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 was checked between the total cations (Ca\(^{2+}\), 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.

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

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

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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).

\[
\begin{align*}
\text{CO}_2 + H_2O & = \text{CO}_3^{2-} + H_2CO_3^- \\
H_2CO_3^- & = H^+ + HCO_3^- \\
HCO_3^- & = H^+ + CO_3^{2-}
\end{align*}
\]

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.
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.

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
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.

REFERENCES


