केंद्रीय भूमि जल बोर्ड

जल संसाधन, नदी विकास और गंगा संरक्षण

विभाग, जल शक्ति मंत्रालय

भारत सरकार

Central Ground Water Board

Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti

Government of India

AQUIFER MAPPING AND MANAGEMENT OF GROUND WATER RESOURCES

CHETLAT ISLAND, U.T.OF LAKHDWEEP

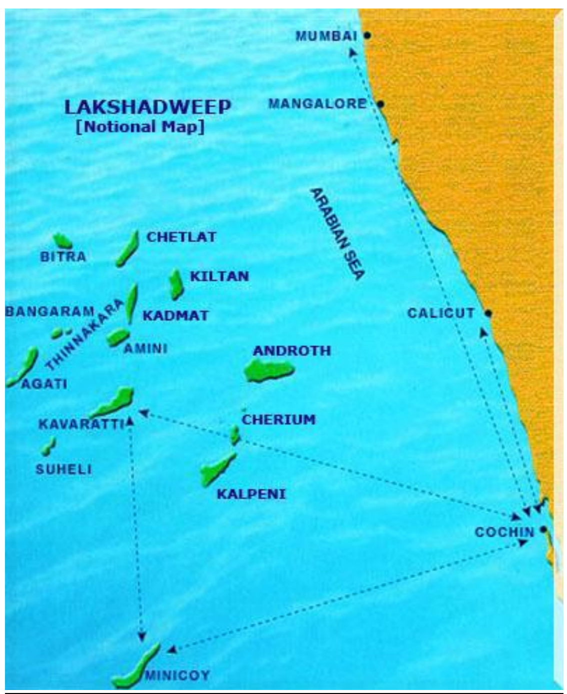
केरल क्षेत्र, तिरुवनंतपुरम

Kerala Region, Thiruvananthapuram

CONSERVE WATER – SAVE LIFE

भारत सरकार
GOVERNMENT OF INDIA
जल शक्ति मंत्रालय
MINISTRY OF JAL SHAKTI
जल संसाधन, नदी विकास और गंगा संरक्षण विभाग
DEPARTMENT OF WATER RESOURCES, RIVER DEVELOPMENT AND GANGA REJUVENATION
केंद्रीय भूजलबोर्ड
CENTRAL GROUND WATER BOARD
केरल क्षेत्र
KERALA REGION
भूजल सूचना पुस्तिका, लक्षद्वीप

AQUIFER MAPPING AND MANAGEMENT PLAN: CHETLAT ISLAND UNION TERRITORY OF LAKSHADWEEP



तिरुवनंतपुरम
Thiruvananthapuram
September 2020

GOVERNMENT OF INDIA

MINISTRY OF JAL SHAKTI

DEPARTMENT OF WATER RESOURCES, RIVER DEVELOPMENT AND

GANGA REJUVENATION

CENTRAL GROUND WATER BOARD

AQUIFER MAPPING AND MANAGEMENT PLAN: CHETLAT ISLAND

UNION TERRITORY OF LAKSHADWEEP

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Chetlat Island at a Glance

#	Item	Statistics
1.	**General Information**	
	Latitudes	$11^0 41^0$N
	Longitudes	72^o 41'
	Total geographical area (sq. km.)	3.00
	Total land area (sq. km.)	1.40
	Total lagoon area (sq. km.)	1.60
	Population (As per 2011Census)	2347
	Normal Annual Rainfall (mm)	1600
2.	**Geomorphology**	
	Major physiographic Units	Coral Islands –Atoll and Reef
	Major Water Body	Lagoons
3.	**Major Soil type**	Coral Sand
4.	**Major Crop**	Coconut
7.	**Main Geological Formations**	Coral Limestone
8.	**Hydrogeology**	
	Major Water bearing formation Depth to water level (m bgl)	Coral sand and Coral Limestone. **1.01-3.98**
9.	**Groundwater Quality**	
	Type of water	Alkaline
10	**Dynamic Groundwater Resources (as in March 2017)**	
	Net annual groundwater availability	**5.4** ha.m
	Annual Ground Water Extraction	**8.7** ha.m
	Stage of Ground Water Extraction, %	**61.6**
	Category	Safe
11.	**Groundwater control and regulation**	
	Number of OE & Critical Blocks.	Nil
	Number of blocks notified	Nil
12.	**Major groundwater problems and issues**	Quality deterioration in summer due to the thinning of the freshwater lens. Anthropological pollution. Saline water up-coning due to pumping.

1.0 Introduction

Oceanic islands have been divided into small and large Islands depending on the size and their hydrological setup. Large islands have surface drainage systems and their hydrogeology and other features are similar to that of the mainland, whereas the hydrogeological environment of small islands is quite different. It is very difficult to draw a clear line differentiating the small islands from the larger ones by any discrete parameter or size factor. The absence of surface drainage makes the small islands quite distinct from other oceanic islands. These oceanic islands are very small in areal extent and groundwater is the only perennial source of freshwater. The Indian peninsula is girdled by about 2500 islands, of which about 1300, including 200 inhabited islands, belong to the neighbouring Maldives. Indian Territory includes more than 600 oceanic islands falling in two major groups viz. the Andaman and Nicobar Islands in the Bay of Bengal and the Lakshadweep group of islands in the Arabian Sea. The sea between the Indian coast and Lakshadweep islands is known as the Lakshadweep Sea after these islands.

1.1 Location and extent

The Union Territory of Lakshadweep islands is scattered in the Arabian Sea between north latitude $8^0$00’ and $12^0$13’N and east longitude $71^0$00’ and $74^0$00’E. The Inhabited islands, Chetlat, Kiltan, and Kadmat are closely spaced and are on the northern part of the archipelago, whereas Kalpeni is on the east-central part of the group, and the Minicoy Island located in the southernmost part of the group and far away from the other islands. The islands Agatti, Kavaratti, Minicoy, and Androth are bigger compared to others. The Bitra island is the smallest one and the residence of tourist staff. The location of inhabited islands of Lakshadweep including Chetlat is depicted (Fig.1.1).

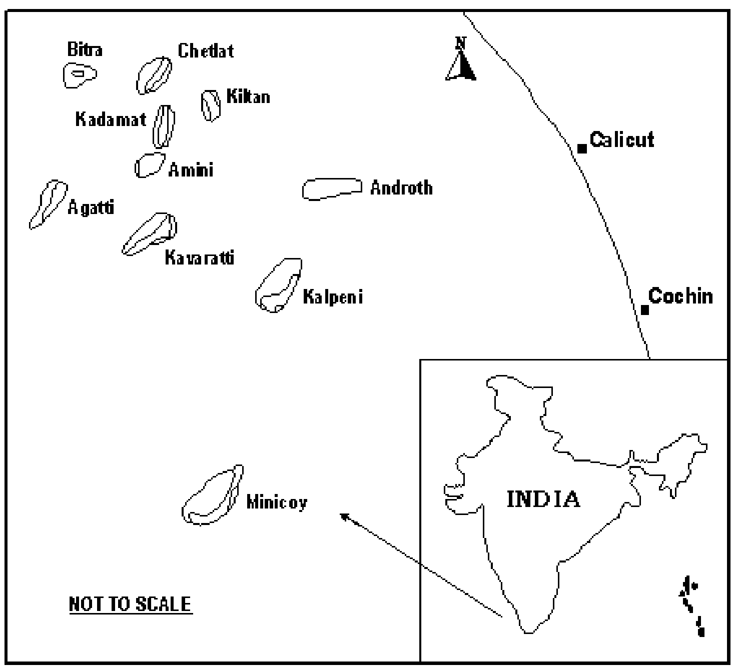

Fig. 1.1: Location of inhabited islands of Lakshadweep including Chetlat

The Lakshadweep group consists of a string of 36 tiny islands of which only ten islands are inhabited. These islands are very tiny, each having an area varying from 0.1 to 4.8 sq. km. The rest comprise seventeen uninhabited islands, four newly formed islets, and five submerged reefs. The total area of these islands is 32 sq.km. Apart from the ten inhabited islands, Bangaram, the only island open to international tourists, is seasonally inhabited. Though the land area is limited, Lakshadweep is one of the country’s largest territories considering its lagoon area of about 4200 sq.km, territorial waters of 20000 sq km. and an 'Exclusive Economic Zone' of about 400,000 sq.km (UNI, 2002). The details of the areal extent of Chetlat is compiled (Tables 1.1).

Table 1.1: Area and location aspects of Chetlat Island, UT of LD Islands

#	Area, km^2		Total area, km^2	Location	
	Island	Lagoon		Latitude	Longitude
1	1.40	1.60	3.00	11°41'	72°41'

The entire Lakshadweep group of islands lies on the northern edge of the 2500 km long North-South aligned submarine Lakshadweep-Chagos ridge. The Lakshadweep Sea separates this ridge from the west coast of India. The ridge rises from a depth of 2000-2700 m along the eastern side and 400 m along the western side. The eastern flanks of this ridge appear to be steeper compared to the western portion. It has several gaps, the prominent being the nine-degree channel. Generally in the islands, the atolls are widest on the southwestern side. The growth of the reef might have been facilitated by the continuous supply of nutrients. Echo-sounding on the reefs of these atolls show that the first break in the profile of the reefs occurs at a depth of about 4-8 m, which extends to about 12 m on the southwest windward reef representing a wave-cut platform of recent origin.

1.2 Administrative set up

The Lakshadweep Islands constitute a uni-district territory with 4 Tehsils (Amini, Andrott, Kavaratti & Minicoy) and 9 Sub-divisions (Agatti, Amini, Andrott, Chetlat (Bitra), Kadmat, Kalpeni, Kavaratti, Kiltan & Minicoy). There are 5 Community Development Blocks namely Amini - (Amini & Kadmat), Andrott - (Andrott & Kalpeni), Kavaratti - (Agatti & Kavaratti), Chetlat - (Bitra, Chetlat & Kiltan) & Minicoy. The Island Councils and Pradesh Councils were originally set up under the Lakshadweep Island Councils Regulation, 1988, and the Lakshadweep (Administration) Regulation, 1988. These have been repealed under Section 88 of Lakshadweep Panchayat Regulation,1994, promulgated by the President of India on 23rd April 1994 consequent on the Constitution (73rd Amendment) Act, 1992. The Island Councils came to an end after the expiry of its terms on 5.4.1995. According to the new Panchayat Regulation, there will be a two-tier system of Panchayats in Lakshadweep, consisting of Dweep Panchayats and District Panchayat and no intermediary panchayat in this territory. Each of the ten inhabited Islands will have a Dweep Panchayat. The District Panchayat has its headquarters at Kavaratti.

1.3 Population

According to the Survey of India, the geographical area of Lakshadweep is 32 sq. km, whereas as per revenue records the area is only 28.5 sq km., which represents only the land use area. As per the 2011 census, the total population of LD Islands is 64473, with 33123 males and 31350 females. The density of population is high and stands at 2015 per sq km. The population of the Chetlat as per the 2011 census is 2347, with 1172 males and 1175 females. The Chetlat island is having a density of population of 2257 per sq km.

1.4 Climate

As the Chetlat lying well within the tropics and extending to the equatorial belt, the island has a tropical humid, warm, and generally pleasant climate. The climate is equable and no distinct and well-marked seasons are experienced. The southwest monsoon period is the chief rainy season which lasts from late May to early October. The mean daily temperatures range between 22 to 33º C. while the humidity ranges between 72 to 85%.

1.4.1Rainfall

Rainfall distribution, including its quantity and its spatial and temporal variation and evapotranspiration, are the major components controlling the availability of freshwater resources. The temporal variation is usually high in the small island whereas the spatial variation is a function of the island's physiography. The inter-annual variability of rainfall is often high in Chetlat. The island is receiving an annual average rainfall of 1600 mm.

1.4.2 Humidity

The Humidity is high throughout the year and is generally higher in the morning hours compared to the evening hours. It is lower during the period from January to April when it is between 70 and 76% in the morning hours and 66 to 69% in the evening hours. It is higher from June to August when it ranges from 85 to 87% in the morning hours and 83 to 86% in the evening hours.

1.4.3 Temperature

April and May are the hottest with the mean minimum and minimum temperatures of 25 ^{O}C. and 35 ^{O}C respectively. December and January are the coldest months with the mean minimum and maximum temperatures of 24 ^{O}C and 31.1^{O}C respectively.

1.4.4 Evapotranspiration (ET)

The ET has a vital role in the hydrological cycle of tropical small islands. This is very high and most of the months except in high rainfall season it exceed the rainfall making the water surplus on the negative side.

1.4.5 Special weather phenomena

A few cyclonic depressions and storms, which form in the south Arabian Sea during April and May, affect the weather over the Island. During the post-monsoon months of October to December also, a few of such systems originating in the Bay of Bengal and travelling westwards emerge into the south Arabian sea, and occasionally affect the island of Chetlat. In association with these, strong winds and heavy rains are common. The cyclonic storms are believed to be responsible for the deposition of coral debris around the islands forming coral beach and the lagoons.

1.5 Soils

Chetlat has a soil layer overlying coral limestone. The soils are mainly derived from coral limestone and include coral sands, lagoonal sands, and mud. The rate of infiltration, the thickness, and the moisture contents at both field capacity and wilting point affect the groundwater resources of the island.

1.6 Vegetation

The vegetation in the Lakshadweep Islands can be classified as either shallow-rooted or deep-rooted. The shallow-rooted vegetation which includes grasses, crops, and shrubs obtain their moisture requirements from the soil moisture zone. The deep-rooted vegetation consists of those trees whose roots can, where conditions are favourable, penetrate below the soil moisture zone and through the unsaturated zone to the water table. Coconut trees are a typical example of deep-rooted vegetation in the islands of Lakshadweep. In relatively shallow areas, coconut trees typically have some roots within the soil moisture zone and some which penetrate to the water table and are referred to as phreatophytes and are common on coral atolls where the depth to the water table is typically 2 to 3 m. bgl.

1.7 Previous studies

Various island hydrogeological studies have been carried out by CGWB and are summarised below.

- Hydrogeological studies by CGWB in Lakshadweep Islands dates back to 1978 when a reconnaissance investigation on the groundwater resources of the LD Islands was carried out.
- In 1987, scientific investigations were taken up by CGWB in Kavaratti Island to study the feasibility of water supply schemes as per directions of the Hon'ble High Court of Kerala. Based on detailed studies, it

was suggested that the extraction of large quantities of groundwater from point sources was not feasible because of the risk of up coning of saline water.

- All the inhabited islands except Bitra (0.1 sq.km) have been studied by CGWB through systematic hydrogeological surveys and subsequently by micro-level studies.
- Groundwater exploration was carried out at five locations in Kavaratti Island down to the depth of 30 m below ground level through the construction of zone wells tapping different aquifer zones at each site.
- CGWB has taken up the implementation of three demonstrative rainwater harvesting schemes in Kavaratti Island through the LPWD under the Central Sector Scheme to popularize cost-effective techniques for water harvesting suitable for island conditions.
- As part of the IEC activities of the Ministry of Water Resources, River Development & Ganga Rejuvenation, Government of India, U.T Level Painting Competitions on Water Conservation for school students are being organized in U.T of Lakshadweep since 2012.
- Detailed mapping of aquifers of nine islands of the U.T of Lakshadweep is being taken up as part of the National Aquifer Mapping Programme of the Board during the XII Plan. This activity envisages the delineation and characterization of aquifer zones and the formulation of strategies for sustainable development of groundwater for the islands.
- A U.T level workshop on Water Management for Sustainable Development was held at Kavaratti under the 'Hamara Jal, Hamara Jeevan' campaign of Government of India during January 2015.
- Several reports have been published on various aspects of groundwater resources in the Lakshadweep Islands based on the studies, as listed below:
- Anon (1978): A preliminary note on the groundwater resources of Union Territory of Lakshadweep Islands - Minicoy and Amini divi. CGWB, KR, Thiruvananthapuram.
- Anon (1994): Hydrogeological and Hydrochemical studies in Kavaratti Island, UT of LD Islands. CGWB, KR, Thiruvananthapuram.
- Anon (1994): Groundwater Resources and Management in the Union Territory of Lakshadweep (Kavaratti, Agatti, and Amini Islands. CGWB, KR, Thiruvananthapuram.
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- Anon (2001): Basic data report of exploratory wells drilled in Kavaratti Island of Lakshadweep. CGWB, KR, Thiruvananthapuram
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- Balakrishnan, K (2018): Ground Water Information Booklet Lakshadweep Islands Union Territory of Lakshadweep, 2019. CGWB, KR, Thiruvananthapuram.
- Balakrishnan, K (2019): Ground Water Information Booklet Lakshadweep Islands Union Territory of Lakshadweep, 2019. CGWB, KR, Thiruvananthapuram.
- Balakrishnan, K, Sreenath, G, Anil Chand, A D (2019): Aquifer Mapping and Management Plan: Union Territory of Lakshadweep. CGWB, KR, Thiruvananthapuram.

2.0 Geomorphology

The Lakshadweep Ridge, approximately 800 km long and 170 km wide, is a fascinating and conspicuous feature of the Arabian Sea. It is inclined southerly (1/715-gradient) with a narrow strip (10 km) near Goa and widens to 170 km west of Cape Comorin, This domain is distinct with scores of islands, banks, and shoals, topographic rises, and mounts, inter mount valleys and sea knolls. A notable feature of the individual island of the ridge is that the relief of all the islands above MSL is uniformly low (4-5 m). However, the height of the submerged banks and shoals varies considerably. Based on the structural features, trends of the individual islands, geophysical anomalies, and related faults/ dislocations, the Lakshadweep islands are classified into northern, central, and southern blocks. All the important islands fall in the central block separated by the Bassas de Pedro fracture in the north and a NNE- SSW trending valley in the south. The northern block is dominated by coral banks and the southern by few islands and small banks.

The Chetlat Island is flat, rarely rising more than two meters, and consists of fine coral sand and boulders compacted into sandstone. Most atolls have a northeast-southwest orientation with an island on the east, a broad well-developed reef on the west, and a lagoon in between. The island is of coral origin and Chetlat is a typical atoll and is in an advanced or mature stage of development. The development and growth of the islands on the eastern reef margin have been controlled by a number of factors. The cyclones from the east have piled up coral debris on the eastern reef while the very high waves generated annually during the southwest monsoon have pounded the reef and broken this into coarse and subsequently to fine sediments which were then transported and deposited on the eastern side behind the coral boulders and pebbles on the eastern reef. The Chetlat island is of coral origin which developed around volcanic peaks. It seems that they first rose to the surface in the form of shallow oval basins and under the protection of the reef, the eastern rim gradually developing towards the center, forming the island. The elongated reefs of this organic limestone that are partly, intermittently, or completely covered by water. Geomorphologically, the island has lagoonal beaches, storm beaches, beach ridges, sand dunes, and hinterlands. The islands are generally flat with localized depressions and sand mounds, which are largely man-made.

3.0 Geological setting

There is no conclusive theory on the formation of the coral atoll of Chetlat. The most accepted theory is the Subsidence Theory of the origin of coral islands proposed by Sir Charles Darwin. He concluded in 1842 that the subsidence of a volcanic island resulted in the formation of a fringing reef and the continual subsidence allowed this to grow upwards. The conditions which favoured the growth of the coral island of Chetlat include

- Area situated between 30º North and South of Equator,
- Water is clear and salty,
- Tropical conditions of the area,
- Favourable temperature of more than 23 to 25ºC.

The island is composed mainly of coral reefs and material derived from them. The litho-units identified include calcareous sand of the beach facies, strandline facies, dune facies, and anthropogenically modified varieties identified on the basis of base morphometric units, grain size, and other physical characteristics. Coralline grit and gritty conglomerates, coralline limestones, and shingles are of submerged reef facies. While the lagoonal beach is made up of fine to medium grade calcareous sand, the berm portions consist of slightly coarser sand and the dune portion, coarse, unsorted sand. The interior parts of the island have anthropogenically reworked calcareous sand. The sand ridge portions consist of assorted sand, which is somewhat compact. The coral limestone, gritty limestone, and gritty conglomerates are exposed on the beaches in the form of wave-cut terraces. The sediments of the lagoon consist chiefly of gravel and sand-sized material, composed mainly of various types of dead corals produced by the breaking up of reefs by the waves.

4.0 Spatial pattern of the groundwater table

Groundwater levels were measured in the open dug wells. The measurements taken during February 2017 were used for the spatial interpolation studies by contouring the water level at 2 m intervals.

4.1 Spatial pattern of groundwater salinity

The groundwater on the island is generally alkaline with a few exceptions. The Electrical Conductivity (EC) ranges from **728 to 5000 µS/cm at 25° C**. Higher concentrations of dissolved solids are generally seen along the periphery of the island and also close to pumping centers. The quality variation is vertical, temporal, and also lateral. The quality is highly variable and reversible. It is also observed that the quality improves with rainfall. Other factors affecting the quality are tides, groundwater recharge, and draft. There is a vertical variation of quality due to the zone of interface and underlying seawater. Perforation created due to drilling or otherwise also affects the quality as it acts as a conduit for the flow of seawater.

Wells manually operated retain more or less the same quality of groundwater over longer time periods as compared to mechanized wells where quality deterioration is observed in the form of increasing EC. Brackish water is present in topographic lows and places where coarse pebbles and corals are present.

Another major threat to groundwater in the islands is pollution. The human and livestock wastes, oil spills are the main polluting agents with sewerage and other biological wastes contributing most. The electric conductivity of groundwater samples was indicative of the presence of brackish water throughout the island, with values higher than standards for safe drinking water. The iso-conductivity contours clearly pointed to a decrease in salinity towards the center of the island. However, this map manifested a major difference from what would be expected in a Ghyben-Herzberg model. For example, the northeast area showed a large inward saltwater intrusion and in the southern part, there was a marked anomaly relative to depth to water level. In these sectors, no correlation was evident between depth to water level and salinity of the water**.**

5.0 Hydrogeological framework

The Chetlat island is made up of coral reefs and materials derived from them, generally enclosing a lagoon. Hard coral limestone is exposed along the beaches of the island during low tides and also in well sections. Hard pebbles of coral limestone along with coral sand are generally seen. Beneath a thin layer of vegetal humus, there is fine coral sand extending over the surface of all the islands. Below this is a compact crust of fine conglomerate looking like coarse oolitic limestone with embedded bits and shell, and beneath this crust, there is another layer of sand.

The coral sands and the coral limestone form the principal aquifer in Chetlat. Groundwater, existing under phreatic conditions at a depth of **1.01-3.98** m.bgl, is seen as a thin lens floating over and in hydraulic continuity with the seawater. Large diameter wells are the most common and traditional groundwater abstraction structures. In almost all the wells, hard coral limestone is exposed near the bottom. The sand below this hard layer has caved in most of the wells.

5.1 Freshwater lens

The freshwater lens in the island is formed due to the radial movement of the freshwater towards the coast, in a dynamic system in hydraulic continuity with seawater. There is a transition zone through which the salinity increases with depth as suggested by the line XY in Fig. 5.1 (Barker, 1984). The dispersion as well as the fluctuation causes continuous mixing of water of different salinities, creating the transition zone. The width of the transition zone depends on the geology, which controls the branching nature of the flow paths, resulting in dispersion and the fluctuation in water levels due to tides and in response to recharge and discharge. The higher the fluctuation, the thicker is the transition zone.

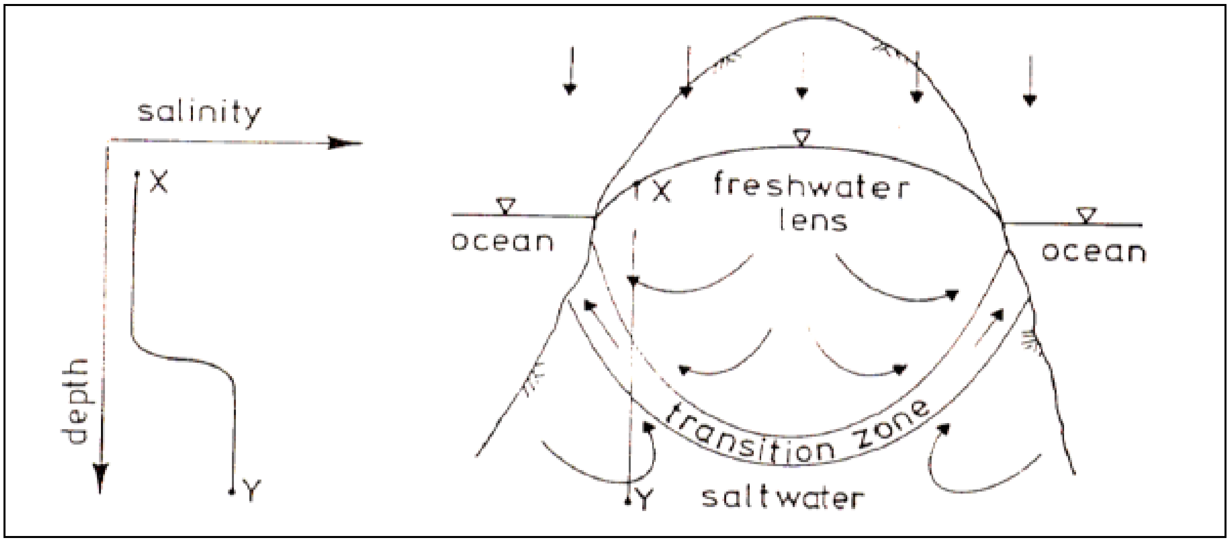

Fig. 5.1: Freshwater lens in Oceanic Islands- Schematic Diagram (Barker, 1984)

The occurrence of the freshwater lens over saline water in island conditions was studied by Badon W Ghyben, 1888 in Netherlands, and by Mike Herzberg, 1901, in the islands of the North Sea off the German coast (Ghassemi. et al. 1990). Both these workers established the relation between the freshwater head above mean sea level (hf) and the depth to freshwater - saltwater interface (hs) to form a freshwater lens floating over saline water as shown in Fig. 5.2 (Ghyben-Herzberg (GH) Rule). In the simplified form of the GH approximation, the ratio of the thickness of freshwater lens below and above mean sea level can be presented as

$$h = \frac{\sigma f}{\sigma s - \sigma f}$$

where, h = thickness of the freshwater lens below msl to that above msl, ϱs = density of seawater (normally 1.025) and ϱf = density of freshwater (normally 1.000) and is simplified as h = 40, which means that each meter thickness of freshwater lens above mean sea level is supported by a 40 m thick lens below mean sea level. However, studies in small islands indicate that the ratio of the thickness of freshwater above and below msl is highly variable. In the Cayman Islands, it is 1: 20 while it is 1: 30 in Tarawa and 1: 20 in Christmas Island (Falkland, 1984).

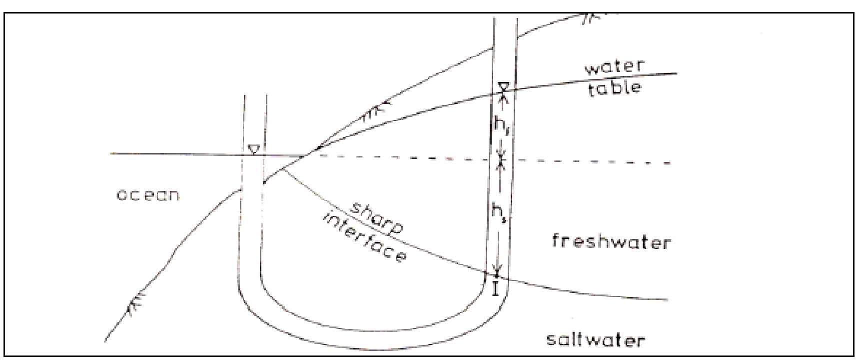

Fig 5.2: Ghyben-Herzberg approximation for oceanic islands

The basic assumptions for the applicability of Ghyben-Herzberg relation are water table lies above msl and the water table slope downward towards the ocean. In order to identify the role of the shape of the island in deciding the freshwater lens, the aspect ratio of the islands is made use of. Since the shape of the islands does not conform to any geometric form, the aspect ratio is computed taking into consideration the length, breadth, and area of the island (Najeeb, 2003). The island area is divided by the ratio of its length to breadth to get the aspect ratio. This ratio has been used to study the stability of the freshwater lens in these islands and the salient features are given in Table 5.1. An island with an aspect ratio greater than 0.5 is found to have a stable freshwater lens, under identical geomorphological settings. As the aspect ratio is well below 0.50, the freshwater lens is found to be stable in Chetlat.

Table 5.1: Salient Features of Chetlat Island

#	Item	Detail
1	Area	1.04
2	Maximum length, km	2.5
3	Maximum width, km	0.65
4	Aspect ratio, A/(L/B)	0.30
5	Shape	Sole
6	Trend of the longer axis	NNE-SSW

5.2 Tidal influence

As the groundwater is in hydraulic continuity with seawater, it is highly influenced by the diurnal tidal fluctuations of the sea. The magnitude of the tidal fluctuation is dependent on several factors amongst which the permeability of the aquifer material, the proximity of the site to the sea, and the magnitude of tidal variation in the sea play significant roles. There is a time lag between tidal fluctuation in the sea and in the groundwater levels, which is also dependent on the above factors.

5.3 Groundwater scenario

In Chetlat island, freshwater floats over marine water in hydraulic continuity with it (Fig. 5.3).

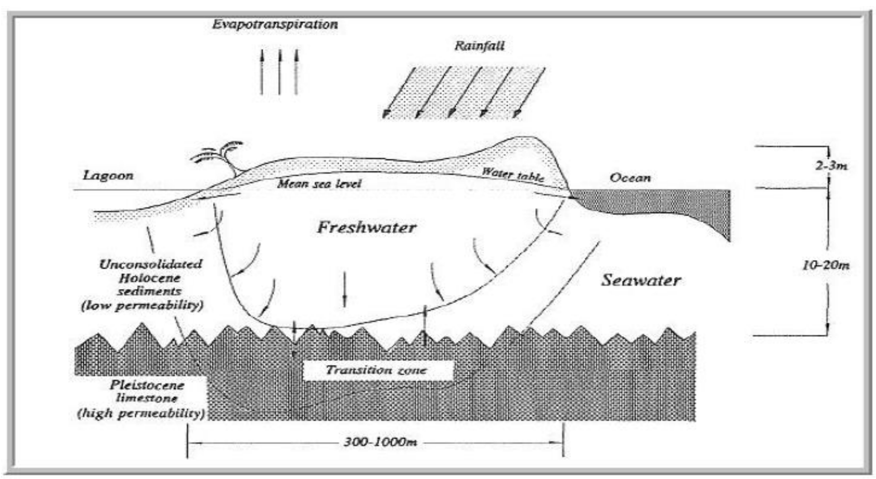

Fig.5.3: Freshwater lens in small Islands (Exaggerated vertical scale)
(Falklands, 1993)

The calcareous sands overlying these islands are highly porous and infiltrate the bulk of the rainfall received. The infiltrating rainfall displaces the saline water to a freshwater lens due to density difference and the hydraulic continuity of groundwater with seawater. There is no rejected recharge of groundwater even during heavy rainfall. About 18 to 51 percent of the annual rainfall gets recharged into the groundwater depending on the intensity, frequency, and distribution of rainfall. However, the rise in water level due to recharge gets adjusted within the lens as per the Ghyben-Herzberg approximation and hence appreciable increment in the water level is not observed. Rainfall received in the Chetlat is fully recharged and adjusted in the freshwater lens, as a result of which significant rise in water levels are not discernible in the wells even after the monsoon rains.

The organic tiny carbonate coral atoll of Chetlat consists of a layer of Recent (Holocene/Anthropocene) sediments, comprising mainly coral sands and fragments or coral, on top of older limestone. An unconformity separates these two layers at typical depths of 10m to 20 m below mean sea level. Several deeper unconformities may exist due to fluctuations in sea level which results in alternate periods of emergence and submergence of the atoll. During periods of emergence, solution and erosion of the reef platform can occur, while further deposition of coral limestone can occur during periods of submergence. The upper sediments are of primary importance from a hydrogeological viewpoint as freshwater lenses occur solely or mainly within this layer. The occurrence of such lenses within this layer is due to its moderate permeability (Typically 5 to 10 m/day) compared with the higher permeability of the older limestone (typically 50 to 100 m/day). Permeability greater than 1000 m/day occurs in solution cavities within the limestone. This extremely high permeability allows almost unrestricted mixing of freshwater and seawater which is less likely to occur in the upper sediments. The upper unconformity, therefore, is one of the main controlling features of the depth of the freshwater lens.
Chetlat has a freshwater lens which is saline to brackish. There exists a high magnitude of temporal and spatial variations in thickness, shape as well as the groundwater quality of these lenses. The exact geometry of these lenses, chemical quality, behaviour under various stresses, and their potential are of great significance for planning and effective management of the freshwater resources in the island. Groundwater is developed by dug/open wells, shallow filter point wells, and step wells. The depth to the water level in the islands varies from few centimeters to about 5 m. bgl and the depth of the wells varies from less than a meter to about 6 m. The water levels on the entire island are highly influenced by tides.

The Lakshadweep Public Works department had established Observation Wells in all the Island for periodic quality monitoring and for the weekly monitoring of water levels of the dug wells. For the hydrogeological studies, select wells from LPWD observation wells and other dug wells and filter point wells were studied. The well inventory details are compiled (Appendix-I), well location details, and Depth to the water level map, hydrogeology as in Fig.5.4, 5.5 & 5.6.

Chetlat is the northernmost island of the Lakshadweep archipelago and has an area of 1.40 sq. km. The island is roughly sole-shaped, oriented in NNE-SSW direction with a small lagoon in the west. Freshwater occurs in about 90 percent of the total area except along the southern and northern tips. This is being tapped through about 480 domestic wells resulting in a well density of 461 wells / sq. km. The depth to water level varies from 1.01 to 3.98 m and the depths of the wells range from1.58 to 4.80 mbgl. Long-term comparison of water levels in select wells does not show any significant change in water levels. Groundwater fluctuation on the island is in the range of 6 to 29 cm. The maps showing locations of the key wells, depth to water table (pre-monsoon 2016), and hydrogeology of the island are given in figures 5.12, 5.16, and 5. 28 respectively.

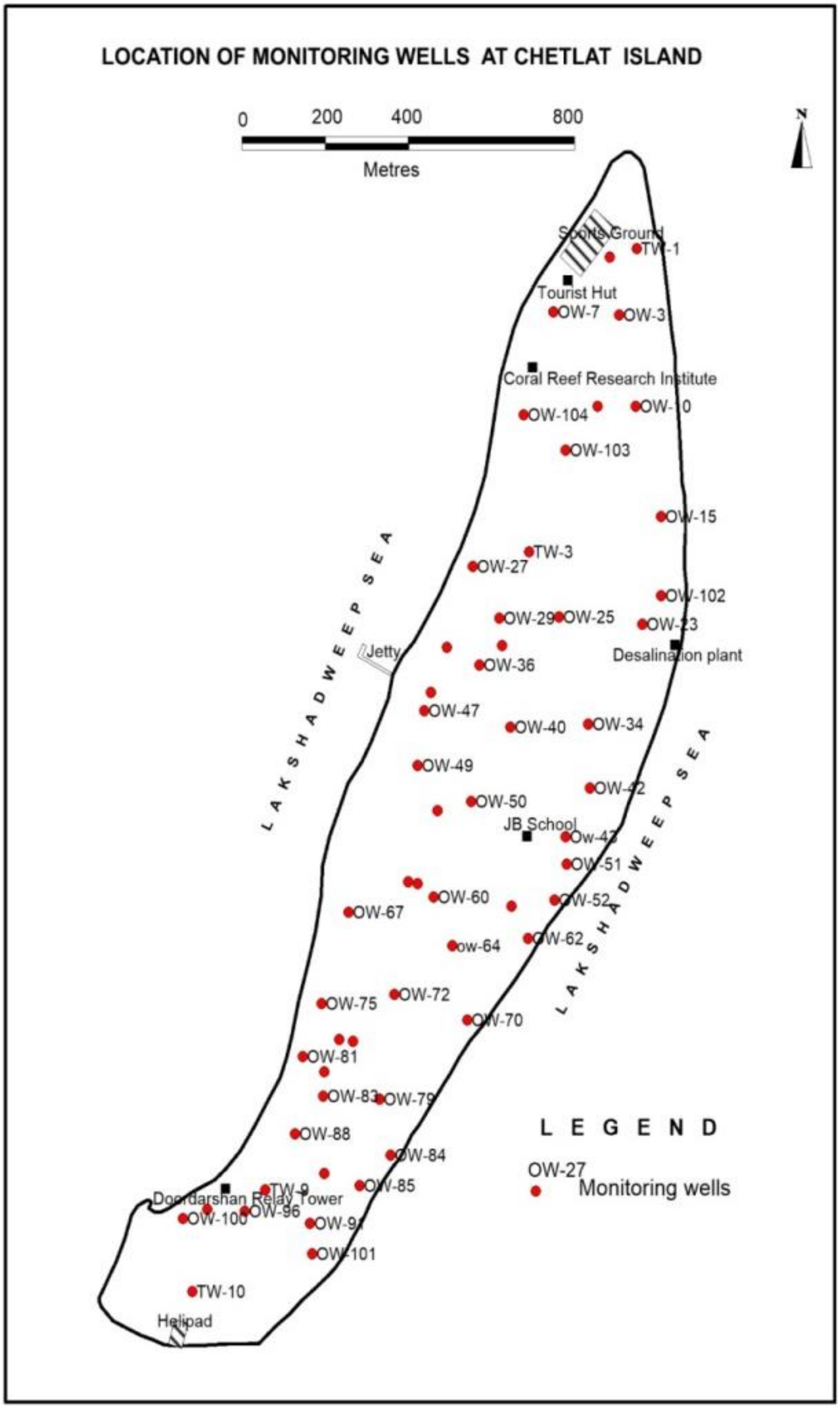

Fig. 5.4: Key well locations in Chetlat Island

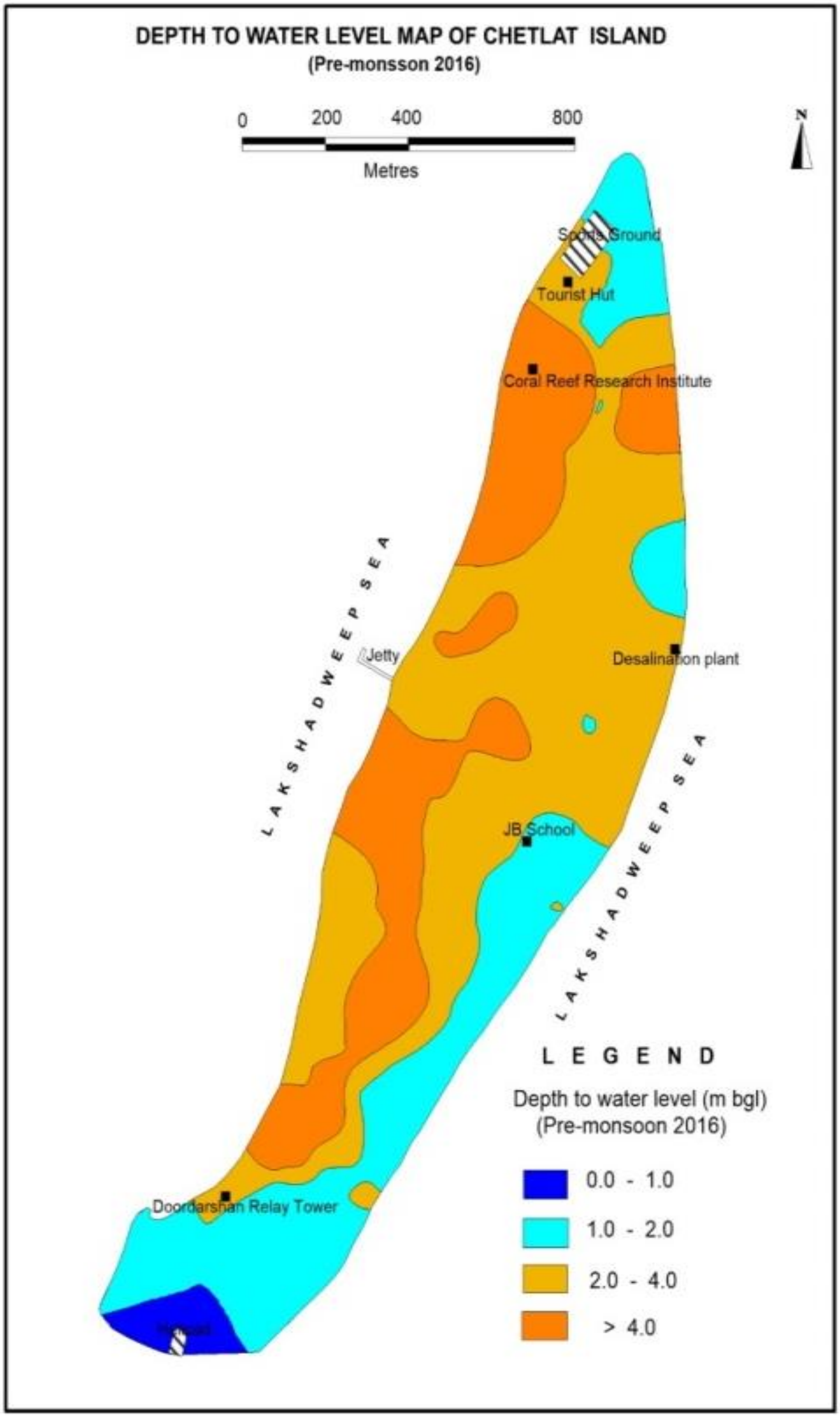

Fig. 5.5: Depth to the water level map, Chetlat Island

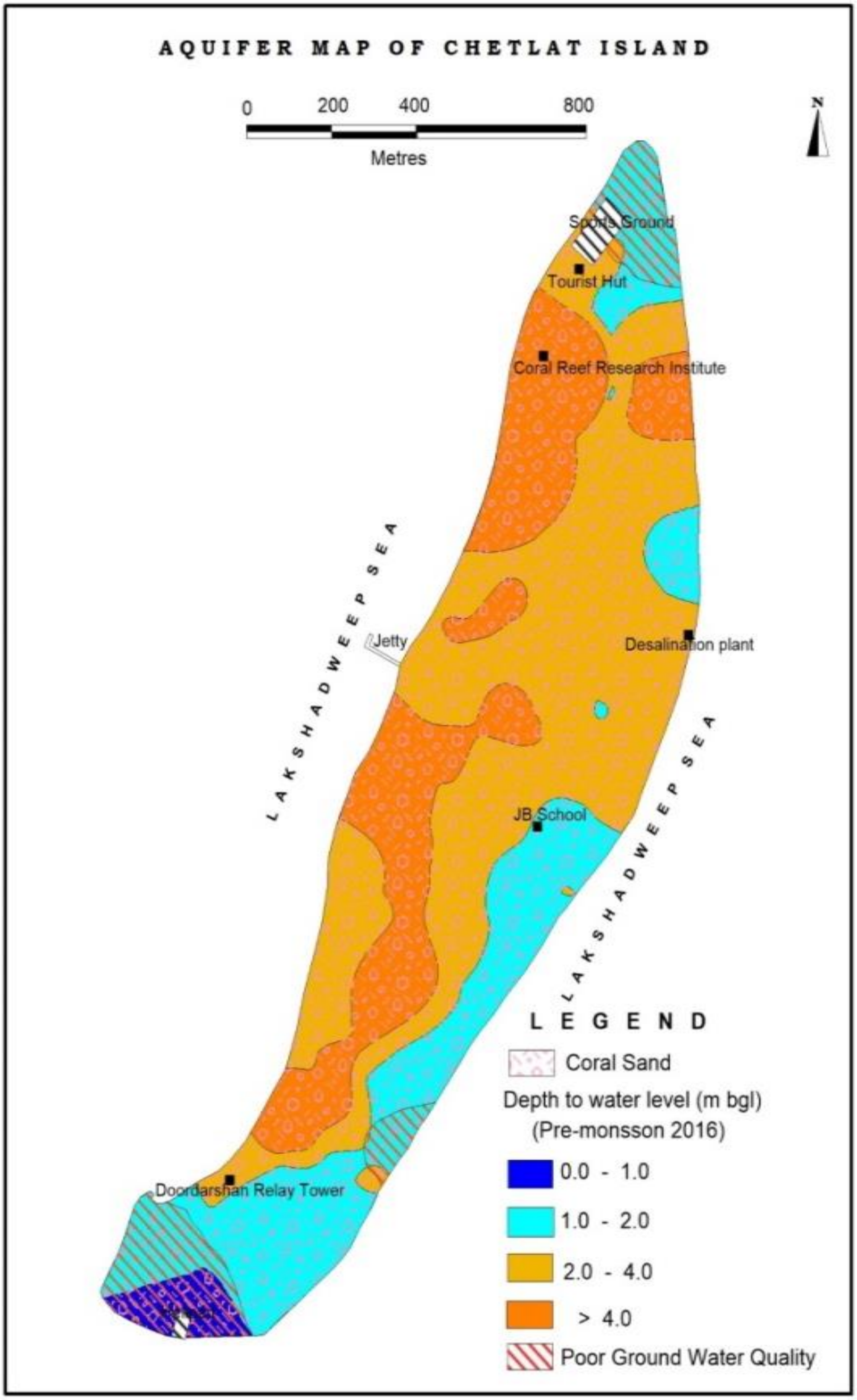

Fig. 5.6: Aquifer map of Chetlat Islands

6.0 Quality of Ground Water

Groundwater in the Lakshadweep Islands is generally alkaline with few exceptions. The electrical conductivity ranges from 500 to 15,000 µS/cm at 25° C. Ranges of pH, EC, and concentrations of important chemical constituents in groundwater in the islands, based on the analytical results of samples collected from select open wells tapping the freshwater lens are shown in Table. 6.1. The LPWD is maintaining chemical lab in all the islands and is monitoring the periodic chemical quality of the Observation Wells. The chemical data from this lab are utilized for the study.

Table 6.1: Hydrochemistry of select groundwater samples collected from open wells in Chetlat in 2010

#	No of Samples	pH	EC (µS/cm)	TDS (mg/l)	Total Hardness(mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)
2010 PRM								
1	4	7.90-8.45	535-819	-	165-290	22-44	27-54	32-71
2010 PSM								
1	4	7.84-8.01	437-817	-	195-300	50-82	12-34	25-75

The major ions in the freshwater lens are within the permissible limits and fluoride varies from 0.93 to 1.29 mg/l during Premonsoon and that post-monsoon 0.52 to 1.40. Lateral, vertical, and temporal changes in the quality of groundwater are observed. The freshwater lens is generally alkaline with pH ranging from 7.90-8.45 and 7.84-8.01 in PRM and PSM respectively. The dissolution of CaCO3 during rainwater infiltration leads to high pH of groundwater. However, samples from the pumping wells immediately after pumping are found to be slightly acidic. This is because of the precipitation of $CaCO_3$ from water due to the instability of equilibrium between Calcium and bicarbonate ions. $CaCO_3$ precipitate is quite often seen at the bottom of such pumping wells. The decrease of pressure that accompanies pumping from a certain depth below water level is likely to cause a decrease of dissolved CO_2 and to render the water more saturated with calcite than it originally was (Mandal, S, and Shiftan, Z.L, 1981). The overall reaction describing $CaCO_3$ dissolution and precipitation is given below:

$CaCO_3 + H_2O + CO_2 = Ca^{++} + 2HCO_3^-$. Higher concentrations of the dissolved solids are generally seen along the periphery of the island and also close to pumping centers.

6.1 Variations in groundwater quality

The groundwater quality variations in the Islands could be lateral, vertical, and temporal. The quality is also highly variable and reversible. It is observed that water quality improves with rainfall. Other factors affecting the quality are tides, groundwater recharge, and draft. There is a vertical variation in the quality due to the zone of the interface and underlying seawater. It is also seen that any perforation like drilling affects the quality. This acts as a conduit for the up-coning of seawater.

The quality of groundwater on the island varies with time too. Wells from which water is drawn by hand retain more or less the same quality over a long period, whereas quality deterioration is observed around pumping centers. A trend towards seawater composition is observed with increasing EC in and around pumping centers. Similarly, brackish water is seen along topographic lows and in areas where coarse pebbles and corals are seen.

6.2 Groundwater quality characteristics in Chetlat

In general, the groundwater on the island is fresh, with all parameters within permissible limits for drinking purposes as per BIS in about 90 % of dug wells in the area. The water is almost neutral to slightly alkaline with the pH in the range of 7.90-8.45. The EC ranges from 437-819 µS/cm at 25° C. The chloride is in the range of 25 to 75 mg/l. Fluoride varies from 0.52 to 1.40 mg/l. The spatial variations in EC are depicted in Fig. 6.8.

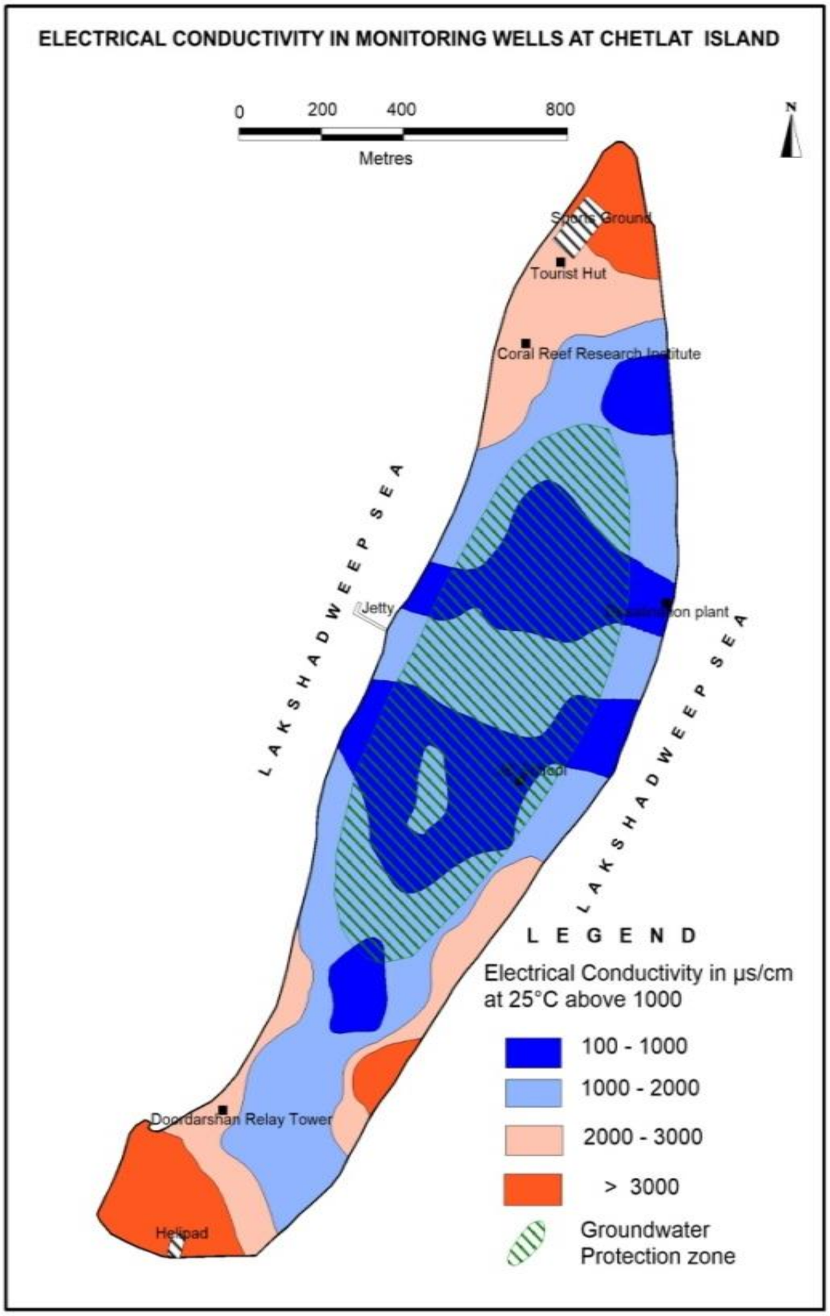

Fig. 6.8: Spatial variation of EC in Chetlat island

6.3 Factors affecting groundwater quality

In Chetlat island, groundwater flow is mostly vertical with fluctuations due to diurnal tidal effects, recharge, and draft. The horizontal flow of groundwater is relatively insignificant as the freshwater lens contracts and expands in response to draft and recharge. The tidal effect on the freshwater lens, shallow groundwater conditions, pollution from unscientific sewerage disposal, use of detergents for washing, presence of soak pits/ septic tanks, and other kinds of human interference with the eco-system are causes of concern as far as the quality of groundwater in the island is concerned. Various factors affecting the quality of water in the tiny coral aquifer system in Chetlat are discussed.

6.3.1 Tidal influence

As the groundwater is in hydraulic continuity with seawater, its quality is influenced by the diurnal tidal fluctuations of the sea. There is a marked variation in water quality with time in Chetlat. Quality variation is observed with tidal fluctuation and some of the wells located in areas where the freshwater lens is very thin and are brackish during low tides yield freshwater during high tides. It is established that the quality variation due to tides is not very significant. However, it is seen that the best quality of water available is during high tide and more specifically, during the rising limb of high tide.

6.3.2 Effect of groundwater overdraft

The freshwater-salt water interface in Chetlat is in a delicate equilibrium and any undue stress on this equilibrium by overdraft results in the up-coning of the saline water from beneath. Thus the movement of the saline front is not horizontal as in the case of inland aquifers. Heavy withdrawal of groundwater from a point source induces the up-coning of saline water and the quality deterioration due to pumping is evident even on limited pumping.

6.3.3 Effect of groundwater recharge

Studies in Lakshadweep Islands revealed that there is no rejected recharge of groundwater even during heavy rainfall. About 18 to 51 percent of the annual rainfall gets recharged into the groundwater depending on the intensity, frequency, and distribution of rainfall. The Ghyben-Herzberg (GH) equation (Todd 1959) indicate that the depth to interface between fresh and saltwater is about forty times the thickness of freshwater above mean sea level in small islands in ideal situations. This indicates that only a fraction of the freshwater lens is available above mean sea level and the rest is below. Consequently, whenever there is a recharge into the groundwater in Chetlat, a major part of the recharged water gets readjusted below mean sea level by the expansion of the lens. Hence, there will not be any significant rise in water level, and only a small fraction of the recharge will be above the mean sea level. Many times this fractional increment will be less than the negative influence created by the tides, which is difficult to decipher by regular hydrograph analysis. The effect of rainfall is evident in improvement in the quality of the freshwater lens, which is very well elucidated from various studies.

6.3.4 Aspect ratio of Islands

The shape and size of the islands have a role in the water quality as well as the stability of the freshwater lens. Hence, the aspect ratio of the island was worked out to study the behaviour and stability of the freshwater lens, as mentioned in one of the previous sections. The aspect ratios of the islands were studied with reference to the stability of the freshwater lens. It is postulated based on the studies that in islands where the aspect ratio is more than one, the fresh lens is stable and the changes in quality due to draft and recharge are not remarkable. In islands where the aspect ratio is less than 0.5, the freshwater lens is highly vulnerable to changes in draft and recharge. As the aspect ratio of Chetlat is 0.30, the freshwater lens is highly vulnerable to changes in draft and recharge.

6.3.5 Marine aerosols

The rainwater quality in Lakshadweep Islands is influenced by aerosols in the atmosphere. The atmosphere in the coastal parts and islands are enriched in Chloride ions, which gets washed down to the ground during the rains. The first rain, after a long dry spell, will have a higher concentration of Chloride compared to the rains received after continuous rainy days. Similarly, the concentration of chloride is less as we go towards the central part of the island as the thick vegetation obstructs the aerosols.

6.4 Seasonal changes in groundwater quality

There is a marked improvement in the quality of groundwater during monsoon months in a majority of the wells in the Chetlat island. Only in wells located in a thick freshwater lens, where the mineralization is very low, the quality variation is not significant which indicates that chemical change is inversely proportional to the lens thickness at any given time. Studies have established that the quality variations in these islands are not irreversible. This is in contrast to the mainland situation, where the reversal of quality deterioration is a very slow process. This finding gives much-needed leverage for the development of the groundwater resources in extreme drought situations. It is established from the studies that a water surplus of 20 mm is sufficient to reverse the deteriorating trend in water quality in summer months. A water surplus of above 100 mm gives a marked improvement in quality that sustains for the next two to three months with the normal rate of draft. The freshwater lens continuously contracts in the absence of rainfall, due to the effect of water lost due to mixing, draft by vegetation, and draft for domestic consumption. The quality variation is higher in the fringe areas of the freshwater lens during various seasons as compared to that of the central part of the freshwater lens, where the water is fresh all through.

7.0 Hydrochemical facies of water lens

The Chadha, 1999 plots for the Premonsoon (PRM) and post-monsoon (PSM) samples of 2010 reveal that all samples are falling under distribution within the field 5 (Fig.7.1 &2). Thus alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions, (Ca+Mg)+ (CO3+HCO3)> (Na +K)+(Cl+SO4). As the samples falling in Field I, the freshwater lens is Ca-HCO3 Type and is of Recharge Type

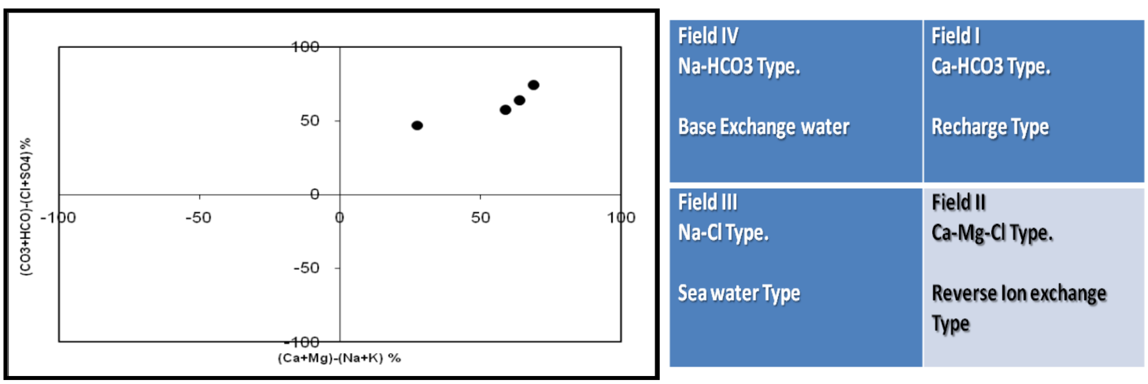

Fig. 7.1: Chadha, 1999 plots for the PRM samples

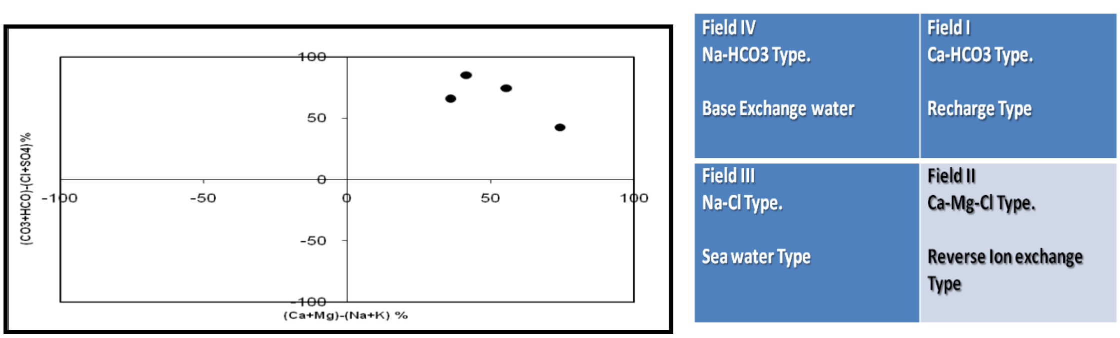

Fig. 7.2: Chadha, 1999 plots for the PSM samples

8.0 Mechanism of formation of the freshwater lens

The plots of TDS Vs. Na+ / (Na+ +Ca2⁺) for cations and TDS Vs. Cl^- / (Cl^- + HCO_3^-) for anions (Gibbs, 1970) prepared to know the process of formation of the freshwater lens over saline water. The evaporation-dominance, Rock-dominance (rock - water interaction), and Precipitation - dominance examined and it is noted that rock – water interaction (carbonate rocks such as limestone/dolomite – water interaction) played a major role in the evolution of freshwater lens over others in the island of Chetlat.

The correlation between Sodium and Chloride concentration (in meq/l) with correlation coefficient, r values of 0.84 (R^2 = 0.698) and 0.8689(R^2 = 0.755) for PRM and PSM samples with a linear relation (Fig.9). This confirms that marine aerosols have also played a role in the chemistry of the phreatic water in the coral island of Chetlat.

The role of aquifer material in the evolution of groundwater chemical composition has been examined by determining the Chloroalkali indices for cations (CAI-1) and anions (CAI-2). The CAI-1 [Cl^- − (Na^+ + K+)]Cl^- and CAI-2 [Cl− − (Na^+ + K^+)/(SO_4^{2-} + HCO_3 − + CO_3 − + NO^-)], developed by Schoeller (1967), relate the ion exchange process between groundwater and aquifer material. The CAI-1 and CAI-2 are negative in the samples indicating the ion exchange between Na+ –K+ in water and Ca2+ –Mg2+ in rocks (McIntosh and Walter 2006) and the ion exchange process occurred between groundwater and the aquifer materials like coral sands and coralline limestones. It is imperative to understand the modifications in water chemistry during its movement and residency time for better evaluation of the hydrochemistry of any area more so when different geological formations are involved in a watershed or river basin (Johnson 1979; Sastry 1994).

Aquifer mineralogy and the presence of clay minerals play a significant role in the ion exchange process. However, coral aquifers are devoid of clay minerals and mainly consist of coral sands and shells (CaCO3). Cation exchange of sodium of seawater for calcium of aquifer material and dissolution of CaCO3 is the major chemical reactions in this aquifer system, leaving apart the daily and seasonal mixing of seawater.

CaCO3+ H2 O + CO2 = Ca++ + 2HCO3- (CaCO3 dissolution)--------- 1

2 Na (water) + Ca – aquifer → 2Na-aquifer + Ca (water) .. …….. 2

Normally, groundwater exchange calcium for Sodium in a groundwater flow regime. But, in the present situation, there is not much scope for adsorbed sodium in the aquifer material for exchange with calcium ion as there is no adsorbing material like clay in the aquifer system. The high sodium concentrations observed are due to the mixing of seawater. The cation exchange process in such mixing zones is reversible in nature, such that the seawater exchanges sodium ion for calcium, with the Ca-HCO3 type water of the freshwater lens which ultimately evolves to Na-Cl type water.

9.0 Correlation coefficient

The relationship between two variables is the correlation coefficient (r) which shows how one variable predicts the other. Associated with r, the multiple correlations, which are the percentages of variance in the dependent variable, explained collectively by all of the independent variables. A high correlation coefficient (near 1 or -1) means a good relationship between two variables, and a correlation coefficient around zero means no relationship. Positive values of r indicate a positive relationship while negative values indicate an inverse relationship (Table 9.1 &2).

The ANOVA analysis shows a significant change in certain chemical composition of groundwater when the groundwater is sampled at different climatic conditions. It can be observed that the concentrations of main ions generally decrease in PSM. This decrease may be due to the high contribution of rainwater in PSM due to dilution and input of more fresh water into the aquifer. From the ANOVA analysis, pH, EC, HCO_3, NO_3, SO_4, Ca, Mg, K, and Na show significant variations with respect to PRM and PSM. A high positive correlation exists between EC Vs TH, Ca and Mg for PRM and a high positive correlation exists between EC Vs TH, Mg, Na, K, and HCO_3. for PSM in 2010.

Table 9.1: Correlation Matrix for Chemical analysis results of Pre-monsoon, 2010

	pH	EC	TH	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3	F
pH	1												
EC	-0.75	1											
TH	-0.71	0.97	1										
Ca	-0.09	0.71	0.65	1									
Mg	-0.87	0.82	0.90	0.25	1								
Na	0.17	-0.50	-0.70	-0.41	-0.64	1							
K	0.59	-0.72	-0.87	-0.33	-0.91	0.89	1						
CO_3	0.88	-0.44	-0.32	0.18	-0.53	-0.31	0.14	1					
HCO_3	-0.85	0.92	0.97	0.44	0.98	-0.63	-0.89	-0.50	1				
Cl	0.04	-0.06	-0.32	0.15	-0.47	0.84	0.73	-0.31	-0.36	1			
SO_4	-0.24	0.76	0.85	0.80	0.61	-0.87	-0.80	0.22	0.71	-0.45	1		
NO_3	-0.99	0.80	0.79	0.15	0.93	-0.31	-0.70	-0.80	0.91	-0.17	0.37	1	
F	-0.42	0.61	0.79	0.31	0.81	-0.96	-0.98	0.05	0.79	-0.83	0.81	0.55	1

Red Good Correlation (r=>0.6 or -0.60)
Yellow and unhighlighted Poor Correlation

Table 9.2: Correlation Matrix for Chemical analysis results of post-monsoon, 2010

	pH	EC	TH	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3	F
pH	1											
EC	0.54	1										
TH	0.13	0.90	1									
Ca	-0.50	0.27	0.59	1								
Mg	0.60	0.88	0.72	-0.13	1							
Na	0.81	0.92	0.67	-0.11	0.92	1						
K	0.06	0.68	0.79	0.83	0.26	0.41	1					
HCO_3	0.00	0.84	0.98	0.57	0.72	0.59	0.69	1				
Cl	-0.77	-0.89	-0.66	-0.15	-0.70	-0.91	-0.67	-0.53	1			
SO_4	-0.07	-0.84	-0.95	-0.41	-0.81	-0.65	-0.55	-0.98	0.50	1		
NO_3	0.82	0.06	-0.33	-0.50	0.04	0.36	-0.07	-0.48	-0.49	0.47	1	
F	-0.59	-0.09	0.22	0.91	-0.51	-0.42	0.66	0.19	0.07	0.00	-0.35	1

Red Good Correlation (r=>0.6 or -0.60)
Yellow and unhighlighted Poor Correlation

10.0 Groundwater contamination

Contamination of groundwater is a major threat to groundwater in the Chetlat island. Human waste, sewerage, biological wastes, and fertilizers are the major agents of pollution of groundwater. The traditional burial grounds also contribute to groundwater contamination to some extent. The chemical analysis data from the Island in 2010 is compiled (Table 11.1).

11.0 Status of Ground Water Resources

The groundwater resource availability in Chetlat Island is restricted to the top few meters of the phreatic aquifers, composed of coral sands and coral limestone. The salient details of the computation of the dynamic groundwater resources of Chetlat Island are described.

11.1 Unit of Computation

The unit of computation is taken as an island. An island with well-defined hydrogeological boundaries is an appropriate Hydrogeological unit for groundwater resource estimation. The geographical area of the island varies from 1.04 sq.km to 4.84 sq.km.

11.2 Groundwater recharge

In small island conditions, the estimation of recharge based on the groundwater fluctuation method is not practicable unlike in the case of continental coastal aquifers as the head build-up due to rainfall recharge dissipates within 2-3 days and diurnal fluctuation is nearly the same as seasonal fluctuation. Therefore, the water table fluctuation method cannot be adopted for assessing the dynamic groundwater potential of the Lakshadweep islands.

The groundwater recharge Chetlat Island has been computed for six months from May to October using the rainfall Infiltration method. The Normal Monsoon Rainfall (NMR) is taken as 1416.9 mm for Minicoy islands, whereas the NMR of 1325.7 mm, recorded at Amini is taken. In areas with no coconut trees, the recharge to groundwater is about 50% of the rainfall and as the coconut tree increases to a full cover, the recharge can reduce to about 30% of the rainfall. A rainfall infiltration factor of 0.30 is adopted for the entire island.

The evapotranspiration (ET) value for coconut tree is taken as 80% of that of shallow-rooted vegetation which in turn is assumed to be equal to the PET of a reference crop. The proportions of the freshwater lens area covered by deep-rooted vegetation can be estimated from ground observations or aerial photographs. For Chetlat island, the proportion is taken as 30%. The PET from the coconut trees has been estimated for a period of 6 non-monsoon months @ 30 liters/ day/ tree for 180 days.

11.3 Total available groundwater resource

About 20% of the total recharge from rainfall on the island is considered lost due to mixing with seawater during tides and another 20% is allocated for reserve for use during periods of delayed or low rainfall. These components, along with the transpiration losses from coconut trees are deducted from the total recharge for getting the total available resource on each island.

11.4 Groundwater draft

The major component of the groundwater draft in Chetlat Island is the extraction through wells for domestic consumption. Almost all households have their own dug well and more than 75% of the wells are fitted with small capacity (normally 0.5 HP) electric pumps. A per capita consumption of 150 lpd has been considered for domestic draft calculation, on the basis of the population as per the 2001 census. Irrigation drat is negligible in the islands as almost all the crops are rain-fed.

11.5 Stage of groundwater development

The stage of groundwater development (SD) has been computed using the following formula
SD = {B/A} x 100; Where B is the gross groundwater draft and A is the total available groundwater resource.

11.6 Categorization of island

The categorization of islands as per the GEC-2015 methodology is not applicable in island conditions due to the peculiar nature of the hydrogeological regime. The freshwater lens will quickly adjust with the incremental additions or abstractions by virtue of its floating nature thereby making long-term trends insignificant. However, categorization has been attempted in this estimation purely based on the stage of groundwater extraction.

11.7 Computation of groundwater resources

The dynamic groundwater resources have been assessed by computing various components of recharge and draft. Rainfall is the only source of recharge in the Islands, whereas domestic draft, evapotranspiration losses, and water loss due to base flow into the sea are the major components of the draft. A part (20%) of the annual water surplus is reserved as a buffer zone for reserve during delayed or deficit monsoon years. The computational details and island wise recharge figures are given in Table 6.1.

Evapotranspiration from coconut trees during 6 non-monsoon months amounts to 11.3 ha.m, whereas the water loss due to subsurface flow into sea is of the order of 8.5 Ha.m. An equal quantum of water is reserved as a buffer to cater to late or deficit monsoon years in the islands. The balance groundwater resources available for development are 14.10 Ha.m.

Groundwater extraction in the Islands, by and large, is for domestic uses of the populace. The extraction component ranges from 8.70Ha.m in Chetlat islands to 41.80 Ha.m in Kavaratti Island, amounting to a total of 238.00 Ha.m.

Balance groundwater resources available in the Islands range from 5.40Ha.m (Chetlat) to 25.10 (Minicoy), adding up to a total of 122.90Ha.m for the group of Islands as a whole.

The stage of groundwater extraction for Chetlat Island is of the order of 61.6 %. In the absence of long-term water level data, the islands have been categorized solely based on the stage of extraction. Based on the stage of extraction (61.6%), Chetlat Island has been categorized as ‘Safe’.

Table 11.1: Dynamic Ground Water Resources of Chetlat Island (As in March 2017)

#	Annual components of Water Balance	Details
1	Population (Projected as on 2017)	2381
2	Area, Ha	104.0
3	Normal Monsoon Rainfall, m	1.355
4	Rainfall Infiltration Factor, %	30
5	Total Resource (Water Surplus) (Ha.m)) [2*3*4]	42.3
6	ET loss from Trees for 6 non-monsoon months, Ha.m	11.3
7	Water loss due to outflow to sea [20% of (3), Ha.m	8.5
8	Buffer zone for reserve during delayed or lesser monsoon period [20% of (3), Ha.m	8.5
9	Balance available resource, Ha.m	14.1
10	Domestic Extraction @100 lpcd [1*100*365], Ha.m	8.7
11	Gross Annual GW Extraction, Ha.m	8.7
12	Groundwater balance available [9-11], Ha.m	5.4
13	Stage of groundwater extraction [11*100/9], %	61.6
14	Category	**SAFE**

12. Groundwater management scenario

12.1 Water Supply

Apart from the rain, groundwater constitutes the only conventional source of freshwater in Chetlat. Due to the typical geological and hydrogeological nature of Chetlat, no single system to provide water supply to the island.

The right approach to solve the problem of drinking water in the island include Use the groundwater to the extent available, the exact quantum of extraction without danger of salinity to be determined by a detailed island wise study, wherever the groundwater is not adequate to provide water to the entire population, this has to be supplemented by desalination of brackish water through Reverse Osmosis Plants and to optimize the availability of the resource by encouraging rainwater harvesting so that at least some of the water which otherwise is wasted could be utilized for part of the year. The water available from the above sources may be distributed through a common network of underground pipes and public stand posts, with the distribution system managed by local Panchayaths. Lakshadweep Administration has prepared a water supply scheme for the U.T of Lakshadweep for the extraction of groundwater through collector wells, which envisages the extraction of groundwater through radial perforated pipes of 5 m length located at specified shallow depths. The groundwater flows under gravity through these pipes and collects in a collector well. This mechanism of groundwater extraction prevents excessive extraction in the following ways: The extraction is not from a point source, but is distributed over a large area. In no case, the water below a pre-decided level will be collected since the inflow is only through the perforated pipes. The bottom of the wells is sealed with concrete and as such does not allow seepage of water from the bottom. There are 4 to 6 such collector wells on each island among the LD Islands (http://lakshadweep.nic.in/depts/lpwd/water_supply.htm). These wells are selected at sites where the quality of water is good and the thickness of the sweet water lens is maximum. Water from these collector wells is pumped intermittently to the collection sump. Extraction of water from each well is done for half an hour and then stopped for an interval of 2 ½ hours to allow time for the interface to subside. After chlorination, the water is pumped from the collection sump to the overhead water tanks. The water is supplied through stand-posts on the streets.

12.2 Rainwater Harvesting Systems

Rainwater collection has long been recognized as the most suitable and adoptable method to make up the shortfalls in groundwater availability Chetlat Island. Rainwater is being collected from the rooftops of the buildings in storage tanks of various capacities ranging from 5000 to 10,000 thousand liters and in some cases, up to 50,000 liters. Such tanks are normally attached to Government quarters, non-residential buildings, and some private houses. The water collected from the rooftops is made to flow to the collection through a filter, designed to remove suspended particles. The water is then chlorinated and distributed to the public. Operation related to the pumping and distribution of water is entrusted with the respective Village (Dweep) Panchayaths in respect of water collected in community rainwater tanks in Hospitals, Schools, etc. Community rainwater harvesting systems using public buildings such as hospitals and schools have also been implemented in Kavaratti and Minicoy islands, from which the harvested water, after filtration and chlorination in a centralized unit, is pumped into overhead tanks for distribution along with water collected from other sources such as groundwater, desalination plants, etc.

12.3 Desalination Plants

As per information available from Lakshadweep Administration, a total of ten brackish water reverse osmosis (R.O) desalination plants have been established in the U.T of Lakshadweep. Desalination plants set up by the National Institute of Ocean Technology (NIOT) under the Ministry of Earth Sciences, GOI, which is based on the temperature differential in the seawater and not on the conventional membrane (RO) technology, are functioning in Kavaratti, Agatti, and Minicoy Islands. Each of these plants has the capacity of 1 lakhs liter of desalinated water/day, which is supplied free of cost to the local residents through taps. The variation in ocean water temperature with an increase in depth is used in the Low-Temperature Thermal Desalination (LTTD) plants to flash evaporate the warm water at low pressure and condense the resulting vapour with the deep sea cold water.

12.4 Groundwater Quality monitoring

There is a water Quality Testing Laboratory installed in Chetlat. The Laboratory is regularly monitoring the quality of groundwater from select wells. The local Public Health authorities are kept informed of any change in the quality of groundwater, especially salinity.

12.5 Groundwater regulation

The Lakshadweep Ground Water (Development and Control) Regulation, 2001 was promulgated on August 6, 2001. As per the regulation, a Ground Water Authority is to be constituted in the U.T of Lakshadweep, which will have the powers to control and regulate the extraction and use of water in any form in Chetlat island in Lakshadweep. The Authority, however, is yet to be constituted.

12.6 Groundwater management issues

Major constraints in the sustainability of limited groundwater resources in the Chetlat Island include the absence of surface water resources in the islands putting stress on the limited groundwater resources available, deterioration of groundwater quality especially during summer months, existing supplies unable to cope with the rapidly increasing demands for drinking and domestic uses and indiscriminate groundwater extraction at places, resulting in up-coning of saline water and consequent quality deterioration.

12.7 Management interventions for sustainable development

A requirement to meet the needs of a growing population and the non-availability of alternatives is likely to put the limited groundwater resources in Chetlat island under increasing stress in the coming years. Some of the feasible management interventions to ensure the long-term sustainability of groundwater on the island are:

- Rehabilitation, restoration, renovation, and protection of available ponds and wells,
- Large scale implementation of rooftop rainwater harvesting schemes through the participation of local communities,
- Regulation/control on the indiscriminate extraction of groundwater through mechanical devices,
- Regular monitoring of water levels and water quality,
- Encouraging the use of water-efficient domestic fixtures like taps/ flush tanks to improve water use efficiency and reduce wastage,
- Decentralized garbage/waste treatment systems to prevent further contamination of available freshwater resources.
- Installation of desalination plants in Chetlat to reduce stress on groundwater
- Sensitization and capacity building of stakeholders at all levels on the importance of water conservation and ways and means for its judicious management for ensuring the long-term sustainability of water resources.

13. Aquifer management plan

In Chetlat Island, groundwater occurs in phreatic conditions and is in hydraulic continuity with seawater. The management strategy suitable for aquifer in the continental land is not appropriate for the tiny island of Chetlat. Since surface runoff is totally absent and recharge of rainfall is taking place naturally, the need for artificial recharge is ruled out. Management strategy needs to concentrate on limited groundwater withdrawal and optimum utilization. The people should be educated about the danger of over-exploitation of the precious resource and about the limitations of island conditions.

13.1 Major natural challenges for groundwater-related Issues

The major natural challenges for groundwater-related Issues in Chetlat Island are

- Climate Change,
- Sea Level Rise,
- Variation in rainfall (tropical cyclones, Drought),
- Natural groundwater discharge to the ocean due to hydraulic continuity between the aquifer and Seawater,
- Evapotranspiration loss due to vegetation-Coconut tree roots are touching water table at places, and

- High population density and associated pressure on the limited groundwater resources.

13.2 Groundwater pollution by sanitation

The thickness of the unsaturated zone through which seepage leaches was found to be the most significant determinant of groundwater contamination in Chetlat island. Groundwater contamination by pathogens has been recorded on the island. Generally, guidelines of 30 meters separation between domestic septic tanks and water supply wells have been applied and found to give inadequate protection from pathogens, especially in permeable aquifers. The U.T administration has taken steps to ensure the installation of scientific septic tanks in all newly constructed houses and other buildings.

13.3 Control Measures

13.3.1. Institutional

- Comprehensive island water legislation would help to resolve institutional uncertainties on roles and responsibilities and provide a firm foundation for addressing systematically and consistently the issues involved in water resource management.
- The need for the introduction of a water-pricing regime should be a priority, essential to the operation and maintenance of the water supply system and o demand-side management.

13.3.2 Community

Control measures to prevent sanitation impacts on water supplies and human health on tropical islands may include one or more of the following:

- ➢ Providing public information on the linkage between sanitation and drinking water quality
- ➢ Developing public health regulations on the design and maintenance of sanitation systems
- ➢ Specifying well-head protection zones (minimum separation distances for contaminant sources)
- ➢ Establishing monitoring procedures for pathogens and nitrogen in drinking water supplies, and
- ➢ Disinfection of water supply wells or finding alternative water supplies (eg rainwater tanks). The acceptability and effectiveness of the various measures will obviously depend on the attitude of the local community

14.0 Conclusions and recommendations

14.1 Conclusions

- ➢ Hydrogeological conditions, problems, issues, and its manifestations in Chetlat are identical with all Islands.
- ➢ The Chetlat Island is lying well within the tropics and extending to the equatorial belt, has a tropical humid, warm climate and the island is flat, rarely rising more than a few meters above mean sea level, and consists of fine coral sand and coral limestone. Chetlat is a typical tiny carbonate atoll.
- ➢ The Chetlat is characterized by the absence of surface drainage and does not have any rivers or other surface water bodies.
- ➢ Groundwater exists under phreatic conditions on the island as a thin freshwater lens floating over the saline water in the porous formation and is in hydraulic continuity with the seawater.
- ➢ The various abstraction structures in Chetlat are open dug wells, filter point wells, and step wells.
- ➢ The depth to water level in the island varies from **1.01 – 3.98** m.bgl and the depth of the wells varies from 1.58 to 4.80m.bgl
- ➢ The depth to water level is influenced by the tides. The water level fluctuation in these islands is significantly controlled by tides when compared to the groundwater recharge and draft. The diurnal fluctuation of water level due to tides is in the range of 6 to 29 cm.

- The freshwater lens in Chetlat Island is fragile and the shape of the island plays a significant role in its occurrence and stability. As the aspect ratio value of 0.30 is less than 0.5, the freshwater lens of Chetlat is unstable and will be subjected to seawater mixing.
- The stage of groundwater extraction as in March 2017 in the Island is 61.6 % and the Island comes under the safe category.
- The water level suddenly rises to a fraction of meters immediately after the rainfall and again falls down to the original level within hours. Hence the magnitude of seasonal fluctuation in water level due to groundwater recharge is not so significant when compared to tidal fluctuations.
- The Electrical Conductivity of groundwater ranges from **728 to 5000** µS/cm at 25° C. The quality variation is vertical, temporal, and also lateral. Brackish water is present along topographic lows and in places where coarse pebbles and corals are present. Human waste, sewerage, and other biological wastes are major sources of groundwater contamination on the island. Groundwater is limited in quantity and its salinity level increases as a function of time during withdrawal in the dry periods.
- Water supply in Chetlat Island is through a combination of groundwater extracted through collection wells and harvested rainwater. Though the "Lakshadweep Ground Water (Development and Control) Regulation, 2001" was promulgated on August 6, 2001, for control and regulate the extraction and use of water in any form in any of the islands in Lakshadweep through the constitution of Lakshadweep Ground Water Authority, the same was constituted in 2019.
- Important constraints in the sustainable development of the limited groundwater resources in the Chetlat include the absence of surface water resources in the islands putting stress on the limited groundwater resources available, deterioration of groundwater quality during summer months, rapidly increasing demands for drinking and domestic uses, indiscriminate groundwater extraction at places, resulting in up-coning of saline water and consequent quality deterioration, lack of proper sanitation, resulting in large scale bacterial contamination. Burial places on the Island are potential microbial contaminant sources.

14.2 Recommendations

- As the full requirement of freshwater in the islands cannot be met with from the limited groundwater resources, water supply schemes in all islands must resort to a combination of groundwater, desalinated water, and rainwater harvesting.

- The indiscriminate extraction of groundwater through electric pumps from the wells needs to be regulated for protecting the limited water resources from salinization due to the up-coning of seawater. The constitution of Lakshadweep Ground Water Authority under the Lakshadweep Ground Water (Development & Control) Regulation, 2001 needs to be expedited to achieve this objective.
- The pumping of water from dug wells directly to multi-storied buildings may be stopped. The water may be pumped from dug wells with low capacity pump and collected in ground-level storage tanks and from this water may be pumped to multi-storied buildings.
- Rooftop rainwater harvesting can provide reliable freshwater for the islands during a part of the year. Efforts to popularize rainwater harvesting needs to be accelerated, through incentives wherever necessary, to reduce the increasing stress on the limited groundwater resources. Legal provisions to make rainwater harvesting mandatory for all future civil constructions may also be made.
- As the shallow, thin floating lens of groundwater is easily prone to contamination, efforts for proper sewage disposal are to be given top priority. The U.T. administration has taken steps to ensure the installation of scientific septic tanks in all newly constructed houses and other buildings. However, the existing soak pit/leach pit toilets need special attention
- Measures for improving water use efficiency through the use of water-efficient fixtures in homes/buildings should be encouraged.
- Judicious pumping from the freshwater lens through radial wells possible on the island, hand-drawn wells to be encouraged over energized wells, pumps above 0.25hp should not be allowed and pumping for water supply should be only from radial wells.
- A low rate of continuous pumping preferred and should have zero tolerance for Wastage.

- Rooftop Rainwater harvesting should be mandatory, abandoned wells and ponds are to be rejuvenated and protected and wells should not be converted into garbage disposal pit.

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Appendix I: Chemical Analysis of Ground Water Samples in Chetlat Island (Pre and Post Monsoon 2010)

#	LOCATION	Well ID	pH	EC	TH	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3	F
Premonsoon, 2010 April															
1	Chetlat (Govt. Quarter ICE 14)	W1	7.9	753	290	28	54	24	0.9	0	409	32	23	1.8	1.4
2	Chetlat (LPWD Office)	W2	8.36	535	165	22	27	39	7.3	6	201	64	10	1	0.93
3	Chetlat (PHC)	W3	7.99	819	290	44	44	32	3.9	0	372	71	24	1.6	1.14
4	Chetlat (Junior Basic School)	W4	8.45	672	250	40	36	23	3.2	18	293	39	27	1	1.29
Postmonsoon, 2010 November															
1	Chetlat (Govt. Quarter ICE 14)	W1	7.88	670	270	82	16	31	7.7	0	360	**32**	**16**	**1.8**	**1.4**
2	Chetlat (LPWD Office)	W2	7.94	817	300	64	34	54	4.9	0	433	**25**	**7**	0.6	0.60
3	Chetlat (PHC)	W3	7.84	437	195	58	12	13	0.6	0	256	75	22	0.3	0.79
4	Chetlat (Junior Basic School)	W4	8.01	642	215	50	22	45	2.9	0	256	25	22	7.4	0.52

Appendix II: Well inventory details in Chetlat, January 2015

CHEMICAL ANALYSIS RESULTS OF WATER SAMPLES COLLECTED FROM PERMANENT OBSERVATION WELLS –CHETLAT ISLAND (LPWD Lab Data)

#	**Sample reference**	**Date f Sample Collection**	**Turbidity (NTU)**	**PH**	**Conductivity (µS/cm)**	**TDS (mg/l)**	**Chloride (mg/l)**	**TH (mg/l)**	**Ca-Hardness (mg/l)**	**Mg-Hardness (mg/l)**	**Alkalinity (mg/l)**	**Salinity (mg/l)**
1	OW-1	02/06/2014		7.96	1000	560	260	300	50	250		470
2	OW-2	02/06/2014		7.68	3700	2072	1450	820	60	760		2618
3	OW-3	02/06/2014		7.18	5000	2800	1750	900	40	860		3160
4	OW-7	02/06/2014		7.49	3300	1848	856	800	130	670		1535
5	OW-10	02/06/2014		7.97	700	392	140	300	70	230		253
6	OW-15	05/06/2014		7.69	1100	616	130	430	40	390		235

#	Sample reference	Date f Sample Collection	Turbidity (NTU)	PH	Conductivity (µS/cm)	TDS (mg/l)	Chloride (mg/l)	TH (mg/l)	Ca-Hardness (mg/l)	Mg-Hardness (mg/l)	Alkalinity (mg/l)	Salinity (mg/l)
7	OW-23	09/06/2014		7.94	800	448	150	270	50	220		271
8	OW-25	09/06/2014		7.69	800	448	80	350	30	320		144
9	OW-27	11/06/2014		8.16	1180	660	150	350	40	310		271
10	OW-29	11/06/2014		8.33	870	487	50	330	30	300		90
11	OW-34	13/06/2014		8.28	1300	728	150	450	50	400		271
12	OW-36	16/06/2014		7.79	1100	616	150	350	100	250		181
13	OW-40	16/06/2014		8.20	1400	784	220	350	60	290		397
14	OW-42	17/06/2014		8.50	1200	672	180	400	100	300		325
15	OW-43	17/06/2014		8.30	800	448	100	300	50	250		181
16	OW-47	19/06/2014		7.87	1300	728	200	360	150	210		361
17	OW-48	19/06/2014		7.95	1400	784	150	440	200	240		271
18	OW-49	19/06/2014		8.30	1200	672	200	380	200	180		361
19	OW-50	19/06/2014		8.22	1000	560	150	370	350	200		271
20	OW-51	23/06/2014		8.39	1512	1223	150	800	150	650		271
21	OW-52	23/06/2014		7.88	2184	728	110	400	100	300		199
22	OW-53	23/06/2014		7.83	728	672	130	400	100	300		235

#	Sample reference	Date f Sample Collection	Turbidity (NTU)	PH	Conductivity (µS/cm)	TDS (mg/l)	Chloride (mg/l)	TH (mg/l)	Ca-Hardness (mg/l)	Mg-Hardness (mg/l)	Alkalinity (mg/l)	Salinity (mg/l)
23	OW-59	24/06/2014		7.86	1200	672	250	380	150	230		452
24	OW-60	24/06/2014		8.09	900	504	120	330	100	230		217
25	OW-62	25/06/2014		8.02	1600	896	180	370	160	210		325
26	OW-64	25/06/2014		8.07	4200	2357	860	780	350	330		1553
27	OW-67	27/06/2014		8.17	1400	784	200	500	120	830		361
28	OW-70	27/06/2014		8.18	2100	1176	380	680	150	530		686
29	OW-72	01/07/2014		8.22	1000	560	150	400	200	200		271
30	OW-73	01/07/2014		8.11	900	504	100	380	100	280		181
31	OW-75	01/07/2014		8.02	11100	6216	3350	1470	450	1020		6050
32	OW-79	02/07/2014		8.38	1100	616	150	320	120	200		271
33	OW-80	02/07/2014		8.27	1800	1008	350	480	50	430		632
34	OW-81	04/07/2014		7.99	8800	4928	2700	1300	400	900		4876
35	OW-83	04/07/2014		8.32	1500	840	150	400	150	350		271
36	OW-84	04/07/2014		8.22	3100	1736	700	720	200	520		1264
37	OW-85	04/07/2014		8.05	3600	2016	750	800	200	600		1354
38	OW-86	07/07/2014		8.39	2300	1288	400	700	190	510		722

#	Sample reference	Date f Sample Collection	Turbidity (NTU)	PH	Conductivity (µS/cm)	TDS (mg/l)	Chloride (mg/l)	TH (mg/l)	Ca-Hardness (mg/l)	Mg-Hardness (mg/l)	Alkalinity (mg/l)	Salinity (mg/l)
39	OW-88	07/07/2014		7.74	2800	1568	700	590	50	540		1264
40	OW-91	08/07/2014		7.86	1300	728	210	400	100	300		379
41	OW-93	08/07/2014		7.90	1500	840	250	400	100	300		452
42	OW-96	08/07/2014		7.96	1600	896	300	400	150	250		542
43	OW-98	08/07/2014		8.35	3000	1600	600	650	300	350		1083
44	OW-100	08/07/2014		7.95	4300	2400	1000	700	280	420		1806
45	TW-2	05/06/2014		7.75	1100	616	170	550	70	480		307
46	TW-3	05/06/2014		7.68	900	504	150	310	80	230		271
47	TW-5	05/06/2014		7.60	1900	1064	300	640	100	540		542
48	TW-6	05/06/2014		7.52	900	504	100	350	60	290		181
49	TW-7	05/06/2014		7.56	1000	560	130	370	70	300		235
50	TW-8	05/06/2014		7.45	800	448	90	290	80	210		163
51	TW-10	05/06/2014		7.36	5000	2800	2150	620	150	470		3882