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Original Research Paper

Principal Component Analysis: Deeper Aquifer Groundwater Quality of Bhaskar Rao Kunta Watershed, Nalgonda District, Andhra Pradesh, India

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ABSTRACT

Principal component analysis (PCA) is an appropriate tool for water quality evaluation and management. In the study area, PCA was used for multivariate factor analysis of hydrogeochemical variables of pH, EC, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, F^-, TH and TDS. Influence on chemical composition of groundwater quality and statistically characterize (Eigen value ≥ 1 and % of variance) two factors were extracted as well as identified, principal component-I and II. The principal component-I accounts for 36.62 and 39.80% of variance and principal component-II accounts for 17.84 and 18.10% of variance in pre and post-monsoon seasons respectively. Graphical presentation of the principal component-I and II showed loading relationship between the variables EC, TDS and Ca^{2+} as high positive relation; and variables between TH, Mg^{2+}, NO_3^- and F^- as low positive relation in pre-monsoon season. Principal component-I and II showed loading relationship variables between pH, as high positive relation; and variables between HCO_3^- and SO_4^{2-} as high positive relation in post monsoon seasons respectively. These two principal components results were predicted for hydrochemical process of rock water interaction, process of degradation products of the ions, process of alkalinity and process of anthropogenesis activity. It was concluded that hydrochemical process is controlled by geogenic and non-geogenic factors.

INTRODUCTION

Principal component analysis (PCA) was designed to transform the original variables into new uncorrelated variables (axes) called the principal component (Mardia et al. 1979). PCA is an appropriate tool for water quality evaluation and management and conducted to understand the underlying geochemical reactions and hydrochemical evolution processes of groundwater data corresponding to large number of variables. This technique produce easily interpretable results and data size were reduced to smaller number of variables which can explain all the parameters. Numerous researchers attempted this method to interpret various hydrochemical problems during last few decades (Douglas et al. 1977, Briz-Kishore et al. 1989, Rao et al. 1996, Voudouris et al. 2000, Parineta et al. 2004, Rao et al. 2007, Shyamala et al. 2008, Kanade et al. 2011, Sajil Kumar et al. 2011). In the present study, Bhaskar Rao Kunta watershed groundwater quality was evaluated from various deep aquifer (tube wells) samples to understand the hydrochemical evolution processes of physico-chemical variables.

STUDY AREA

Semi-arid region of Bhaskar Rao Kunta watershed is located at the Krishna lower basin and covered in Survey of India (SoI) Toposheet No: 56 P/6 & 56 P/10 (1:50000 scale). It is geographically lies between northern latitude from 16°42' 25' to 16°37'58' and eastern longitude from 79°28'15" to 79°32'30" and politically placed in Damaracherla Mandal, Nalgonda district of Andhra Pradesh state, India (Fig. 1). The watershed area is exposed 40.25 sq.km and has slightly undulated terrain with moderate slopes. Altitude varies from 80m to 140m above the mean sea level. Annual normal rainfall is 737mm and average maximum and minimum temperature is 40°C and 28°C respectively. Drainage pattern shows dendritic to sub-dendritic, governed by relief, regional slope, and homogenous lithology, exhibited by streams, which could be either due to structural or topographic control. 146 streams contribute the flow of mostly dry except for seasonal run-off.

Geology and soils: The area is geologically consisted of the Kurnool group of Palnadu sub basin and partially covered with Srisailam succession of Kadapa super group. General sequence of sub-surface strata encountered with top soil, weathered/semi weathered, and shale/quartzite. Srisailam sub basin rock is exposed with quartzites. The quartzites was inter bedded with thin siltstone units and usually thick bedded, dense and fine to medium grained. Palnadu sub-basin rocks were exposed with calcareous (chemical precipitates) sediments like quartzites, shales and flaggy-massive limestones. Soils are consisted of red, red sandy and black soils.

MATERIALS AND METHODS

Twenty groundwater samples were collected from working deeper bore wells (depth 60m) during pre and post-monsoon seasons in June and December of 2009 at identical locations. Locations of sampling points were determined using a global positioning system (GPS). The locations of the collected groundwater samples are shown in Fig. 2. Collected samples were labelled, sealed and transported to the laboratory under standard preservation methods. The APHA (1998) standard analytical procedures were followed to determine major anions and cations. The accuracy of the concentrations were checked between the total cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and the total anions (HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, F^-). The results of the chemical analysis are presented in Tables 1 and 2. The multivariable factor analysis of the hydrochemical variables was carried out by PCA using software SPSS 18.0 version. In the present study the first two principal components were utilized on basis of Eigen values, which explain the reasonable percent of the variance.

RESULTS AND DISCUSSIONS

The PCA was used for factor analysis of pH, EC, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, F^- and TH, TDS. Influence on chemical composition of groundwater and to statistically characterize (Eigen value ≥ 1 and % of variance), two factors were extracted as well as identified PC-I and PC-II. The PC-I explains as much as possible the total variance of the observations, and PC-II explains as much as possible the residual variance (Grande et al. 2003). PCA solutions were obtained as a result of Eigen values greater than one (Kaiser 1958) and percent (%) of the variance (Table 3).

The output of the final rotated loading matrix data was obtained with two principal components which explained cumulative Eigen values of 6.53 and 6.95 and cumulative variance of 54.46 and 57.90 % in both the seasons (Table 3). The scatter plots of the PCA loadings between PC-I verses PC-II are illustrated in Fig. 3. These show the variation of the positive to negative loadings of each PCA with one pair of the scatter (factor loading > 0.70 was typically regarded as excellent; factor loading < 0.30 as poor for interpretation). The results of PC variables of groundwater samples are presented in Table 3.

Premonsoon Principal Component Analysis

Principal Component-I: The first component (PC-I), explaining 36.62% of the total variance, shows strong and positive loading related to EC (0.91), TDS (0.92) and Ca^{2+} (0.81); moderate positive loading related to Cl^- (0.61), HCO_3^- (0.57) and K^+ (0.41); poor loading related to TH (0.22), Mg^{2+} (0.16), SO_4^{2-} (0.20), F^- (0.05); and negative loading related to Na^+ and pH (Table 3). EC was explained to directly control the TDS concentrations. It is resulting from the interaction of the carbonate rock dissolution and rock water interaction that occur and enriched in the groundwater due to their higher solubility. Hence, it is considered as a lithologically controlled factor.

Principal Component-II: The second component (PC-II), explained 17.84% of total variance and showed poor loading related to Ca^{2+} (0.24), Cl- (0.12). The reaming parameters have high negative loading with K+ (-0.72), SO_4^{2-} (-0.70), Na^+ (-0.68), HCO_3^- (-0.57), and poor negative loadings

Table 1: Hydrochemical parameter concentrations of pre and post-monsoon seasons.

Longitude	Latiitude	Pre-monsoon													Post-monsoon												
		pH	EC	TH	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	TDS	F^-	pH	EC	TH	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	TDS	F^-
79.48184	16.69462	8	859	407	96	72	72	0.8	199	57	23	25	425	3	8	862	418	103	78	75	0.8	206	61	27	29	431	3
79.52091	16.69261	8	795	446	79	83	120	1.0	231	37	39	26	395	3	8	798	450	82	89	122	1.0	241	39	41	28	399	3
79.51853	16.69924	8	840	495	88	87	80	1.0	219	95	33	25	425	4	8	855	500	92	89	81	0.9	226	97	34	29	427	4
79.50391	16.67703	8	1300	423	127	88	110	1.0	192	115	28	26	650	4	8	1304	425	132	89	109	0.9	195	120	29	26	652	4
79.50153	16.67625	8	751	422	97	65	103	0.8	184	50	31	23	377	2	8	758	425	101	68	106	0.7	189	51	32	24	379	2
79.49611	16.68746	8	1349	523	140	94	81	1.0	237	110	23	40	670	3	7	1355	525	144	97	86	1.1	244	113	25	41	677	3
79.49947	16.67665	8	873	396	116	100	70	0.8	217	60	19	29	435	3	8	876	400	118	103	74	0.8	220	61	19	30	438	3
79.49188	16.67732	8	965	446	118	72	81	0.8	241	95	31	30	480	3	8	967	450	122	73	82	0.7	247	96	32	32	483	4
79.52731	16.69863	8	689	323	108	53	89	0.7	165	93	23	29	348	2	8	698	325	112	53	91	0.6	168	96	26	31	349	2
79.51375	16.70373	9	781	397	86	91	81	0.6	196	47	27	21	390	2	8	782	400	89	92	82	0.5	198	48	29	22	391	2
79.52091	16.70356	8	829	370	91	67	75	1.0	221	38	43	35	414	3	8	830	375	92	69	74	1.0	229	39	46	39	415	3
79.47841	16.66934	8	661	573	95	102	102	0.9	179	30	25	40	328	4	8	662	575	96	107	106	0.9	183	31	26	41	331	4
79.48162	16.68361	8	650	349	73	56	63	0.7	177	35	19	38	321	3	8	650	350	72	58	66	0.7	183	36	19	39	325	3
79.48616	16.67927	9	852	447	130	76	71	0.8	196	73	39	24	420	4	8	849	450	131	76	72	0.7	198	76	41	26	425	4
79.52356	16.67901	8	1001	347	85	69	106	1.0	260	46	36	17	500	2	8	1008	350	88	71	110	0.9	262	47	38	18	504	2
79.51143	16.65753	8	1421	396	114	70	80	1.0	244	102	37	49	711	2	8	1428	400	116	73	83	0.9	250	109	39	51	714	2
79.51427	16.66217	9	1453	520	151	91	77	1.0	236	54	35	20	729	3	8	1460	525	152	93	78	1.1	241	59	37	21	730	4
79.50864	16.67751	8	1027	542	124	95	80	0.9	192	97	24	31	573	3	8	1031	550	128	96	81	0.7	189	99	25	32	576	3
79.50442	16.66661	9	901	497	97	97	91	1.0	212	98	27	41	452	3	8	910	500	101	98	93	1.0	214	106	29	43	455	3
79.52186	16.65682	9	1497	536	119	88	91	1.5	237	83	38	34	651	3	8	1526	550	127	94	97	1.0	243	87	42	39.7	663	3

All units are expressed in mg/L except pH, EC (μS/cm)

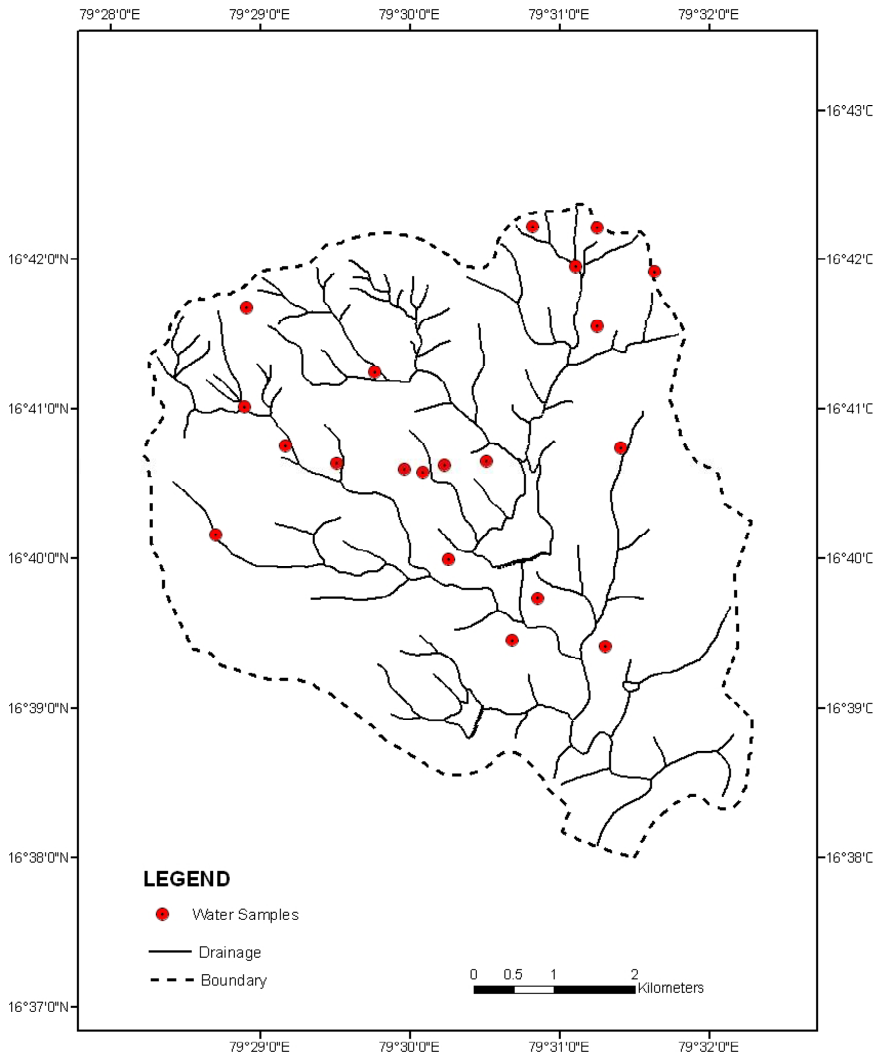

Fig.1: Location of the study area.

with pH (-0.19), EC (-0.29), TH (-0.14), TDS (-0.22), Mg^{2+} (-0.02), NO_3^- (-0.10) and F^- (-0.04). It is signature of drastically different geochemical conditions in close proximity. Samples with large negative values were elevated and indicate the presence of degradation products.

Postmonsoon Principal Component Analysis

Principal Component-I: The first component (PC-I) explaining 39.80% of the total variance, shows strong and positive loading related to pH (0.80), low positive loading related to Na^+ (0.27), SO_4^{2-} (0.08), high negative loading related to Ca^{2+} (-0.89), TDS (-0.81), EC (-0.77) and Cl^- (-0.76), low negative loading related to Mg^{2+} (-0.11), K^+ (-0.19), HCO_3^- (-0.18) and NO_3^- (-0.10) ions. TH and Mg^{2+} were closely related (Fig. 3). It was indicated that their relationship comes under the single process. EC and TDS are also closely related (Fig. 3b) and EC is directly controlled by the concentration of the TDS which was derived from the interaction of water and rock and gets enriched in the groundwater due to their higher solubility. In the post-monsoon season during recharge, the surface water absorb large amounts of CO_2, which can covert into HCO_3^- in the weathering reactions (Jacks 1973). Such reactions lead to enhance the pH by conversion of HCO_3^- to CO_3^{2-} (Berner et al. 1987).

$$CO_2 + H_2O = CO_2 + H_2CO_3$$
$$H_2CO_3 = H^+ + H_2CO_3^-$$
$$H_2CO_3^- = H^+ + CO_3^{2-}$$

According to the above equations pH exceeds in all the samples of post-monsoon season (Table 1). Here soil appears to play a major role in the process of alkalinity and hence PC-II was considered as a lithologically controlled factor.

Table 2: Summary statistics of hydrochemical parameter concentrations of pre and post monsoon seasons.

Parameters	Pre-monsoon									Post-monsoon								
	Min	Max	Mean	SD	SE	SV	CV	Kur-tosis	Skew ness	Min	Max	Mean	SD	SE	SV	CV	Kur-tosis	Skew ness
PH	8	9	8	0.35	0.08	0.13	4.29	-0.59	0.36	7	8	8	0.24	0.05	0.06	2.97	1.53	-0.73
EC	650	1497	981	281	65	79167	28.69	-0.80	0.78	650	1526	987	285	65	81094	28.86	-0.75	0.80
TH	323	573	445	74	17	5469	16.63	-1.09	0.09	325	575	449	75	17	5658	16.76	-1.11	0.10
Ca	73	151	107	22	5	470	20.22	-0.74	0.29	72	152	110	22	5	492	20.13	-0.87	0.15
Mg	53	102	81	15	3	222	18.33	-0.96	-0.44	53	107	84	15	4	239	18.51	-0.82	-0.44
Na	63	120	87	15	3	229	17.40	-0.23	0.66	66	122	89	15	4	236	17.25	-0.53	0.60
K	0.57	1.53	0.92	0.20	0.04	0.04	21.38	5.01	1.38	0.46	1.12	0.84	0.18	0.04	0.03	20.79	-0.50	-0.41
HCO_3	165	260	212	27	6	732	12.73	-1.13	-0.07	168	262	217	28	6	794	13.00	-1.35	-0.09
Cl	30	115	71	29	7	826	40.22	-1.65	-0.01	31	120	74	30	7	903	40.49	-1.64	0.00
SO_4	19	43	30	7	2	52	23.75	-1.12	0.02	19	46	32	8	2	61	24.47	-0.89	0.02
NO_3	17	49	30	8	2	71	27.71	-0.33	0.47	18	51	32	9	2	77	27.18	-0.52	0.34
TDS	321	729	488	134	30.73	17945	27.46	-1.01	0.64	325	730	491	135	31	18171	27.44	-1.05	0.63
F	2	4	3	0.70	0.16	0.50	24.02	-1.13	-0.17	2	4	3	0.74	0.17	0.54	23.88	-1.34	-0.30

All units are in mg/L, EC in μS/cm; SD = Standard Deviation; SE = Standard Error; SV = Sample Variance; CV = Co-Variance

Table 3: Rotated component matrix of the chemical variables of the groundwater.

Parameters	Principle component			
	Pre-monsoon		Post-monsoon	
	PC-I	PC-II	PC-I	PC-II
pH	-0.04	-0.19	0.80	0.26
EC	0.91	-0.29	-0.77	0.54
TH	0.22	-0.14	-0.19	0.08
Ca^{2+}	0.81	0.24	-0.89	0.05
Mg^{2+}	0.16	-0.02	-0.11	0.02
Na^{+}	-0.27	-0.68	0.27	0.38
K^{+}	0.41	-0.72	-0.19	0.68
HCO_3^-	0.57	-0.57	-0.18	0.85
Cl^-	0.61	0.12	-0.76	-0.02
SO_4^{2-}	0.20	-0.70	0.08	0.82
NO_3^-	0.10	-0.10	-0.10	0.02
TDS	0.92	-0.22	-0.81	0.49
F^-	0.05	-0.04	-0.16	0.10
Eigen Values ≥	4.39	2.14	4.78	2.17
% Variance	36.62	17.84	39.80	18.10
Cumulative Variance %	36.62	54.46	39.80	57.90

Principal Component-II: The second component (PC-II) explaining 18.10% of the total variance, shows strong and positive loading related to HCO_3^- (0.85), SO_4^{2-} (0.82); moderate positive loading related to K^+ (0.68), EC (0.54), TDS (0.49) and Na^+ (0.38); and poor loading related to pH (0.26), TH (0.08), Ca^{2+} (0.05), Mg^{2+} (0.02), NO_3^- (0.02), F^- (0.10) and Cl^- (0.02).

Irrigation return flows and anthropogenic activities were the additional contributors of ions, especially HCO_3^-, SO_4^{2-} and K^+ to the groundwater (Rao et al. 2007). PC-II was controlled by anthropogenic activity so it is considered as a non-lithologically controlled factor.

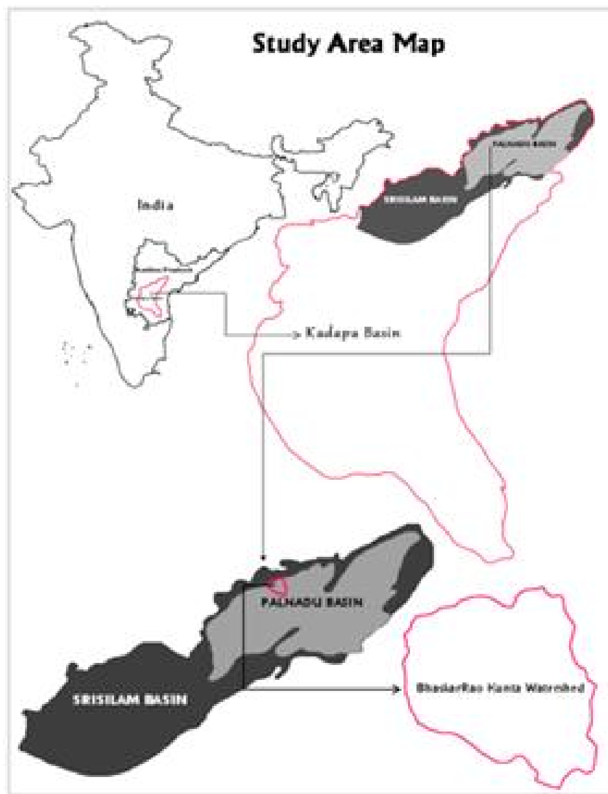

Fig.2: Groundwater samples locations.

CONCLUSIONS

The present study suggests that the principal component analysis determines the assemblages of water quality. These two principal components results were predicted for hydrochemical process of rock water interaction, process of

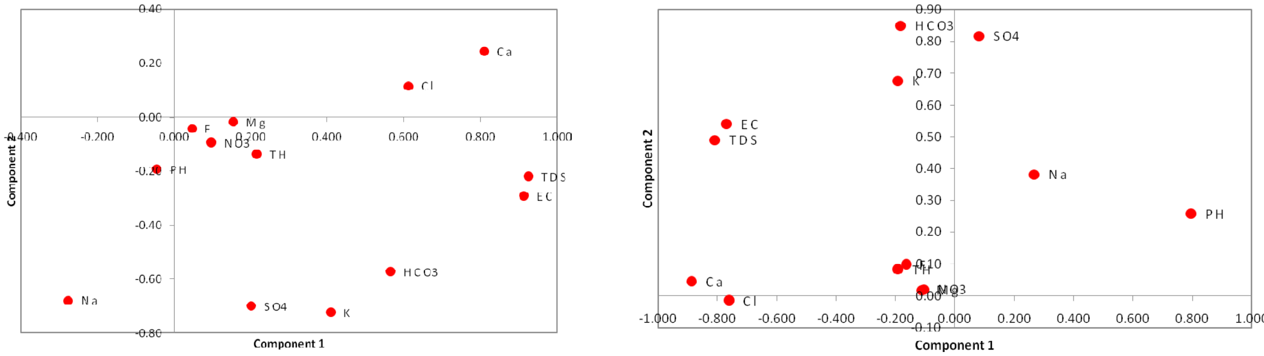

Fig. 3: Principal component analysis for experimented variables in groundwater samples in pre and post-monsoon.

degradation products of the ions, process of alkalinity and process of anthropogenesis activity. It was concluded that hydrochemical process is controlled by geogenic and non-geogenic factors.

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