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Vijay Shankar Singh

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Foreword

The demand for the potable water is increasing day by day in most developing countries, particularly in India. Major part of this demand is met from groundwater. In many parts of India, the groundwater is indiscriminately being exploited, resulting in depletion in quantity and degradation in quality. The situation is more alarming on tiny coral islands of India. Lakshadweep islands are one such group of islands. The potable water in the form of groundwater is the only resource available on the coral islands. It is in the form of floating lens fraught with many stresses, some of them natural and some are anthropogenic. The net result is deterioration in the groundwater quality and reduced availability of potable water. Therefore, there is urgent need to consider several issues for the sustainability of groundwater resources on the tiny coral islands of Lakshadweep.

The need of the hour is to evaluate various factors affecting the precious groundwater resources on coral island. Dr. Singh has wide experience of working in the field of groundwater hydrology. He has worked in different terrains. He has particular interest in characterization of aquifer system and simulation of aquifer response using numerical methods. The techniques developed by Dr. Singh are published and widely used. His papers are cited in many research papers. Dr. Singh has carried out hydrogeological, geophysical and geochemical studies on different coral islands. I have been associated with some of the projects. I would like to congratulate Dr Singh for successfully completing these projects and bringing out this excellent book.

This book is the outcome of various investigations carried out by Dr. Singh on coral islands of Lakshadweep. Dr. Singh has presented features of the islands of Lakshadweep, their genesis, physiography etc with elucidated diagrams. The occurrence of groundwater is described in detail. In order to assess groundwater resources on the tiny coral island, various approaches such as hydrogeological, geophysical, chemical, and numerical simulation through modelling are presented. The occurrence and movement of groundwater is characterised by aquifer parameters. The sustainable development and management of groundwater resources on the coral island requires data on hydrogeology, chemical analysis of water,

meteorological parameters, apart from increasing demand of potable water. Different approaches for the management of groundwater resources are presented in the book.

In order to illustrate various approaches to evaluate the groundwater resources on coral island, four examples of island are presented. The various data are presented that could be helpful for future research and monitoring of groundwater resources on the island. People engaged in R&D and groundwater management may find the approach and data presented in the book very useful. The time-referred data may be useful for future comparative studies and evaluation.

Hyderabad, India
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Preface

There is a growing demand of potable water all over India. The demand is more significant on the tiny coral islands of Lakshadweep, where the occurrence of potable water is limited. The potable water is supplied through the pumping of groundwater on the coral island. It was feared that in the absence of any assessment of sea water ingress or upconing due to pumping of groundwater on the island, the entire groundwater regime on the island may become saline. Therefore, to evaluate groundwater on the island of Lakshadweep, various hydrogeological investigations are vital. The primary objective of this book is to describe the formation of tiny coral island, occurrence of groundwater and its characterization with particular reference to islands of Lakshadweep.

The work relates to the occurrence and management of groundwater resources on the tiny or very small coral island. At the outset, the status of freshwater available on the earth is described. In the context of India, the total freshwater resources, particularly, the groundwater resource is described. Further, the groundwater scenario on the small coral island is presented.

The formation of small coral islands, particularly, Lakshadweep (in Arabian Sea) is described in the introduction. All the small coral islands, sand bars and reefs, are presented. Each of the islands is described in detail. Some of these small coral islands are inhabited.

The major source of potable water on the island is groundwater. The hydrogeological conditions of occurrence of groundwater on the small coral island are described in following chapter. The relationship between height of water table measured in the well and sea level is discussed. This relationship is often affected or modified under various hydrogeological conditions. It is discussed in detail in Chap. 2.

In order to quantify the groundwater resources on the island, it is essential to map the aquifer system on the island. Various methods to delineate the aquifer system on the island are presented with latest references in Chap. 3. These are geophysical and hydrogeological approaches to map subsurface aquifer system on the island. The geophysical method includes electrical resistivity method, seismic and electromagnetic methods. The most easy-to-use, rapid and economical

electrical resistivity method is discussed in detail including data collection and its interpretation. The latest technique of *Resistivity Imaging* is also described. The seismic and electromagnetic methods are also described in detail. The hydrogeological approach includes application of Ghyben–Herzberg relationship. It gives the first-order estimate of shape of groundwater lens or depth of middle of transition zone on the island. The other approaches are rainfall–width–permeability relationship and rainfall–width–lens thickness relationship. These methods are presented in detail. The analytical and numerical approach to estimate the thickness of the groundwater lens is described in detail.

The other essential character of groundwater is its movement. The parameters that define the movement of groundwater are hydraulic head, transmissivity (permeability) and storage coefficient. A common approach to estimate the aquifer parameters is through pumping test. On the small coral island the pumping test is restricted by many factors. These are described in Chap. 4. In order to overcome the difficulties and derive the representative aquifer parameters, analytical as well as numerical approaches considering the hydrogeological conditions on the island are discussed. The water table on the islands is affected by tides. The occurrence of tide is discussed in detail, particularly with reference to Lakshadweep islands. The detail interpretation of the tides observed at well water with sea tide is presented. The method gives the estimation of *aquifer diffusivity* that is characteristic of movement of groundwater in the aquifer.

The quality assessment of the groundwater on the coral island is vital and various approaches to assess the water quality are described in Chap. 5. The major cations and anions are estimated from the water samples collected from the wells on the island. These samples are collected after the rainy season, just before the rain begins and/or whenever it is required. Since most rains in the region of Indian Ocean and Indian continent is limited to the four months of monsoon, it is essential to observe the effect of monsoon on the groundwater quality as well as deterioration during non-monsoon days. Sometimes it may be needed to monitor the quality on a regular interval of time. Various methods of interpretation such as Piper diagram and Gibbs diagram are described to assess the quality of groundwater and the possible influence of various factors on it. The Piper diagram allows grouping of samples by major groundwater constituents. It allows multiple samples to be plotted on the same diagram. It is used to visualize the relative abundance of common ions in the groundwater samples. Similarly, the Gibbs diagram is used to distinguish between precipitation dominance, evaporation dominance and rock–water interaction dominance in the groundwater samples. The other approaches such as statistical analysis and water quality index approach are also described to assess the groundwater quality on the island and influence of various factors such as sea water ingress. These methods are used for both premonsoon and postmonsoon water samples to bring out the effect of groundwater withdrawal during non-rainy season and dilution due to rain water recharge. There are anthropogenic pollutions on the small coral island. The major anthropogenic pollution is caused by the faecal pollution on the island. In the absence of any sewage system, each house has septic tank at the back of the house. The bottom of the septic tank is very close to water

table giving rise to possibility of leakage of pollution to groundwater system. Similarly, the oil spillage from the power generating station also reaches the water table causing pollution.

The groundwater which is limited needs to be properly managed in view of increasing demand of groundwater resources on tiny island. Various methods of assessing the total availability of groundwater resources on the small coral island are described in Chap. 6. The different approaches such as water balance method and aquifer simulation methods are discussed in the book. The numerical approach includes simulation of aquifer system using double-density model of USGS-SUTRA. The required data for the aquifer simulation are described. The successful simulation of the groundwater regime on the island helps in prognosing the future scenario with different inputs such as optimum pumping scheme, effect of increased pumpage of groundwater, effect of subsurface dam to mitigate the groundwater resources, etc.

The last chapter describes actual implementations of all the methods of investigation as described above, considering four typical islands of Lakshadweep (India). Details of data collection on each island are presented in graphical form. The data is interpreted to arrive at the groundwater scenario on each island. Hydrogeological conditions have been described and presented in the form of figures. These data will be valuable for any future studies on these islands. Finally, suitable measures for sustainability of groundwater resources on the islands are suggested.

The data collection on these islands was financed by Department of Science and Technology (DST, Government of India), and major part was supported by its division of Natural Resources Data Management System. The officials of Union Territory of Lakshadweep have been very courteous and provided all the available information as well as helped in carrying out investigations from time to time. My colleagues from CSIR-National Geophysical Research Institute have assisted in collecting various data from the islands of Lakshadweep. The beginning of data collection effort started with the help of Mr. Y.M. Ramchandra, Mr. V. Krishnan and Mr. G.R. Babu. Subsequently, Mr. B.C. Negi, Dr. Deepak Sawade, Dr. R.K. Prasad, Mr. Tarun Kumar Gaur, Mr. Ajay Singh, Mr. M.V. Nand Kumar, Mr. M.P. Kesari, Mr. Bipin Gedam and Prof. Pallavi Chattopadhyay helped in data collection and assisted in interpretation. The guidance and encouragement from Dr. C.P. Gupta, Dr. V.P. Dimri and Dr. Bhoop Singh were of immense help. Mrs. Ch. Navya Bharathi helped in preparation of figures. Necessary facilities were provided by Director, NGRI. I express my gratitude to them.

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Vijay Shankar Singh

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Chapter 1
Introduction

Water is essential for the survival of living being and their development. A very small part of total water available on the earth is potable. The water resource of India is described. The significance of the potable water resources becomes very significant in case of small coral island with high population density. The potable water on small coral island is found in the form of thin floating groundwater lens. The formation of small coral island is presented.

The small coral islands, particularly, Lakshadweep, are described in detail. The sand bars, reefs and coral lands of Lakshadweep are presented in the form of maps with their locations, shapes and sizes. The population on these small islands is also presented with rate of growth of population. The higher population density on small coral island gives an idea regarding demand for potable water on these islands.

1.1 Fresh Water Resources

Water is essential element for the survival of lives on the earth. It is vital for the continued existence of any form of life on the earth. It is used for consumption and fulfills other needs of human, animals and plants. Also, it is being used for different purposes such as agricultural, industrial, power generations, navigations and recreation, etc. It is one of the most important elements for the prosperous growth of population and its sustainability on earth. In the past, many famous civilizations of world have grown and flourished in the vicinity of rivers with fresh water. The great old civilizations such as Harappan and Vedic, Ancient Egyptian, Shang, and Mesopotamia and Babylonia civilizations have flourished in Indus, Neil, Yellow and Tigris and Euphrates river valley systems. These river valleys have provided easy access to fresh and clean water to the populations. Further, the transportation through water ways was developed. The river valleys have also provided fertile soil for agriculture during floods.

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The water is found to occur in ocean, lakes, rivers, ponds, in the pores of subsurface formations, and in the frozen regions on the earth. A total of 1386 million cubic kilometres (km^3) of water is found on the earth. The details of distribution of water on the earth are described by Shiklomanov (1993). Out of total water on the earth, most of it (97.5%) is saline and major part of it is contained in the ocean. Only 2.5% of water on the earth is in the form of fresh water. Out of total fresh water, about 68.6% of the fresh water is in the form of glaciers and ice caps. Only 30.1% of fresh water is in the form of groundwater, whereas 1.2% is in the form of surface water and other forms of fresh water.

1.2 Water Resources in India

Rainfall is the major source of water that India receives every year. India receives about 4000 km^3 of annual rainfall (Kumar et al. 2005). The rainfall that our country receives is highly variable in space as well as time. It varies from less than 100 mm in Rajasthan to average annual rainfall of 11,777 mm in Cherrapunjee in Meghalaya State. The total surface water availability in different basins is about 1869 km^3 per year (Ministry of Water Resources, Govt. of India). The rain water flows over the land surface and into the rivers. It also percolates to the subsurface strata in the form of groundwater recharge. The annual groundwater replenishment of the country is estimated as 431 billion cubic metre (bcm) (CGWB 2011). The net groundwater availability is estimated as 391 bcm. The net groundwater draft for irrigation, domestic as well as industries is estimated as 243 bcm. Therefore, the stage of overall groundwater development in the country is estimated as 61% as on 2009.

The availability of groundwater is again highly variable from place to place in India. At places, such as tiny coral island, although the annual recharge may be high, most of it goes as subsurface runoff to sea and very little is left in the form of groundwater.

According to an estimate by CGWB (2015) the annual replenishable groundwater resource on Lakshadweep islands is 0.011 bcm. Out of this, 0.007 bcm goes as natural discharge and the net groundwater available is about 0.0035 bcm. The total annual draft on these islands is about 0.0023 bcm indicating the overall stage of development as 67%. However, at some of the islands such as Kavaratti island (Lakshadweep island), the stage of development is reported as 89% (CGWB 2015). Therefore, the assessment of groundwater on tiny islands is vital requirement to be carried out. Further, it is essential to develop sustainable groundwater management scheme on these islands considering the current environmental situations prevailing on these islands.

1.3 Coral Islands

Coral islands are found in tropical and subtropical oceanic regions. It is formed from the organic materials derived from the skeleton of dead coral, other dead animals and plants associated with corals. Coral islands are often small in size. These are in low land with a few metres above sea level. The corals form reef in shallow water.

In the tropical and subtropical areas, coral colonies are grown under favourable oceanic conditions. These are found between 30°N and 30°S latitude. The growth of coral takes place at the shallow sea water (about 50 m) where there is abundant sun light. The ideal sea temperature required for the growth of corals is about 20 °C. There should be adequate supply of oxygen, microscopic sea food and saltwater.

Darwin (1842) postulated the three stages of formation of coral island considering submerging volcanic island. It was considered that the volcanic ocean island gets eroded at the edges due to sea waves and storms. As the island submerges, the coral begins growing at the submersed platform. Due to fall in the sea level, the corals are exposed to the atmosphere. The sea storm, cyclonic storm and winds make the dead corals accumulated and get deposited with sands and other solid materials above each other. These, in course of time, form coral island. There are three stages of development of coral islands. Initially, under suitable environmental conditions coral colonies are developed at the fringe of partly submersed volcanic mountain. These are called fringing island. As the island gets further submersed, the coral colonies are developed away from the shore and all around the island, leaving a pool of lagoon water separating the coral reef and mountain. These are called barrier reef. Many of these are circular, and some of these are linear forming chain of reef structures. Further, submergence of mountain leaves only barrier reef where atolls are formed as shown in Fig. 1.1.

However, the recent studies on reef growth have found that only considering the Darwin's theory of subsidence is not enough to explain the formation and growth of coral reef and their present distribution. Numerical models have been used to explain the morphology of coral island and its evolution. The sea level oscillation over the glacial sea level cycles, geological evidence and paleoclimatic data, has been considered along with subsidence theory to model the growth and distribution of coral reef and atoll (Toomey et al. 2013).

In India, the reefs are formed in the area of the Gulf of Mannar, Palk bay, Gulf of Kutch, Andaman and Nicobar Islands and the Lakshadweep islands (Venkataraman 2011). The reef forms coral island only in the area of Lakshadweep while at other places these are fringing reefs.

The people on the islands of Lakshadweep depend on groundwater for their various needs, apart from small amount of water preserved through rainwater harvesting, desalinization and reverse osmosis plants. With growing population and change in life style, the demand for fresh water is also increasing which in turn increases the abstraction of groundwater. Since the groundwater is in the form of