J. Ind. Geophys. Union (October 2011)
Vol.15, No.4, pp.221-227

Geophysical investigation for groundwater exploration in Lakshadweep Islands – A case study

N.B. Narasimha Prasad
Centre for Water Resources Development and Management,
Kozhikode 673571, Kerala State, India
E-mail: nbnprasad@hotmail.com

ABSTRACT

One of the main problems experienced by the islanders of Lakshadweep is associated with the availability of fresh water for drinking purpose. The scarcity of fresh water is due to the peculiar hydrologic, geologic, geomorphic and demographic features. Proper understanding of the groundwater condition, in terms of availability, distribution and quality, is very important to meet the increasing demand and also to formulate future planning and development of water resources. However there is very limited data / information available with regard to hydrogeological aspects of Lakshadweep. It is in this context; this study has been carried out. Geophysical investigation, using electrical resistivity method, is employed to locate potential zones of ground water in Andrott Island, one of the 10 inhabited islands in Lakshadweep. The data has been interpreted with the help of computer-aided techniques and presented in the form of spatial maps. The details of sub-surface lithology, as observed from the nearby existing dugwells and the water quality of the surrounding wells have also been considered during the interpretation of resistivity data.

INTRODUCTION

People living in Lakshadweep suffer due to inadequate availability of fresh water for drinking purpose. The scarcity of fresh water is due to the unique hydrologic, geologic, geomorphic and demographic features. Groundwater is the only source of fresh water. The demand for groundwater is increasing every year due to growing population and urbanization in the island. Proper understanding of the groundwater condition, in terms of availability, distribution and quality, is very important to meet the increasing demand and also to formulate future planning and development of water resources. However, there is very limited data / information available with regard to hydrogeological aspects of Lakshadweep. It is in this context; this study has been carried out. This study was carried out as part of a mega research project entitled "Management of fresh water sources in the Lakshadweep Islands" funded by India-Canada Environment facility (ICEF), New Delhi, and implemented by Centre for Water Resources Development and Management (CWRDM), Kozhikode.

Built on the ancient volcanic formations is the Lakshadweep (meaning a hundred thousand islands), the tiniest Union Territory of India. The Lakshadweep in the Arabian Sea is one of the most important regions in the country, strategically and economically. Lakshadweep the only coral archipelago of our country, are a group of coral atolls enclosing lagoons, submerged reefs and banks, situated at a distance of 300 – 480 Kms from west coast of India. The atolls have formed on the Lakshadweep-Chagos ridge. There are 10 inhabitted islands and lagoons (Kavaratti, Kalpeni, Agatti, Chetlat, Bitra, Kiltan, Kadamat, Amini, Minicoy and Andrott). Lakshadweep group of atolls is separated from the Minicoy by the 9^0 Channel (Mallik 2001). The atolls poised on submarine banks, harbor 36 islands having an area of 32 sq.km.

THE STUDY AREA – ANDROTT ISLAND

General Details

Andrott Island is at a distance of 150 NM (270 kms) north-west off Kochi (nearby Airport). This Island lies between north latitude 10°48′08" and 10°48′58" and east longitude 75°39′35" and 75°42′09" (Fig.1). The Andrott Island is oriented in east-west direction and characterized by the absence of lagoon. This Island is egg shaped and has an areal extent of 4.84 sq. kms, with a maximum length of 4.25 kms and a maximum width of 2.60 kms. The total population of this Island as per 2001 census is 10,720 with a density of 2215 persons / Km^2.

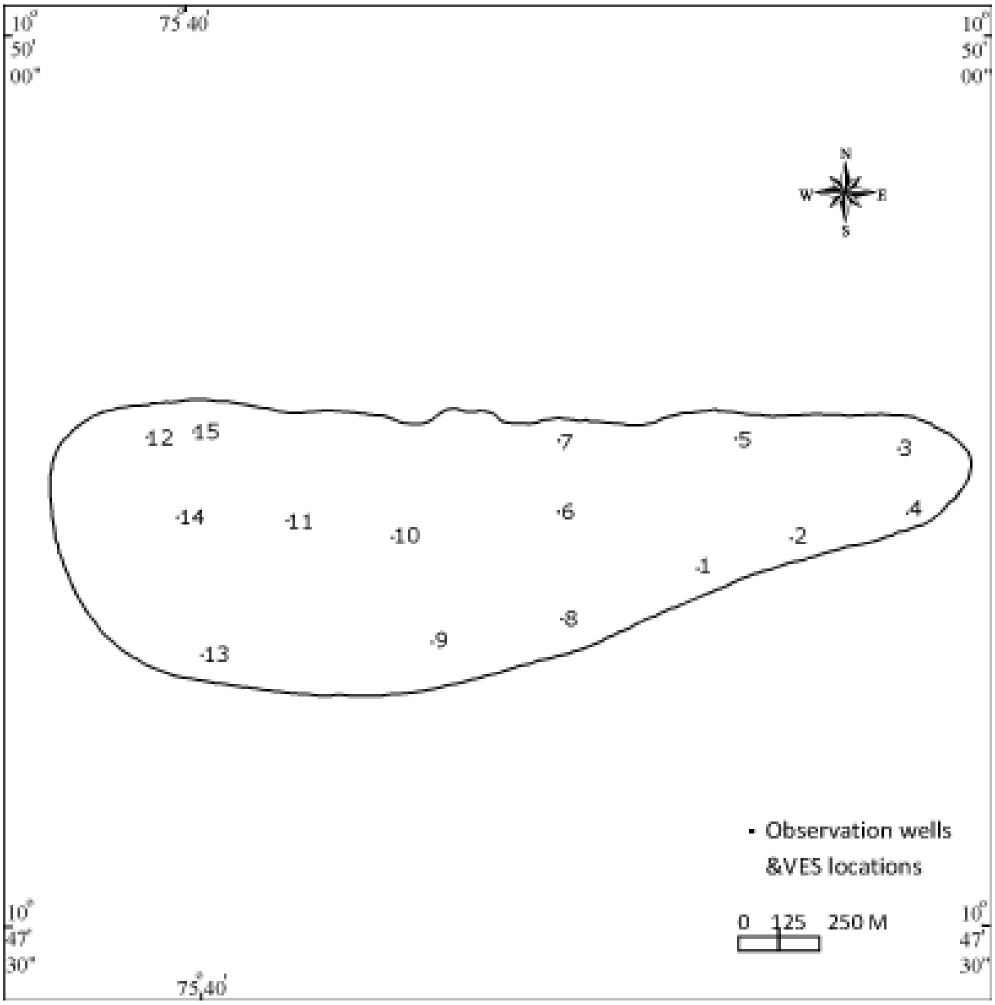

Table 1. Map of Andrott Island with Observation Wells and V E S Locations

Rainfall and Drainage

The long-term rainfall recorded at the nearby Amini Island has also been considered as the rainfall amount for Andrott Island. According to this long duration rainfall record, the average annual rainfall is 1512mm. About 72% of this annual rainfall is received during southwest monsoon (Jun-Sep). Out of the rest 18% is received during northeast monsoon (Oct-Dec). The remaining 10% is received as pre-monsoon showers.

As the area is covered by sandy soil, all rainfall received immediately infiltrates into the soil, reaches the ground water table and thereafter reaches the nearby sea as sub-surface runoff. Hence, there is no surface runoff or drainage channel in this Island.

Geology and Geomorphology

Andrott Island is mainly an atoll type of coral island, consisting of coral reefs, coralline limestone and carbonate / coral sand, formed by wind and wave action. This Island is characterized by the absence of lagoon and is entirely surrounded by the sea. The Island is covered by medium to fine-grained assorted coral sand, mixed with coral pebbles at some places, which is underlain by a thin hard coral limestone at a depth of 1.5 to 3.0 m. The hard coral limestone is characterized by cavities. This hard coral limestone is seen in the well sections. Loose coral sand underlies the hard coral limestones. The most important sediment-forming site is the reef area (Mallik, 2001).

Geomorphologically, the Island has storm beach, beach ridges, sand dunes (Eolian / Anthropogenic) and hinterland (Muralidharan & Praveen Kumar, 2001). The Island is generally flat with localized depressions or sand mounds, which are largely due to man made activities. The ground level varies from less than one meter to about 6m above mean sea level.

HYDROGEOLOGICAL CONDITION

Groundwater Occurrence

Groundwater occurs under phreatic condition in the coral sandy aquifer. The fresh groundwater is floating as a lens over the brackish water underlain by saline water. The seawater is in hydraulic continuity with the groundwater and the same is evidenced by the tidal influence in almost all the wells in the island (CGWB, 1995, Narasimha Prasad et al, 2006).

Groundwater Level Fluctuation

The depth to water level varies from 0.5 m to 4.0 m depending on topography. It is observed that the increase in groundwater level even during peak rainfall period is very low or insignificant, indicating the fresh-water lens floating over the seawater gets re-adjusted through out the lens as per Ghyben-Herzberg relation. Some rise is noticed in the groundwater level fluctuation during non-rainy days. This rise in water level is mostly due to the tidal influence (Jerry & Vacher 1986; Singh & Gupta, 1999; Narasimha Prasad & Abdul Jabbar, 2010). Thus in this Island, the groundwater level fluctuation is due to a combination of factors like rainfall, tidal activities, sub-surface runoff and draft. The height of annual groundwater level fluctuation varies from 0.01m to 0.24m.

The groundwater level fluctuation for a rise of 0.65 m in the sea level (tidal influence), varies from 0.09 m to 0.14 m depending on the distance of the well from the coast / sea. Groundwater is mainly extracted through large diameter dug wells of 1.5 to 2 meters. Wells close to sea show higher fresh water fluctuation compared to those nearer to lagoon (Narasimha Prasad and Abdul Jabbar, op cit). The lag time is between 1 to 3 hours (CGWB, op cit).

Current Status of Groundwater Development

Groundwater is extracted in Andrott Island through, large diameter dug wells, tanks / ponds and radial wells.

Large diameter dugwell is the main groundwater extraction structure in this Island. There are 1753 dugwells in an areal extent of 4.84 sq. km in this Island with almost each family having its own well. The depth of these wells ranges between 1.15m and 5.18 m below ground level depending on the ground elevation. The diameter of the dugwells varies from 0.80m to 3.0m, with majority of the wells having a diameter of 1.5 to 2.0m.These open wells are mostly constructed using cement rings or cement bricks up to the hard coral limestone to prevent the collapsing of sandy formation. Thereafter the well wall is unprotected. Groundwater is extracted from the cavitiferous hard coral limestone. The density of dugwells in this Island is 362 wells / sq. km. The present well density is very high considering the sensitive hydrogeological condition in which groundwater occurs in this Island. 99% of the pumping wells are fitted with pumps of 0.5 HP capacity. These wells are generally pumped for10-20 minutes in a day. Though the water level recovers in the wells within 10-15 minutes after pumping, the main problem associated with the pumping lies in the very limited thickness of fresh groundwater column. Due to this one has to be very careful during pumping. Any amount of over pumping adversely affects the quality of water. Almost all the dugwells are used for domestic purpose. Rarely well water is used for irrigating plants in the house compound (Narasimha Prasad et al, 2004).

GEOPHYSICAL INVESTIGATIONS

Geophysical investigations are very commonly employed to locate potential zones of ground water. Among the different geophysical methods, electrical resistivity prospecting has acquired greatest importance in groundwater investigations and this is due to the fact that, this method is the only geophysical method wherein the presence of groundwater affects the physical property measured. The resistivity of water bearing rocks largely depends on the amount of water they contain, the chemical composition and temperature, and the distribution of water. In addition, this method also provides variety of measuring procedures (in the form of different electrode configurations) that enhance the utility of this method. Groundwater investigation in the coastal areas is affected by seawater intrusion. And as such one should be judicious in selecting proper electrode configuration and generation of sufficient current to probe various water columns (fresh water, brackish water, pure saline water). The case of investigations in an island is further complicated because of the presence of the zones of seawater intrusion on at least two sides.

Electrical resistivity survey was carried out in Andrott island making use of Terrameter SAS 300 C. Vertical Electrical Soundings (VES) were carried out in 15 locations, which are representative of the entire island (Fig. 1). The objective of this investigation was to understand the sub-surface geologic and hydrogeologic conditions. Schlumberger electrode configuration was applied for conducting VESes. Half of the current electrode spacing (AB/2) was kept as low as 1.0m and extended to a maximum of 50m, depending on the availability of space. There were some difficulties and limitations in carrying out electrical resistivity survey, due to thick density of coconut plants (more than 1,21,000 yielding plants in 4.84 Km^2), network of roads and buried electrical cables, houses, etc.

A typical VES data obtained from the study area is given in Table-1. The VESes have been interpreted through curve matching techniques, using Orellana-Mooney master curves and also using the RESIST soft ware.

RESULTS AND DISCUSSION

The field data appears as a double descending Q-type curve. All the field curves represent 3 to 4 layered geoelectric sections. The apparent resistivity (ra) values show a decreasing trend with depth, indicating the presence of saline water. A typical interpreted data for the location of data given in Table –1 is shown in Fig 2. The details of sub-surface lithology, as observed from the nearby existing dugwells, and the water quality aspects of the surrounding wells have also been considered during the interpretation of VES data.

The top sandy soil mixed with corals shows a resistivity range of less than 100-ohm m to more than 1500-ohm m. The second layer comprising of fresh groundwater shows a resistivity range of 50 to 650 ohm m. The third layer comprising of brackish water shows a resistivity range of 15 to 75 ohm m. The last layer representing the saline water zone shows a resistivity range of less than 10 to 55 ohm m. All the resistivity values and their ranges obtained for different geoelectric layers are due to the effect of formation resistivity.

Apparent resistivity distribution maps for different half-electrode separations (AB / 2) have been prepared using the field data and the same for AB/2 = 5m & 20 m are shown in Fig 3. Resistivity reduces with increasing current electrode separation and the lowest apparent resistivity value is obtained for AB/2=20m.

Figure 3 shows the spatial variations in the apparent resistivity obtained using the half current electrode separation of 5 m and 20m. In general, it can be observed that the values are very high at almost all the locations for AB/2=5m compared to AB/2=20m

Table –1: A Typical Vertical Electrical Sounding Data

SI. No	AB/2 in meters	MN/2 in meters	Apparent Resistivity (ρa) in Ohm m					
			VES Location No.					
			2	5	6	11	13	15
1.	1.00	0.25	1340	1685	645	603	594	1161
2.	1.40	0.25	1299	1633	565	456	566	1066
3.	1.70	0.25	1261	1580	464	369	550	957
4.	2.00	0.25	1224	1508	366	271	521	841
5.	2.50	0.25	1150	1438	260	190	406	685
6.	3.00	0.25	1044	1235	185	161	300	561
7.	3.50	0.25	940	1071	138	122	200	418
8.	4.00	0.25	738	930	104	97	132	311
9.	5.00	1.00	563	686	73	71	68	172
10.	6.00	1.00	369	421	57	58	34	84
11.	7.00	1.00	240	233	51	53	24	45
12.	8.00	1.00	138	155	48	50	19	29
13.	10.00	2.00	66	79	45	45	16	19
14.	15.00	2.00	23	30	40	40	14	8.1
15.	20.00	4.00	14.6	22	35	36	11	7.7
16.	30.00	4.00	8.0	7.5	15	31	9	6.0

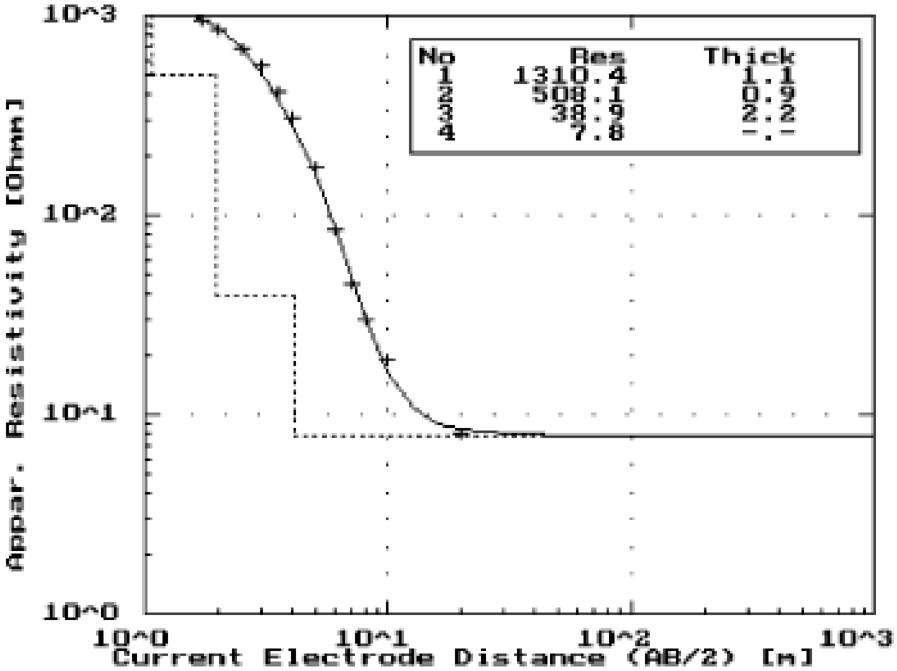

Figure 2. A Typical Interpreted VES Result

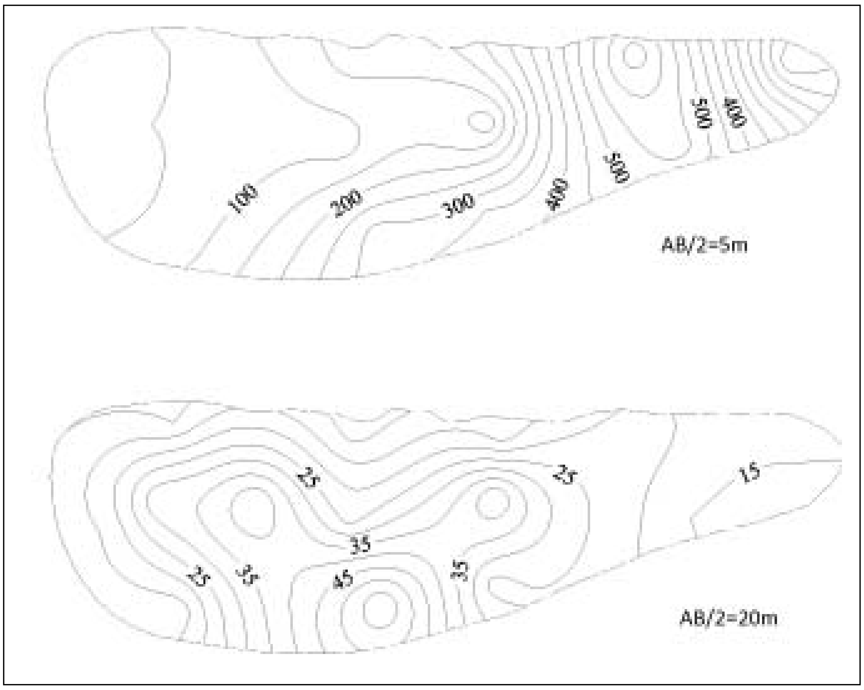

Figure 3. Apparent Resistivity Distribution in Andrott Island

(The low resistivity values are due to the influence of the saline water). For both the separations, it can be seen from the Fig.3 that the apparent resistivity is more in the eastern and western end, as these areas are characterized by high concentration of coral pebbles within the coral sand. Dry sand mixed with coral pebbles present near the surface of the earth gives these high values and the variations are due to the changes in the moisture content of the sand.

The central portion of the island shows a low resistivity values for both AB/2= 5m and 20m, as the areas around this region are of low topography. Usually the region contains very high moisture even at shallow depths. Mostly these areas have by fresh groundwater or comparatively low salinity groundwater, at very shallow depths. However, these fresh water columns are thin in nature. This is evident from resistivity values for AB/2 of 20. It can be observed that the resistivity values for AB/2 of 20m are less for almost the total area, confirming that the groundwater at this depth is highly saline in nature.

The spatial variation diagram for different current electrode separations indicates that in general the apparent resistivity values reduce with increasing current electrode separation indicating the presence of saline water at depth. Even at smaller electrode separation, of AB/2=20m, resistivity values are very less in the entire island, indicating the occurrence of saline groundwater at shallow depth.

CONCLUSIONS

Andrott Island in Lakshadweep is facing with acute scarcity of fresh water. Groundwater is the only source of fresh water for the islanders. Groundwater occurs under phreatic condition and the fresh groundwater is floating as a lens over the brackish water underlain by the saline groundwater. Seawater is in hydraulic continuity with the groundwater and all the wells are influenced by tidal fluctuations. The apparent resistivity values show a decreasing trend with depth, indicating the progressive increase in salinity of groundwater with depth. Even at smaller electrode separation of AB/2=20 metres, the resistivity values are less for almost the entire island, indicating the occurrence of saline groundwater even at shallow depth. The thickness of fresh groundwater aquifer is found to be between 1m and 1.5 m. Groundwater being the only source of fresh water, the demand is increasing every year. However, the groundwater potential is very limited. In this type of a scenario, groundwater conservation and management techniques have to be adopted, to control further deterioration of the status of groundwater in this Island.

Some of the groundwater management and conservation strategies that can be adopted in the Andrott Island are as follows:

- Pumping groundwater from the wells should be restricted to avoid saline water intrusion and public should be encouraged to extract groundwater through pulley and rope. Intensity and duration of pumping of groundwater from private and public wells should be monitored and indiscriminate use of groundwater should be controlled.
- Rainwater harvesting structures / tanks should be constructed in as many places as possible through public participation such that the dependence on groundwater can be reduced (already some action is being taken by the UTL authorities, CWRDM and some NGOs).
- Recharging of wells through rooftop rainwater harvesting should be propagated and if possible, the same should be made mandatory for achieving long term benefits such as better quality and increased fresh groundwater availability.
- Public awareness should be created on the wise use of limited fresh groundwater resources.

ACKNOWLEDGEMENTS

The work presented here is part of a mega research project entitled," Management of fresh water sources in the Lakshadweep Islands" funded by India -Canada Environmental Facility, New Delhi and implemented by CWRDM, Calicut. Dr. E J James, Executive Director (Retd), CWRDM, provided unlimited help and encouragement. The staff of LIWAMP Cell, CWRDM, gave all necessary help and cooperation. The staffs of LPWD and DST of Lakshadweep in general and Dr. Syed Ismail Koya, Director, DST, in particular, were of great help during the field work and data collection. All these are duly acknowledged.

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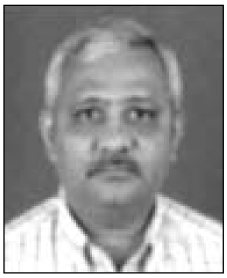

Dr. N B Narasimha Prasad is working as a Groundwater Scientist in the Centre for Water Resources Development and Management (CWRDM), Kozhikode, Kerala, since October 1983. Presently he is heading ground water division. He has secured M. Sc (Geology), M. Tech (Hydrogeology) and Ph. D (Geology) degrees from the University of Mysore. He has 28 years of R & D experience and his main areas of research interest are in the application of hydrogeological and geophysical techniques for groundwater assessment, development and management. Dr. Narasimha Prasad has implemented more than 40 R & D projects, funded by various State and Central agencies, addressing different issues of groundwater assessment, development and management, related to Kerala State and Lakshadweep Island, which in turn can be used in other similar humid tropical regions. Based on the results obtained from various projects, 80 research papers have been published in International/ National journals/conferences. More than 110 research reports on various aspects of groundwater have been published.