Groundwater Perspectives of Small Islands—Lakshadweep Islands, India

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Abstract: Hydrological perspective of small islands is low and scarce. All the atolls of Lakshadweep islands and more than five hundred islets/islands of Andaman and Nicobar islands are of the group of small and low islands. The size of the biggest island (Androth) in Lakshadweep is less than 5 sq.km and the smallest (Bitra) is less than 1 sq.km Ground water is the major component of the water balance in Lakshadweep islands and majority of the Andaman and Nicobar Islands. Lakshadweep islands consist sandy soils with high permeability. Sandy soil with high permeability may also genesis submarine groundwater discharge. The availability of fresh water resources of two islands Kavarathi and Bengaram of Lakshadweep islands were estimated using Ghyben-Herzberg equation for oceanic island, and impact of sea level rise were estimated using Brunn's rule. Seasonal fresh water fluctuations in the observation wells were measured from Kavarathi and Bengaram islands. The intrusion of saline water and its seasonal variation were surveyed and estimated. The present study consists of scenario of ground water, impact of sea level rise on coastal aquifer, the present utilization of ground water and problems related to submarine groundwater discharge of small islands.

INTRODUCTION

Islands are of three types in origin. They are part of the continent and separated due to sea level rise. Islands that are part of the volcanic arc are formed in the subduction zones. Island is also formed due to activity of hotspots. Islands are of extreme diversity in nature. The diversity of islands made them the perfect natural experiments on the evolution and biography (Cox and Moore, 2005). The Lakshadweep islands and Andaman Nicobar islands are part of volcanic island formed in the subduction zones. Pratap (1990) observed that Lakshadweep islands are of coral origin. It is developed over volcanic peaks.

The Lakshadweep island and Andaman and Nicobar Islands are situated in the South Arabian Sea (latitude 8° and 13° N, and longitudes 71° and 74° E) and Bay of Bengal (6° and 14° N and 92° and 94 °E) respectively (Fig. 1). Lakshadweep islands comprise 36 islands, islets, reefs and sand banks distributed north to south in the Lakshadweep Sea. Ten of these islands are inhabited. The Andaman and Nicobar Islands spread over 780 km of ocean, comprise 554 islands including rocks, islets and sandbanks. Thirty-six of these islands are inhabited.

Islands have been classified on the basis of area, geology, climate, fresh water lens geometry, and water balance (Falkland, 1991). Islands of area less than 2000 sq.km and width less than 10 km are defined as small islands. The surface area less than 100 sq.km are classified as very small islands. Falkland (1991) classified small islands as High Island and Low Island. The low islands are very small and are a few metres above sea level. They have little surface water and have a thin often brackish groundwater lens. The islands of Lakshadweep have the characteristics of very small low islands. These islands have a flat topography with a minimum surface runoff. Ground water is the major source and part of the water balance of low islands.

The Lakshadweep islands are observed to be young of late tertiary periods. They are flat and a few metres above sea level. They have no bays, creeks, estuaries, rivers, streams, lakes, tanks, hillocks, forests and deserts. A few brackish water ponds are observed at Bangaram and Minicoy islands. It has thin layer of topsoil. The topsoil is formed from fragmentation of coral lime, stones and sedimentary rocks. The surface soil is quite porous and retains very little moisture. The surface soil is so porous that even after heavy rain all the water percolates to the aquifer. Fresh water is available in all the inhabited islands, 1-2 m below the ground level. Many of these islands still remain uninhabited due to lack of potable water((Rao, 1991).

Coastal groundwater potential and groundwater flow is a subject of great concern for the last one decade (Alicia, 2005). Ground water is an important water resource in the coastal regimes and islands. Ground water of both terrestrial and marine origin flows into coastal surface waters as submarine groundwater discharge (SGD) and forms an important source of nutrients, contaminants and trace element to the coastal ocean (Holly A. Miichael, 2005). The net discharge of ground waters in coastal areas shape the saline intrusion to the fresh water aquifer. The SGD were measured directly using

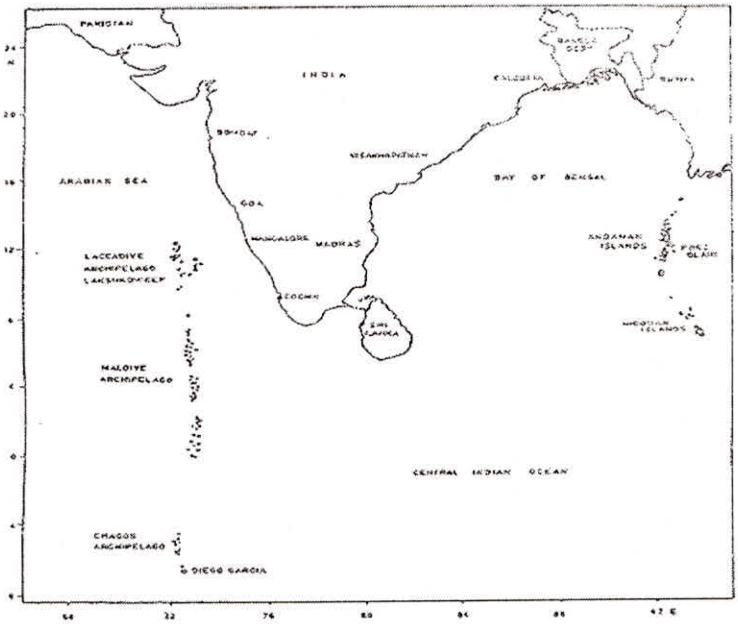

Fig. 1. The location of Lakshadweep and Andaman Nicobar islands.

seepage meters to examine the dynamics of the flow. However, it is observed that in many of the cases the seaward flow near coastal regions consists saline water, whereas the landward flow is not sufficient to explain the above phenomena (Kim et al., 2003; Michael et al., 2003; Smith et al., 2003). The conditions in equation of continuity are to be further examined for a proper explanation of the above phenomena.

The studies regarding the hydrological aspects of Islands are a few. The hydrological aspects of the atolls of Lakshadweep islands have been described in Sundaresan (1993), Varma and Ramachandran (1996), Bobba (1998), Singh and Gupta (1999). The present study describes the salinity contaminated regimes and fresh water potential of Kavarathi and Bengaram islands. Seasonal groundwater level fluctuations, depth of interface between fresh water and saline water are discussed. Attempts are also made to predict the fresh water contamination due to predicted sea level rise.

MATERIALS AND METHODS

The Kavarathi and Bengaram islands were divided into smaller segments based on the observation wells fixed in the islands. Periodic water level variations were recorded from the observation wells. The piezometric studies were done based on above observations. The elevations of the observation well from mean sea level (msl) were surveyed. Salinity was determined from water samples collected from observation wells. The temperature of the water sample was recorded using thermometer. Water table variations with respect to msl were estimated from well spot survey and well depth from ground surface.

The density of the ground water is calculated from salinity and temperature using the relation (Lafond, 1951)

$$\sigma_t = E_{1t} + (\sigma_0 + 0.1324)[1 - At + \beta_t (\sigma_0 - 0.1324)] \tag{1}$$

where $E_{1t} = -\left(\frac{t-3.98}{503.51}\right)^2\left(\frac{t+283}{t+67.26}\right)$; $At = t(4.7867 - 0.098185t + 0.0010843t^2)\,10^{-3}$; $\beta_t = t\,(18.030 - 8164t + 0.01667t^2)\,10^{-6}$; $\sigma_0 = (0.069 + 1.4708\,cl - 001570\,cl^2 + 0.0000398\,cl^3$; $S = 0.03 + 1.805\,cl$; $cl = \frac{S-0.03}{1.805}$; $\rho = \frac{\sigma_t}{10^{-3}} + 1$; in which '$\rho$' is the density, '$S$' is the salinity and '$t$' temperature.

The depth of fresh water saline water interface is determined from Ghyben - Herzberg relation for ocean island (Todd, 1980).

$$Z^2 = \frac{W - (R^2 - r^2)}{2K\left(1 + \frac{\Delta\rho}{\rho}\right)\left(\frac{\Delta\rho}{\rho}\right)} \tag{2}$$

where 'R' is the island radius; 'W'—effective recharge from rainfall; 'K'—permeability; 'Z'—the depth to the interface below msl at radius 'r' and '$\Delta\rho$ ' density of water, is the density gradient between sea water and ground water. It is assumed that for coral islands all the rainwater percolates to groundwater lens and the permeability is 150 (Todd, 1980). The change in island radius 'R' due to shoreline recession for different SLR scenarios was calculated using Bruun's rule (Bruun, 1990).

RESULTS AND DISCUSSION

Kavarathi Island

The hydrological observations of Kavarathi Island were carried out using 154 observation wells (Fig. 2). The ground elevations of these observation wells with respect to msl were surveyed. The aquifer systems along the southern tip of the island were contaminated by saline water intrusion. Water table at station 3 is below mean sea level (-2 m). The distance between surface soil and water table is very small. The chances of contamination of fresh water table due to saline water are more. Water table is relatively high in the lagoon beach than in the stormy beach. Salt-water intrusion is more on the eastern side. The areas consisting intruded saline water are depicted in Fig. 3. The southern zone is of minimum width (30 m). It has stormy beaches on three sides. This causes high saline water intrusion into this area. There are patches of saline water in the northern region of the island. This may be due to the upcoming of saline water due to excess intake of fresh water. The northeastern regions consists many salinity-contaminated aquifers. This may be due to the severe coastal erosion persisting in these regimes.

The annual availability of fresh water potential is presented in Fig. 4. The maximum fresh water potential is present at 3500 m away from southern tip. Figure 4 also depicts the impact of sea level rise of 20 cm on the fresh water potential in the island. It is estimated that 11.6% of fresh water will be contaminated due to 20 cm sea level rise. The salt-water invasion due to sea level rise will be more in the eastern side, which is about 30 per cent at stations 40 and 148. The saline water intrusion due to sea level rise will be vulnerable on the south of lagoon beach and at the north east of stormy beach. This may be due to the low-lying characteristics of this region.

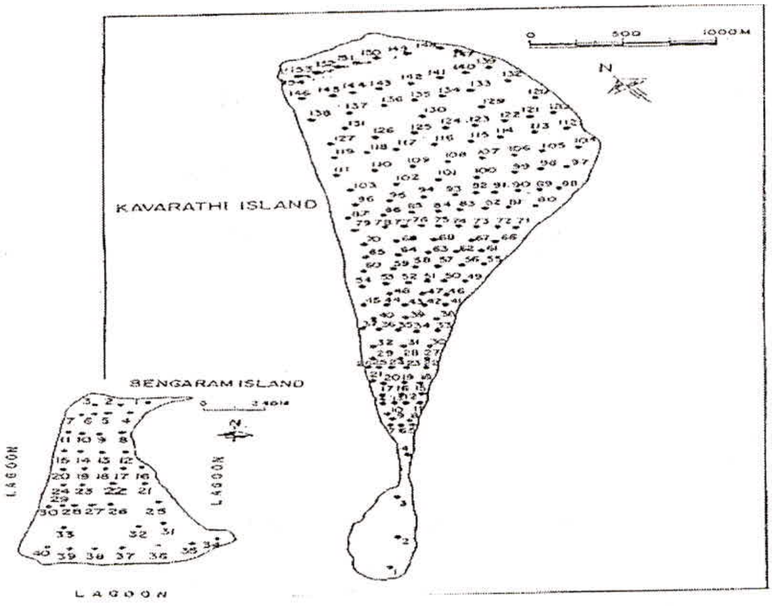

Fig. 2. Location of observation wells (a) Kavarathi island (b) Bengaram island.

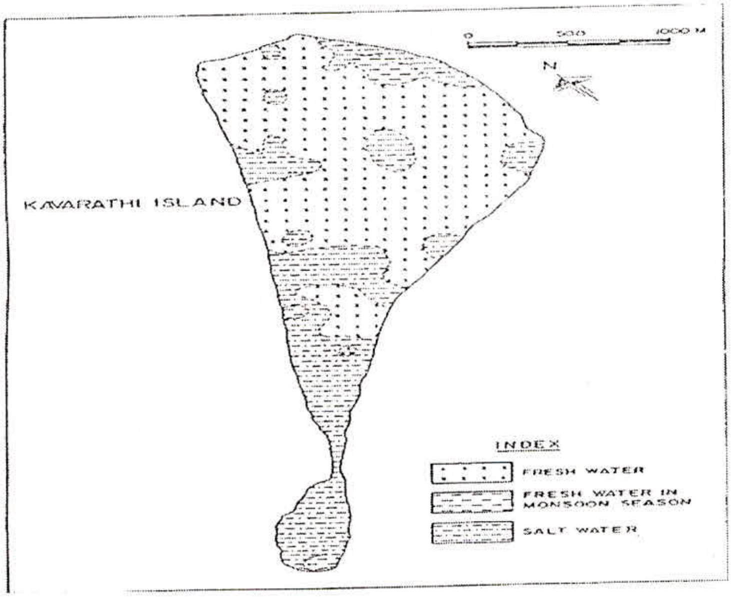

Fig. 3. Location of salt-water intrusion of aquifers in Kavarathi island.

Kavarathi atoll is a water scarce area. The annual water consumption for drinking and washing of the people was approximately estimated as 220 million litres during the year 1991. The water consumption is projected as 460 million litres during year 2030. The predicted sea level rise of 20 cm may significantly reduce (by 11.6%) the freshwater source. During the year 2030 the water consumption of the projected population will be 108% more than the water consumption today. If the sea level rise in the next few decades as predicted, it will exacerbate the present water dilemma of this atoll.

Bengaram Island

The hydrological observations at Bengaram were done using 40 observation wells (Fig. 1). The piezometric surface varies from 150 cm to 210 cm. The water level variations are more towards northwest and depleting towards south. The well inventory reveals that the water level rises soon after rainfall. However the water level recedes within few days. The distance between water table and ground surface of this atoll are very small. The soil consists of coral sands. It does not retain significant amount of moisture under unsaturated conditions. The above study reveals that the ground water in this atoll is near phreatic conditions.

The salinity-contaminated aquifer of the atoll is ascribed in Fig. 5. The fresh water aquifer is more towards south of the island. A natural water body of length 500 m and average width of 40 m is present about the middle of the atoll. This water body is saline during the periods other than monsoon season. It characterizes like a lagoon with its inlet permanently closed due to accretion in this coastal tract. Saline water patches are observed along the southeast tip of the island. The saline patches reveal that there is a change in the slope of saline water and fresh water interface. It is due to the extended coastal hydraulic processes. The Bengaram resort and other establishments are located towards the

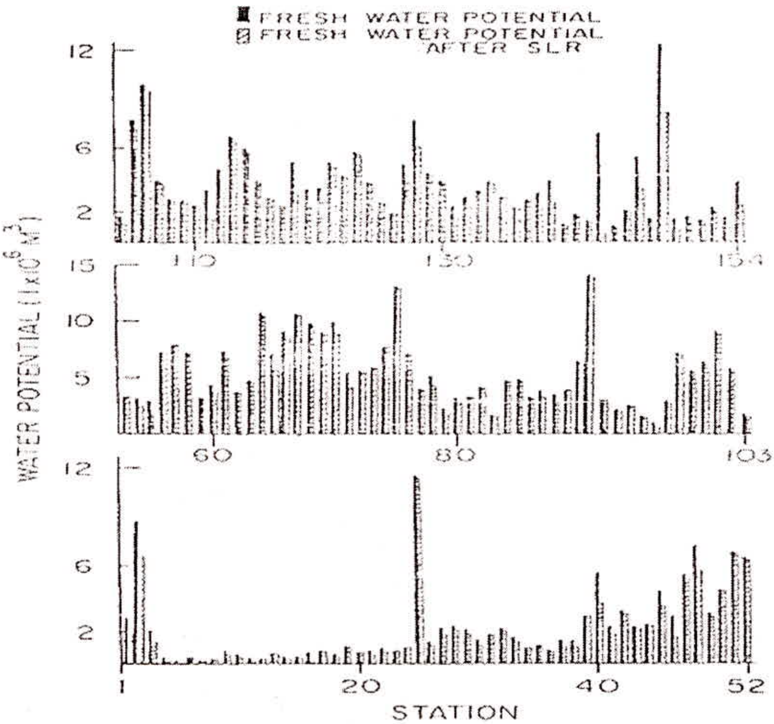

Fig. 4. Fresh water potential and impact of sea level rise of 20 cm scenario on the freshwater aquifer of Kavarathi Island.

north of the atoll. Hence, there is optimum extraction of water from the coastal groundwater lens in the northern region. A heavy-duty pump is operating at 250 m from the north and 120 m from the west coastline. The pump will extract more water from the fresh water aquifer. It lowers the piezometric head of fresh water. The saline water will intrude to the freshwater aquifer. If the fresh water is extracted in excess, the upcoming of salinewater will come into effect. This may cause permanent intrusion of saline water in the well. The relatively more patches of saline water observed in the northern region of the atoll is due to the above phenomena.

The maximum fresh water zone is found in the south and minimum at 250 m from south. The thickness of freshwater lens decreases towards shore. There is a hydraulic gradient towards the sea. The zone of contract between sea water and fresh water below msl concave downwards, like a bowl. The central regime of the atoll behaves like a basin and western side is steeper towards the middle. The basin characteristics of the atoll results more fresh water towards the middle of the island. Bear (1979) also highlights the natural replenishment and topography of ground surface. The water level in the well rises soon after rain. However the water level recedes soon. The fluctuations of water level after rain, and in accordance with tidal force, reveal the possibility of SGD in this atoll.

Freshwater potential of the aquifer system of Bengaram atoll is exhibited in Fig. 5. The maximum water potential at station 37 (16.22×10^5 m^3) and water potential is minimum at stations 5, 19 and 20 (0.52×10^5m^3). The impact of sea level rise of different scenarios of 50 cm and 100 cm are also presented in Fig. 5. The sea level rise will cause an apparent risk of invasion of saline water into

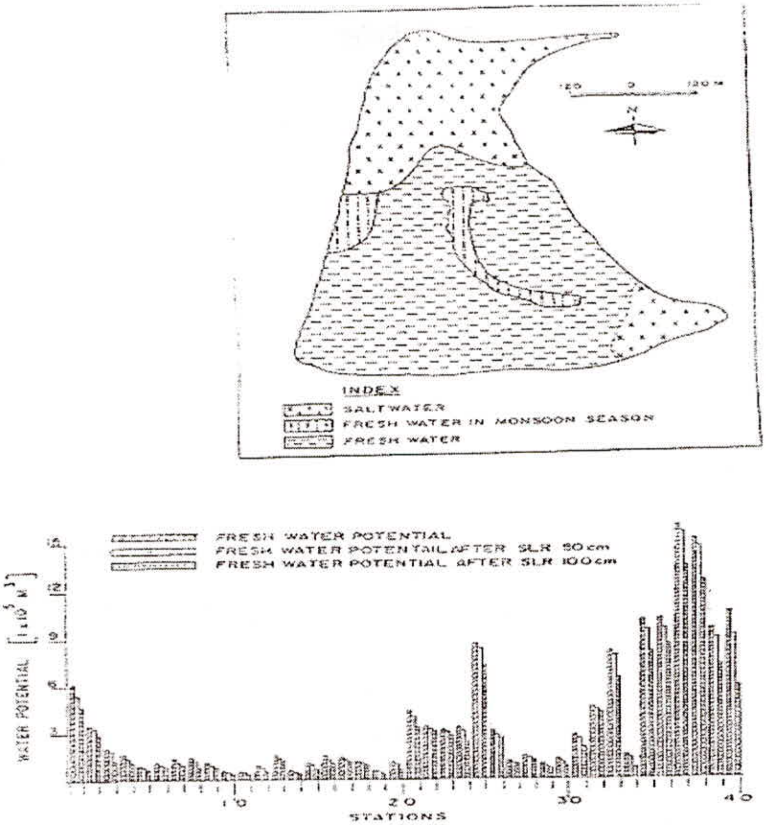

Fig. 5. (a) Location of salt water intrusion of aquifer in Bengaram island (b) Fresh water potential and impact of sea level rise of scenarios 50 cm and 100 cm on the fresh water aquifer of Bengaram island.

freshwater aquifer. It is estimated that 50 cm SLR will contaminate 5.99% of the existing freshwater aquifer system. The sea level rise of 100 cm will contaminate 21.66% of the present freshwater aquifer system. The seawater invasion will be more on the southern side of the atoll. Sea level rise of more than 50 cm will exacerbate the water availability of the island.

CONCLUSION

The water table up to 2 km from southern tip of Kavarathi atoll is below MSL. This regime has been permanently contaminated by saline water invasion. Substantial quantity of freshwater is present towards the north especially in the region of more width. The early receedings of groundwater level after rain reveals the increased submarine groundwater flow in this island. There are many regions of patches of salt water. The upcoming of water in the Kavarathi is an alarming phenomenon in specific locations. This is due to the excess withdrawal of fresh water in these regions. The freshwater aquifer of Kavarathi atoll will be highly invaded by saline water due to rise of sea level. The predicted sea level rise of 20 cm will contaminate significant portion of the freshwater aquifer. This will aggravate the present water scarcity of this atoll.

The fresh water potential is more towards the southern regime of Bengaram island. The water table in this atoll is in phreatic conditions. The upcoming phenomena is persisting towards the northern regime of the atoll. The hydraulic gradient of the aquifer system is towards the sea. This may result in the submarine ground water (SGd) flow and early drains of rain water into the sea. The impact of sea level rise is relatively less in the freshwater aquifer of Bengaram island. The water body in the middle of Bengaram atoll persists the rain water like a bowl. The excess withdrawal of water and the pumping of water in the northern region of the atoll will accelerate the saline water invasion into the freshwater aquifer of these regions.

REFERENCES

Alicia, M. Wilson (2005). Fresh and Saline groundwater discharge to the Ocean: A regional perspective, *Water Resources Research*, **70:** 1-11.

Baryy Cox MA, C. (2005). Biogeography: An ecological and evolutionary approach, 7th edition, Blackwell, USA.

Bobba, A.G. (1998). Application of numerical model to predict fresh water depth in islands due to climate change effect: Agati island, India. *Jour Environmental Geology*, **6:** 1-13.

Bruun, P. (1990). World wide impact of Sea Level Rise on shorelines. *In:* Handbook of coastal and ocean engineering, (ed. Horbich, J.B.). J.B. Gulf Publishing Company, Huston.

Falkland, A. (1991). Hydrology and Water Resources of Small Islands. A Practical Guide. UNSCCO, Paris.

Kim, G., Lee, K.K., Park, K.S., Hwang, D.W. and Young, H.S. (2003). Large submarine ground water discharge (SGD) from a volcanic island. *Geopys. Res. Lett.*, **30**, doi 10. 1029/2003 GLO18378.

Lafond, E.C. (1951). Processing Oceanographic data: H.O. Pub. No.. 614, U.S. Navy Hydrographic Office, Washington, pp. 1-47.

Michael, Holly A., Mulligan, Ann E. and Harvey, Charles F. (2005). Seasonal Oscillations in water exchange between aquifers and the coastal ocean. *Nature*, **436:** 1145-1148.

Michael, H.A., Lubetsky, J.S. and Harvey, C.F. (2003). Characterising submarine ground water discharge: A seepage study in Waquoit Bay, Massachusetts. *Geophys. Res. Lett.*, **30**, doi:10.1029/GL016000.

Pratap, V. (1990). A review on the Geology of Kerala Laccadive basin with special reference to its petroleum prospects; *In:* (ed. N. Balakrishana Nair), Proceedings of the second Kerala Science Congress, STEC, Trivandrum, 130-132.

Rao, C. Chandrasekhra (1991). Lakshadweep : General features, Fauna of Lakshadweep. *In*: Director Zoological Survey of India, Zoological Survey of India, Calcutta.

Singh, V.S. and Gupta, C.P. (1999). Ground water in a coral island, *Environmental Geology*, **37:** 72-77.

Smith, L. and Zawadzki, W. (2003). A hydrogeologic model of submarine groundwater discharge: Florida intercomparison experiment. *Biogeochemistry*, **66:** 95-110.

Sundaresan, J. (1993). Impact of sea level rise on aquifer system of Agatti atoll. *Environmental Geology*, **21:** 51-54.

Todd, D.K. (1980). Ground water Hydrology, 2nd edition. Wiley, New York.

Varma, R., Ajaya Kumar and Ramachandran, K.K. (1996). Resistivity Survey for describing the fresh water lenses of Agatti atoll, Lakshadweep, India. *Jour. Assoc. Expl. Geophys*, **XVII:** 11-16.