Evaluation of the hydro geochemistry of groundwater using factor analysis in the Cuddalore coastal region, TamilNadu, India

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The hydrochemical facies and its aerial distribution of groundwater present in the coastal region of the Cuddalore region, Tamilnadu had been examined as a part to map their aerial hydrochemical distribution and attempts to explain the geochemical processes controlling its water quality/facies. In the study area aquifers occur in Quaternary deposit. Ten major ions (Ca$^{+2}$, Mg$^{+2}$, Na$^{+}$, K$^{+}$, Cl$^{-}$, HCO$_3^-$, H$_4$SiO$_4$, F$^-$, SO$_4$ and NO$_3$-) were determined for each of 54 water samples collected in two seasons (pre and post monsoon). The factor analysis was performed for pre-monsoon and post-monsoon data set. This gives an insight into the source of dissolved ions and the hydro geochemical chemical processes which are responsible for the water quality changes that are occurring here including the intrusion of seawater. The present study elucidates the effectiveness of factor analysis in evaluating hydrochemical processes occurring in the coastal regions which are dominated by agriculture and industrial zones.

Key words: hydrochemical, percolation, factor analysis, aquifer

Introduction

Groundwater is one of the earth’s most important resources for human life. The water quality depends upon the geological environment, natural movement, recovery and utilization. The chemical quality of the ground water percolating through the soil zones of anthropogenically polluted layers, are significantly reduced. Hence understanding the coastal ground water quality changes, solute transport and identifying recharge areas in the coastal groundwater zone especially in the present context of contamination problems especially after tsunami inundation has become major priority. In this context, multivariate analysis is very useful due to its relative importance in evaluating the combination of large chemical variable data set. They are used as analytical tools to reduce and organize large hydro-geochemical datasets into groups with similar characteristics. The rotation mode factor analysis is widely used statistical technique in hydro geochemistry. This analysis is useful for the interpreting the groundwater quality data and relating them to specific changes in hydro geological processes. The factor analysis has been successfully applied to the sort out of hydro geochemical processes from commonly collected ground water quality data1-5. The basic purpose of such analysis for the study of the hydro-geochemistry of an aquifer is to find a set of factors, few in number, which can explain a large amount of the variance of the analytical data. Anthropogenic activities and improper management of natural resources also led to unequal distribution of major and minor elements in nature. The present study using factor analysis has great potential to demonstrate its usefulness as a tool for the estimation of the extent of salinity/salt water intrusion problems especially after tsunami in space and time in the Cuddalore coastal aquifers system in Tamilnadu.

Methodology

Study area

The study area is located in southern part of Cuddalore district, that which lies between north latitudes 11.36 to 11.70 and longitude 79.51 to 79.86. The district of Cuddalore lies on the east coast (Fig 1). The average rainfall is 1164 mm per year. The general aquifer system is discontinuous confined to semi confined aquifers. Groundwater in this area is overexploited for agriculture, Industrial purposes are predominant land use in this area which induces salinity in the coastal aquifers.

Sample collection and analysis

Samples from 49 bore wells and hand pumps (filter points) were collected for two seasons, post monsoon (February 2006) and pre-monsoon (July 2006). The water samples water collected from bore wells after

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pumps ran for minimum 5-10 minutes in order to get representative samples of the aquifer systems. Water samples were collected in the polyethylene water bottles and kept in the cool condition before transporting to lab and kept at 4°C for further analysis.

The collected samples were analyzed in the field for pH, EC, HCO₃ and TDS. In the lab they are analyzed for major ions such as Ca⁺⁺, Mg⁺⁺, Na⁺, K⁺, Cl⁻, HCO₃⁻⁻, H₂SIO₄⁻, F⁻, SO₄ and NO₃⁻ following standard procedure. Summary of hydrogeochemical statistics data listed in Table 1.

### Data processing
Data obtained from the laboratory analysis were used as variable inputs for factor analysis. Factor analysis was performed using the SPSS package described by Nie et al. the data were standardized according to criteria presented by Davis (1973). This procedure renders a new rotated factor Varimax (Tables 3) in which each factor is described in terms of only those variables and affords greater ease for interpretation. Factor loading is the measure of the degree of closeness between the variables and the factor. The Rotation mode factor analysis provides several positive features that allow interpretation of the data set. By examining the factor loadings, communalities and Eigen values, those variables belonging to a specific chemical process can be identified and the importance of the major elements can be evaluated in terms of the total data set and in terms of each factor. Communality is an indicator of the error term (1-communality) or random noise. Since the factor scores are calculated for each sample and reflect the importance of a given factor at that sample site, we can contour the factor scores for each factor and evaluate the aerial importance of the chemical process represented by that factor. Because the original data were standardized, factor scores Values obtained were also in the same form, i.e. with a mean of zero and standard deviation of one. Dalton and Upchurch (1978) have shown that factor scores can be related to intensity of the chemical process described by each factor. Extreme negative numbers (<-1) reflect areas essentially unaffected by the process, and positive scores (>+1) reflect areas most affected. Near-zero scores approximate areas affected to an average degree by the chemical process of that particular factor.

### Results and discussion
The first three factors show Eigen values >1 for post-monsoon, thus these three factors were chosen. In the pre-monsoon period only three factors have Eigen values >1; thus these two factors were chosen for the subsequent factor extraction.

#### Factor 1 Post-monsoon
Factor 1 of the Post-monsoon samples has high loading of the ions Na⁺, K⁺ and NO₃⁻ (Table 2) The concentration of Na, K and NO₃ in seawater is much greater than that in continental water. Therefore, factor 1 can be associated with the salt water inundation which leached into the aquifer system, increases the concentrations of these ions by its percolation and longer residence time i.e marine water inundation during high tides and from the 2004 tsunami inundation remnants which enhance leaching and may be the most important process affecting the ion concentrations of the ground water in these aquifer. This factor accounts for 34.60% of the
variance of the concentrations of the samples, which is a higher percentage than that attributable to the other factors. Cl concentration average is around 145.13 ppm it may be the direct salt water intrusion affecting the aquifers. Figure 2 shows the aerial distribution of factor scores for factor I of post-monsoon. It can be seen from the figure that the Uppanar river mouth is highly affected by the tidal action and is indicated in the figure from contours above 0.2. This may due to the river water seepage into the aquifer system in the monsoon period and the center part of the area is higher in concentration than others indicating the predominance of weathering and sediment water interaction processes. Result of factor analysis of the groundwater chemistry data (n=25) indicates three trends (factors) that can be related to various controlling processes presumed to have been produced by the different water species. This suggests that saltwater inundation, percolation of natural water i.e. recharge and water-soil-sediment interaction were the predominantly factors controlling the water chemistry. A small zone in the south-central portion near the town shows exceptionally high scores. This is the agriculture intense activity area and consequently witnesses’ higher groundwater abstraction. This probably establishes local freshwater depression cones, which induces saltwater infiltration into this area. Over drafting of the groundwater for various purpose in the area thus was the main factor induces the infiltration of salt water.

Factor 2 Post – monsoon

Factor II of the post-monsoon samples includes mainly Ca, Mg and Cl. Even though the seawater has a higher concentration than the continental water, the higher contribution of Cl and Ca in this factor indicates that the excessive interaction of water with the aquifer formations. The average concentration of Mg is 38.82 ppm this may be due to the uptake of Mg by ion exchange sites on clays and other Mg rich minerals (Table 3). Figure 3 shows the aerial distribution of factor scores of factor II (post-monsoon) and is represented by high Mg which may be due to sediment water interaction and weathering processes. The figure 3 shows that the entire coastal track is affected by Cl due to the over exploration of groundwater. Ca is rich in shallow aquifers when compared to the pre-monsoon period. This figure shows that the Central part of the study area which is above 0.2 contour indicate the over exploration of groundwater due to the Neyveli lignite mining activity.

Factor 1 Pre – monsoon

The pre-monsoon factor I, loaded heavily with Ca$^+$, Mg$^{++}$ and Cl$^-$ (Table 3) resembles the concentration of seawater. Ca$^+$ and Mg$^{++}$ showed low concentrations in the post-monsoon period and reaches high concentrations in the pre-monsoon water sample. The higher concentrations of Ca$^+$, Mg$^{++}$ and Cl$^-$ are due to the salt water intrusion and inundation during high tide in the coastal area during this period, which activate the seawater into the groundwater system through seepage. Figure 4 shows the aerial distribution of factor I scores and also the extent of the saltwater intrusion in the pre-monsoon period.
Seawater intrusion is higher in the pre-monsoon period as compared to the post-monsoon period. It may be also due to higher amount of groundwater exploration in this area due to the dry climate condition exist in this area during this period, and this clearly induces the seawater intrusion along with the tidal effect, which ultimately causes saline water intrusion in the groundwater system.

Factor 2 Pre – monsoon

The factor 2 of pre-monsoon samples is represented mainly by Na, K and HCO$_3^-$ as the shallow aquifers are intensively used for agricultural purposes. The higher concentration of Na and K indicate the leaching and dissolution of secondary salts in the pore spaces. Figure 5 shows the distribution of factor score as indicated by the Na and K which are in high concentration in the Southwest part and in near coastal region of the study area. This factor score diagram resembles the factor 1 of Pre-monsoon. It’s also mainly due to the saline water intrusion due to excess groundwater exploitation in this area.

Conclusion

The result of the multivariate statistical analysis, as applied to the chemical data set of groundwater in this coastal area provides an insight into the underlying factors controlling hydrogeochemical processes in the region. Three factors in post monsoon including factor 1 (Na, K and NO$_3^-$), factor 2 (Ca, Mg and Cl) and factor 3 (SO$_4^{2-}$ and NO$_3^-$) extracted from the dataset represent the signatures of saltwater intrusion, interaction with the geological matrix and dissolution of secondary precipitates related compounds respectively in the groundwater. Factors 1 and 2 represent ions with dominant concentrations and therefore are the main contributors to the groundwater salinity. The spatial distributions of these two factors indicate a zone of mixing of the two water types especially close to the back water channels and near coastal areas. Perhaps of greater significance is the decrease in intensity of the two dominant factors away from the coast. This indicates a decrease in the concentration of ions (K, Na, Cl, Mg, Ca and HCO$_3^-$)
that are predominantly responsible for the salinity of groundwater away from the coast.

The present study has thus demonstrated the usefulness of factor analysis in interpreting the hydrogeochemistry data and relating those data to salt-water inundation, percolation/infiltration and leaching and sea water intrusion processes occurring in general in the coastal aquifers of India. In the present study the salt-water intrusion into the groundwater in these two periods under study (pre-monsoon, due to over extractions; post-monsoon, due to monsoon storms and high tides) are very well represented by the factors with the loading of Cl, Ca, Mg, F, HCO₃ and H₄SiO₄. The anthropogenic signatures are also well demarcated by NO₃ factor enrichments. Thus this technique can be applied to all coastal aquifer system as a complement to standard hydrogeochemical methods. Further the numerical analysis can also help to resolve ambiguities and provide unique hydrogeochemical information.

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