO_2	1.00	0.45	0.31	0.41
Mg	0.45	1.00	0.16	0.002
Na-HCO_3	0.31	0.16	1.00	0.005
SO_4	0.41	0.005	0.00	1.00

(e) Fifth Step

	Ca-Cl-EC-SiO_2 Mg	*Na-HCO_3*	SO_4
Ca-Cl-EC-SiO_2-Mg	1.00	**0.24**	**0.21**
Na-HCO_3	**0.24**	1.00	0.005
SO_4	0.21	0.005	1.00

(f) Sixth Step

	Ca-Cl-EC-SiO_2-Mg-Na-HCO_3	SO_4
Ca-Cl-EC-SiO_2-Mg-Na-CO_3	1.00	**0.11**
SO_4	**0.11**	1.00

systematically searched for the highest correlation coefficients of the similar pairs of elements of the hydrogeochemical data followed by lower and lower correlation coefficients of similar pairs of elements. This procedure was continued until all the chemical constituents were clustered. A dendrogram was prepared (Figure 2) using arithmetic averaging method (Davis, 1986).

In the first step of the cluster analysis, mutually highest correlation value in each column of the matrix is identified for pre-monsoon water samples as shown in Table 3 (in bold face type). Next, similar highest correlation coefficients of chemical constituents of SiO_2-EC are clustered first. The new correlation coefficients between SiO_2-EC cluster and independent constituents are recalculated by arithmetic averaging method. The rest of the correlation coefficients of individual constituents are retained as they are (Table 3b). Cl and SiO_2-EC are clustered as a single element. New correlation coefficients between SiO_2-EC-Cl and other independent constituents are recalculated by arithmetic averaging procedure (Table 3c). SO_4 and SiO_2-EC-Cl are clustering as a single unit. Next Mg is clustered with SiO_2-EC-Cl-SO_4 as a unit and in the subsequent step Na and HCO_3 are clustered as another unit (Table 3d). Finally these two individual clusters SiO_2-EC-Cl-SO_4-Mg and Na-HCO_3 are clustered (Table 3e). Stepwise dendrogram was constructed according to the step correlation matrixes as shown in Figure 2. The same clustering procedure is repeated for post-monsoon groundwater samples; mutually high pairs are sought out and clustered. The complete dendrogram for post-monsoon water samples is then constructed (Figure 2).

Results and Discussion

Table 4 shows the summary of the chemical constituents of groundwater of the study area. pH is in the range of 7.4 to 8.8 indicating an alkaline nature. The total concentrations of dissolved solids (TDS) is between 257 and 787 in both the seasons with a mean of about 500 mg/l. According to the classification based on TDS, the groundwaters come under fresh environment (TDS <1000 mg/l). The concentrations of TH vary from 72 to 532 mg/l with mean of 254 mg/l in pre-monsoon and 164-600 with mean of 286 mg/l in post-monsoon, which indicates that the waters belong to hard (>300) categories (Sawyer and McCarty, 1967). The concentrations of Ca, Mg, Na+K, HCO_3, SO_4, Cl and F varies from 10 to 152 (pre-) and 10-238 (post-), 3-46 (pre-) and 1-47 (post-), 35-182 (pre-) and 5-143 (post-), 152-488 (pre-) and 120-432 (post-), 5-100 (pre-) and 5-40 (post-), 15-134 (pre-) and 20-184 (post-), and 0.7-2.6 (pre-) and 0.8-2.5 mg/l (post-) with a mean of about 75 & 89, 17 & 16, 98 & 49, 385 & 333, 20 & 14, 78 & 71 and 1.5 & 1.4 mg/l respectively. The groundwaters are characterized by

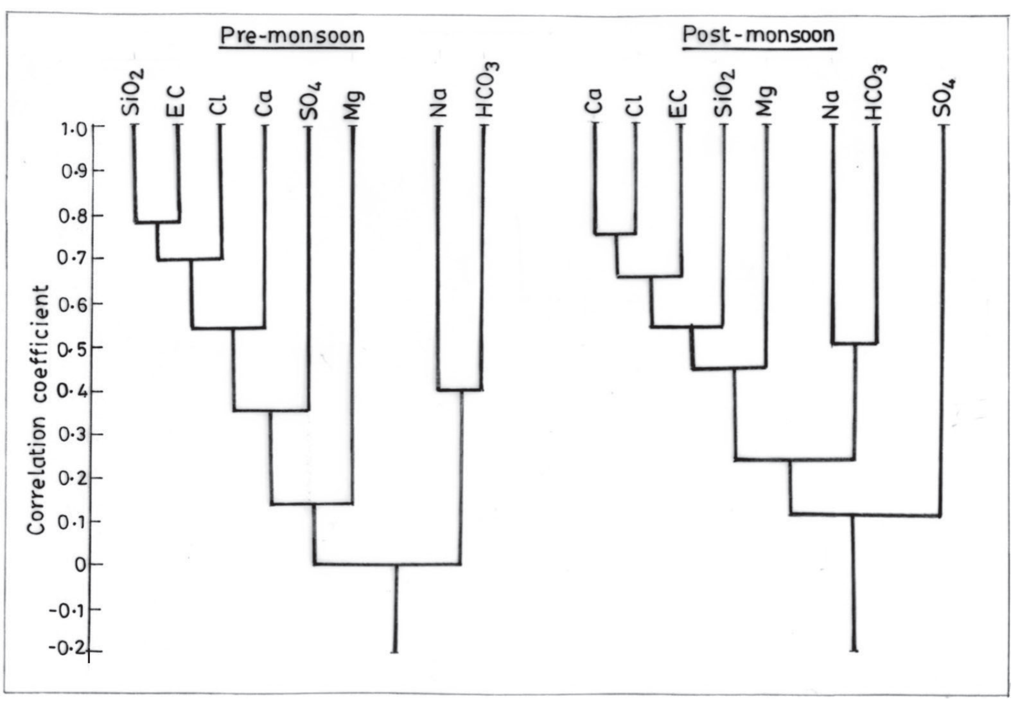

Figure 2: Dendogram showing clusters for both pre- and post-monsoon.

Table 4: Statistical parameters of groundwater samples

	Minimum	*Maximum*	*Mean*	*Std. Dev.*	*Std. Err.*
			a. Pre-monsoon		
Ca	10	152	75.00	31.040	4.850
Mg	03	46	17.70	10.685	1.669
Na	35	182	98.56	34.141	5.332
SiO_2	05	28	14.02	6.780	1.059
HCO_3	152	488	385.02	80.297	12.540
SO_4	05	100	20.73	21.052	3.288
Cl	15	234	78.17	46.213	7.217
F	0.7	2.6	1.55	0.507	0.079
EC	429	1367	812.24	202.168	31.573
TDS	257	787	507.97	116.489	18.192
TH	72	532	254.46	92.027	14.372
pH	7.4	8.8	8.2	20.92	2.366
			b. Post-monsoon		
Ca	10	238	89.27	41.790	6.526
Mg	01	47	15.95	11.734	1.833
Na	05	143	49.78	29.585	4.620
SiO_2	05	25	10.95	5.770	0.901
HCO_3	120	432	333.56	69.316	10.825
SO_4	05	40	14.51	9.862	1.540
Cl	20	184	71.17	42.946	6.707
F	0.8	2.5	1.42	0.441	0.069
EC	405	1127	668.04	177.922	27.787
TDS	257	700	429.585	116.874	18.253
TH	164	600	286.32	86.848	13.563
pH	7.4	8.2	7.7	10.86	1.624

Na>Ca>Mg/Ca>Na>Mg; HCO_3>SO_4>Cl type. According to Soulin (1948) the waters of the present area is of Na-HCO_3 in pre-monsoon and mixed type in post-monsoon.

The water samples of the area, when compared with various standards specified by different organizations (Table 5), was found suitable for domestic and drinking purposes (except fluorine). The ground water is also suitable for irrigation in general. However the waters of the study area are not suitable for industrial purpose as they contain high amounts of Total Hardness and TDS in post-monsoon.

The clusters observed in the study area for both the seasons are mixed type (Si-Ec-**Ca**-Cl-SO_4-Mg or **Ca**-Cl-EC-Si-Mg) and **Na**-HCO_3 type, whereas in post-monsoon in addition to these two clusters one more cluster has been formed in the form of SO_4. On the basis of cluster analysis it can be said that there are two main interrelated types of chemical constituents, which are responsible for the hydrogeochemical variability in the quality of ground water of the area. From the dendrograms, the following groundwater types are identified.

Pre-monsoon :	Type I	: Si-Ec-**Ca**-Cl-SO_4-Mg (Mixed Type)
	Type II	: **Na**-HCO_3 type
Post-monsoon :	Type I	: **Ca**-Cl-EC-SiO_2-Mg (Mixed Type)
	Type II	: **Na**-HCO_3 type
	Type III	: SO_4 type

Mixed Waters

Generally, recharge waters dilute the chemical concentrations during post-monsoon season, which tends to increase towards pre-monsoon, because of the effect of evaporation. In both the seasons in this type Ca is showing significantly high positive correlation at 0.65 and 0.75 in pre- and post-monsoon seasons respectively. Later, Mg is linked with calcium chloride cluster at a lower level of correlation. So this type may also be called as calcium waters. Calcium and magnesium chloride water is rare and shows base exchange phenomenon. Chloride in association with calcium and magnesium indicates permanent hardness in water. This type of water predominantly persists in the central portion of study area,

Table 5: Parameters of water quality characterization and standards

S. No.	Parameter	ISI (1993)	WHO (2004)	ICMR (1975)	European Std. (WHO, 1970)	High Tec. Miss. (TMPD, 1986)	Study area	
							Pre-monsoon	Post-monsoon
1	**Ca (ppm)**	75	500	75	100	75	**75**	**90**
2	**Cl (ppm)**	250	250	200	250	200	**78**	**71**
3	**F (ppm)**	1.5-1.9	1.5	1.0	1.5	1.5	**1.55**	**1.41**
4	**Mg (ppm)**	30	150	50	50	30	**17**	**15**
5	**Na (ppm)**	—	200	—	120-175	—	**99**	**50**
6	**SO_4 (ppm)**	150	400	200	250	200	**21**	**14**
7	**pH**	7.0–8.5	6.5–8.5	7.5–8.5	6.5–8.5	7.5–8.5	**7.4–8.4**	**7.2–8.4**
8	**EC (µS/cm)**	1500	1400	800	400	—	**812**	**668**
9	**T.H. (ppm)**	300	500	300	—	200	**254**	**286**
10	**T.D.S (ppm)**	500	1000	500	500	500	**508**	**421**

ICMR, 1975: Manual of standards of quality of drinking water (3rd ed). Special report. Indian Council of Medical Research Series 44.
ISI, 1993: Indian Standard Specification of drinking water. Indian Standard Institution, New Delhi, IS: 10500.
TMPD, 1986: General guidelines for Standard/Norms. Technology Mission Project Document, Dept. of Rural Development, Govt. of India, pp. 21-24.
WHO, 1970: European Standards for drinking water. World Health Organisation, Geneva.
WHO, 2004: Guidelines for drinking water quality (Vol. 3). World Health Organisation, Geneva (3rd Edition).

which is controlled by schist belt. It makes the possible occurrence of at least a part of calcium and magnesium chloride due to the flow system of ground water through the granite and granite gneiss, containing calcium and magnesium minerals like feldspars, pyroxenes, amphiboles etc.

Sodium Waters (Bicarbonate Waters)

Sodium and bicarbonate are correlated positively at higher level in both the seasons. Of all the clusters, sodium and bicarbonate have clustered without any lower level (correlation) clustering. This type of water persists in western and eastern portions of the study area and is controlled by granite and granite gneisses having soda-rich plagioclase feldspars. Soda-rich feldspars easily dissolve and contribute to the high concentration of sodium in ground water of the study area. Sodium bicarbonate is an indicator of base exchange enrichment of sodium. Poor drainage and scanty rainfall may also contribute high sodium content to the ground waters of the study area, as it lies in a semi-arid region (Karanth, 1987).

The source of HCO_3 is mostly from decayed organic matter and sulphate reducing bacteria. The source from weathering of silicate minerals is also possible (Kumaraswamy et al., 1996). High loadings on HCO_3 can be attributed to the CO_2 present in the soil. Oxidation of organic matter by microbes generate CO_2 which then combines with water to form carbonic acid, which further dissociates to H and HCO_3.

$$CH_2O + O_2 \longrightarrow CO_2 + H_2O$$

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

$$H_2CO_3 \longrightarrow H + HCO_3$$

Sulphate Waters

High proportion of SO_4 with Na and K shows that the rock must have abundant plagioclase than mafic minerals present in granite and gneisses (Garrels and Mackenzi, 1967).

The third cluster in post-monsoon is due to the application of excessive sulfate fertilizers to improve the yield of the crops (Scanlon, 1989; Cain et al., 1989).

Conclusions

Cluster analysis is performed to characterize the groundwater hydrochemical system. Cluster analysis of the ground water in Kadiri schist belt area in and around Kadiri, Anantapur district, has indicated three types of ground waters namely mixed type, carbonate type and sulphate type. Mixed type of waters is distributed in central region and sodium bicarbonate type in both east and western regions of the study area. Sulphate type occurs only in the post-monsoon season due to the use of excessive sulfate fertilizers to improve the yield of the crops. Mixed type was controlled by schistose rocks and bicarbonate waters are controlled by the granite and granite gneisses in this study area. On the whole, the three clusters as shown in the dendrograms indicate that the groundwater quality of the study area is hard and alkaline in nature, suitable for drinking, domestic and irrigation purposes.

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