Sea Water Ingress into an Indian Atoll

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Abstract

Groundwater is the prime source of fresh water in small coral islands. It is a fragile resource in the islands and floats in the form of thin lens. Sustainability of the resource on tiny atoll is a major challenge for the policy makers and managers. Prime goal of the work is to identify vulnerable part of aquifer in order to develop sustainable management scheme and systematic assessment of groundwater quality on such island have become imperative. Detailed hydrochemical study has been carried out to identify contaminated parts of aquifer on Minicoy Island, UT of Lakshadweep, India. The analysis has given an early signal of deterioration in groundwater quality in some parts of the island during non-monsoon period, whereas the quality becomes slightly better during monsoon period. The study suggests immediate measures for arresting the deterioration in groundwater quality is prime requirement.

Keywords

Atoll Aquifer; Groundwater; Seawater ingress; Sustainable management

Introduction

There are several highly populated tiny atolls off western coast of India (Mallik 2001; Sarwade et al., 2006; Banerjee et al., 2008; 2011; 2012). The surface water potential is negligible in the atolls. Groundwater is the only source of fresh water on these atolls and to meet the increasing demand there has been indiscriminate exploitation of groundwater resources. Aquifers in these islands are in the form of thin fragile floating lens, which are
often vulnerable to overexploitation that causing seawater ingress (Chandramohan et al. 1993; Singh and Gupta 1999a).

Lakshadweep is an archipelago of coral islands in the Arabian Sea, off the western coast of India. In the range of 220–400 km off the western coast of India, there are about 12 atolls that spread over an area of 32 km in the Arabian Sea (Chandramohan et al. 1993). Tens of these islands are habited. The study was carried out in Minicoy Island (08°32’N and 73°17’E). The island is second largest habited island of the archipelago (Fig. 1). Population growth during 1991 to 2001 is 17.5 percent. The areal extent of the island is about 4.8 km².

Figure 1 The study area and water level in observation wells at Minicoy Island

The overexploitation of groundwater on island has led to decrease in fresh water potential as well as deterioration in groundwater quality due to seawater ingress. The topography of the island is undulating and the ground surface is about few meters above mean sea level (amsl). The island is of elliptical shape with major axis in N–S direction. The island is enveloped with sparkling white carbonate sand beach. There is no surface water
storage on the island. Earlier workers have described geology, geomorphology and hydrogeology of the island in detail (Nazeeb 1995; Wagle and Kunte 1993; Singh and Gupta 1999b; Mallik 2001; Revichanndran et al. 2001).

The groundwater occurs in the coral sand underlined by shell limestone, in the form of floating lens. The aquifer depth varies from 1 meter (above mean sea level) to -0.1 meters with respect to mean sea level. The areas with low water level are vulnerable to seawater contamination. The groundwater is being exploited for various needs of islanders through hand-dug shallow well. Most of the rain occurs during the month of June to September (monsoon season). The average annual rainfall for the period of 2000–2005, on the island, is about 1,817 mm. Due to high permeable coral sand on the surface, most of the rain percolate down and finally goes as subsurface runoff to sea.

Methodology

Samples are collected from the existing wells twice a year (during pre-monsoon and post-monsoon seasons) in order to assess groundwater quality. Total 18 samples were collected from the existing open wells in each season. The sampling wells are selected in such a way that they represent most of the shallow aquifer region that is more vulnerable to seawater ingress and adequately cover the area of interest. The analysis of water samples were carried out to assess major cation and anion such as calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), bicarbonates (HCO), chloride (Cl), sulphate (SO4), nitrate (NO3) including total hardness (TH), pH and electrical conductivity (EC).

Since the wells are shallow, the samples are collected using bailer. All the necessary precautions are taken. The temperature is measured by mercury thermometer that has a scale marked for every 0.1 °C. The samples are analyzed for major ions (Ca2+, Mg2+, Na+, K+, HCO3-, SO42-, Cl). pH and EC are measured on site with portable EC and pH meters that
are calibrated with standard solution in the Lab at 25° C. Sodium (Na\(^+\)) and potassium (K\(^+\)) are determined by Atomic Absorption Spectrophotometer (AAS). Sulphate \(\text{SO}_4^{2-}\) is estimated by spectrophotometric technique, whereas nitrate \(\text{NO}_3^-\) is determined by ion chromatography. TDS is calculated by gravimetric method after filtration (filter size is 0.45 micron). Titration Erichrome black T indicator is used to analyze total hardness (TH). Complexometric titration using EDTA solution and Erichromeblasck T methods are used for calcium (Ca\(^{2+}\)) measurement. Bicarbonate \(\text{HCO}_3^-\) is measured by titration method using phenolphthalein and methyl orange indicator. Chloride (Cl\(^-\)) content is determined by Argentometric titration method. Magnesium (Mg\(^{2+}\)) is calculated from total hardness (TH) and Ca\(^{2+}\) contents. The chemical analysis data have been interpreted to assess the groundwater quality on the island. Further, principle component analysis (PCA) technique is also used to compare the similarities and dissimilarities of the ions simultaneously for pre- and post-monsoon samples.

**Results and discussion**

The comparison of maximum, minimum, standard deviation and median of selected parameters (TDS, EC, Cl, and Ca) are calculated. It shows that TDS, EC and content of Cl are higher in pre-monsoon samples, whereas the content of Ca is higher in post-monsoon samples. The higher content of Cl is indication of mixing of seawater during non-monsoon period, whereas the higher content of Ca in post monsoon may be due to dissolution of Ca from coral sand during infiltration process that takes place during monsoon. Study indicate that the Cl content exceeds the permissible limit of drinking water quality standard [250 ppm, ISI (1983)] in both the seasons. Similarly, maximum EC content exceeds the permissible limit of drinking water standard [1,500 ppm, ISI (1983)] in both the season, whereas minimum EC content is very near to permissible limit in pre monsoon month. It indicates the areas are severely vulnerable during dry season.
During the pre-monsoon period, higher content of TDS is observed at the western end of the island and at the peripheral parts of the south side. But during the post-monsoon period, the western part of the island is less affected due to seawater ingress during monsoon period and seawater intrusion in southern part also has reduced during post-monsoon period due to recharge. Majority of pre-monsoon samples have shown dominance of Na and Cl whereas during the post-monsoon Ca is also prominent but Na and Cl is seen amongst cations and anions, respectively. This dominance of Na may be due to seawater mixing during pre-monsoon and post-monsoon period. Presence of bicarbonate during both pre and post-monsoon may be only due to interaction with coral formation. In the central diamond shaped field, majority of the pre and post monsoon samples fall in ‘no cation or anions exceeds 50% area’, whereas some of the post-monsoon samples fall in ‘carbonate hardness exceeds (Todd, 1980). The diagram indicate that the little increase in chemical properties are dominated by alkaline earth (Ca) or corals and week acids (HCO3) in 50%’ area during post monsoon. Calculation of sodium hazard is ignored among the water samples of the study area because it is not required. There is no agriculture practice in the area.

All above results show that majority of the selected pre monsoon samples fall in high salinity zones indicating non-suitability of groundwater use. The post-monsoon samples fall in the range of medium to high salinity hazard zone indicating limited use of water for different purposes. The aquifer is facing more evaporation and less recharge during pre-monsoon period that may cause the higher seawater ingress. The host sea water intrusion and lithological units are mainly controlling the groundwater chemistry of post monsoon and the evaporation or no rainfall, pre-monsoon samples.

EC and Cl cross plots are shown in the Figure 2. The correlation between the chloride and EC is found 0.99 and 0.95 during pre- and post-monsoon, respectively. Cl is showing strong
correlation with EC during the pre-monsoon and post monsoon. The cross plots are showing dominance of seawater intrusion during pre and post monsoon seasons.

PCA is a simple mathematical reduction of the data without any elaborate assumptions (Anderson 1958; Morrison 1964), which enables us to describe the information with considerably fewer variables than was originally present. In the present investigation, the pre- and post-monsoon hydro-chemical data are subjected for PCA using standard statistical packages on computer. The variables considered are TDS, TH, Ca, Mg, Na, K, HCO₃, Cl, SO₄, and NO₃.

Fig. 2 Cross-plots of EC with chloride during a) pre- and b) post-monsoon
Among the principle components of pre-monsoon, component I is negative for non of the element, component II is negative for F, Cl and Mg, whereas component III is negative for NO3 and Ca. The eigen values are helpful in deciding the number of components required to explain the data variation. In the present case, the cumulative percent of trace of first four eigen values account for 83.6% and 78.3% of the total variance for pre- and post-monsoon data, respectively. Hence, these first three component scores are used to explain the background hydro-chemical processes without losing much of the significant characteristics. The component scores are cross-plotted, i.e., I versus II, I versus III, I versus IV and II versus III, II versus IV as shown in Figure 5. Cross plots of component I versus III, component II versus III component I versus II and component I versus IV separates out sample nos. 2, 3, 7, 8, 12, 11, 14, 15, 16, and 17 which have TDS of range 672–1,184, Na of range 56–1,305 and Cl of range 60–2,210 mg/l. Most of the samples separated out from the cluster are located nearer to the coast. The principle components of post-monsoon, component I is negative for F; component II is negative for HCO3, Cl, K and Mg; component III is negative for Ca and HCO3 whereas component IV is negative for F, SO4, Mg and HCO3. Cross plots of component I versus III, component II versus III and component I versus II and component I versus IV separates out samples no. 4, 11, 17, and 18, which have TDS of range 546–2,225, Na of range 128–995 and Cl of range 130–1,175 mg/l. Most of the samples separated out from the cluster are located nearer to the coast (Figure 3).
Figure 3 Principle component analyses of pre and post monsoon major elements

Conclusions

The various plots for chemical analysis data clearly suggest seawater ingress during non-monsoon period in the western as well as southern part of the Mincoy Island. Groundwater is affected due to sea water ingress and dissolution of calcium from the coral soil and aquifer formation in the island during post monsoon. The groundwater quality is found to be deteriorated in the western and southern parts of the island. It is suggested to minimize the groundwater abstraction in these zones and implement rainwater harvesting.

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